The multiple dimensions of urban contexts in an Industrial Ecology perspective. An integrative framework

Alberto Simboli[1], Raffaella Taddeo, Andrea Raggi

University "G. d'Annunzio", Department of Economic Studies,
V.le Pindaro 42, 65127 Pescara, Italy

Accepted version

Please cite as:

Simboli, A., Taddeo, R., Raggi, A. (2019). The multiple dimensions of urban contexts in an industrial ecology perspective: an integrative framework. International Journal of Life Cycle Assessment. ISSN 0948-3349. Vol.24 pp 1285-1296.

DOI: https://doi.org/10.1007/s11367-017-1411-y

[1] Corresponding author: a.simboli@unich.it (Alberto Simboli), Tel.: + 39 (0) 85 4537935; fax: + 39 (0) 85 4537956

The multiple dimensions of urban contexts in an Industrial Ecology perspective. An integrative framework.

ABSTRACT

Purpose - This article analyses, in an Industrial Ecology (IE) perspective, urban contexts with specific features, such as a reduced space scale, a hybrid nature, which includes a residential, industrial and rural dimension, a strong spatial contiguity among these three dimensions.

Methods - The study starts with a retrospective investigation of such contexts and the development of an approach based on contributions from Urban Metabolism and Industrial Symbiosis. An integrated analytical framework, based on empirical data and a literature review, is also proposed.

Results and Discussion - The integrated view of the three dimensions, associated with a fourth dedicated to waste and energy flows, can be useful for efficiently identifying and managing material and energy flows beyond the typical use and consumption of "pure" urban systems. The results of a pilot survey, carried out with reference to the territory of the Province of Pescara (Italy), confirm the widespread diffusion of these "hybrid" urban contexts, which can potentially grow in a synergistic way.

Conclusions - Through this framework, land use policies and local improvement actions can be defined in a better way for a sustainable local development, together with a more effective governance. Significant areas of scientific advancement in the IE research field also emerge.

Keywords: Industrial Ecology, Urban Metabolism, Industrial Symbiosis/Metabolism, Urban Economies, Urban Systems

1 Introduction

Industrial Ecology (IE) is recognised as a wide research field, focused on environmental improvements in production and consumption activities (Erkman 1997; Ayres and Ayres 1996; Garner and Keoleian 1995). Within IE, some approaches are aimed at an efficient management of resources and a reduction of the environmental impacts associated to limited spatial contexts (Bateman 1999). These actions, which are inspired by biological systems, often exploit the potential associated to the heterogeneity of the various entities that compose a given system. Recent studies on IE show a great interest in the analysis of urban contexts, which are considered to be very promising for the achievement of the economic, environmental and social sustainability at a local level (e.g., Kennedy et al. 2007). However, urban contexts are traditionally depicted as residential systems that mainly include consumption activities; from an IE perspective, this implies a limited variety of the entities and the flows involved and an even more limited set of achievable synergies. More recently, scholars in economic geography and urban planning have increasingly considered urban contexts as complex systems that may have different forms and that constantly change (Walloth et al. 2013; Bretagnolle et al. 2006). As a consequence, also industrial ecologists recognise the need of an expanded view of the "urban contexts", in a way to include different entities, with which the residential areas interact strictly, by means of material, energy, service and human flows (Pandit et al. 2015; Dinarès 2014). The expansion of the boundaries allows scholars to analyse such contexts in synergy with other approaches in IE. Cases of mixed/multiple-nature urban contexts are largely represented in local economies; such urban contexts show a strong integration among the urban (intended as residential), and the neighbouring industrial and rural areas (e.g., in the districtual models, small towns, and rural economies).

This article, after an analysis of the approaches that are deemed suitable for urban contexts, offers an integrated framework, in which the main flows and potential synergies among the residential and the neighbouring rural and industrial dimensions are described. As a result of an integrated view, the local flows (e.g., products, energy, food, water) can be identified and efficiently managed beyond their use phase; additionally, more effective policies for a sustainable local development can be defined in a better way. The article is structured as follows: Sections 2 and 3 outline the research methods used and the theoretical framework of the article. In section 4, the analytical framework is described in order to explain the dimensions, the spatial boundaries and the variables included. In the second part of the article, the potential synergies and the benefits for the contexts and the spaces for integration are discussed with reference to the Province of Pescara (Abruzzo Region, Italy), which is used as a representative context of the study and as a source of sample data. Finally, conclusions are drawn.

2 Methods

The study applied a systemic and interdisciplinary approach of sustainability-related sciences and IE, encompassing a comprehensive analysis for to the identification of potential areas for the theoretical, methodological and practical advancements of these fields of research. The background of the analysis presented here comes from the empirical experience gained by the authors in the study of the potential development of IE approaches in industrial clusters and districts. During such studies, the presence of local contexts emerged progressively showing particular characteristics which are not covered by IE approaches, such as those based on Industrial Symbiosis; those characteristics are: i) a small scale; ii) a "hybrid" nature (involving residential, industrial and rural dimension); iii) a strong spatial contiguity among the three dimensions. This led to further investigate such contexts; in particular the following questions were raised: how can such contexts be qualified? How can they be approached in the perspective of IE? What specific synergies might emerge?

The theoretical results are mainly based on a qualitative analysis of the scientific literature and secondary data. The role of urban contexts and UM in the field of IE was investigated through desktop and direct research with the use of up-to-date and reputable sources. For the parts of the study that required a literature overview, the authors defined a set of key-concepts (Urban Metabolism, Industrial Symbiosis/Metabolism, Urban Economies, Urban Systems) and combined them for a keyword research; the sources were retrieved from the Scopus database. General information about empirical contexts were obtained by Regional and local regulations, technical reports and official websites. Data were obtained through public documents that were made available by the regional administrations. Empirical evidence emerging from recent studies conducted by the authors in the same territories (Taddeo 2016; Simboli et al. 2015; Simboli et al. 2014; Taddeo et al. 2012) was also used. Figure 1 shows a map of the research aims, the basic constructs and the methodology, as performed in the study.

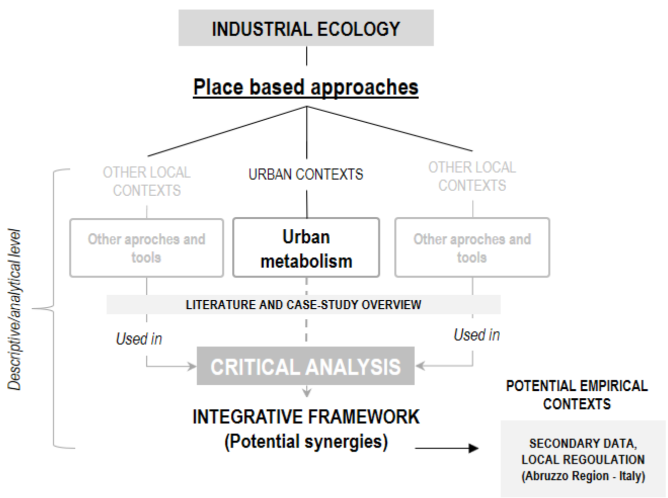

Fig. 1 The research model

The study starts with an analysis of PB approaches to EI, with particular reference, even though not exclusive, to urban contexts. This overview, which includes theoretical contributions and case studies, is used for critical synthesis to identify potential solutions that are suited to the characteristics of hybrid urban contexts. The set of solutions identified is the basis for the development of the integrated framework, which serves to identify potential synergies; those are then tested in a potential empirical context.

3 Place-based approaches to Industrial Ecology

The concept of IE starts from a metaphor of natural ecosystems, in which energy and material flows are efficiently managed, by minimising waste generation (Frosch and Gallopoulos 1989). In IE, issues such as biodiversity, carrying capacity, life cycle, metabolism are analysed to learn and try to implement “nature lessons” into anthropogenic (economic and industrial) systems (Schwarz and Steininger 1997). IE currently involves various perspectives of analysis (White 1994). Specific approaches in IE investigate how communities of co-located companies could improve their economic and environmental performances through cooperative management of material and energy flows (Desrochers 2002; Côté and Cohen-Rosenthal 1998; Lowe 1997); such approaches have been also identified as Place-Based (PB) (Deutz and Gibbs 2008; Bateman 1999). In these approaches, the involved agents (producers, consumers) are represented as systems that are placed in an input/output relation with the other agents and with the natural environment (Fig. 2). The interaction among the agents may generate environmental, economic and social effects for the system and its surroundings (Jelinski et al. 1992).

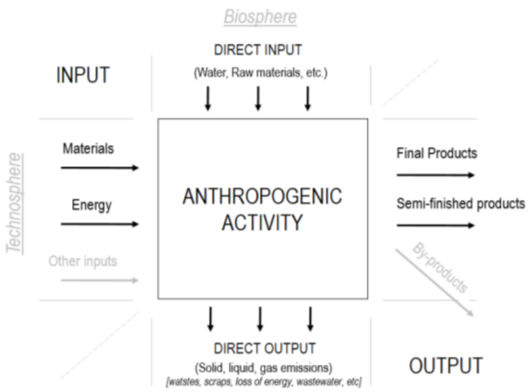

Fig. 2 Scheme of an agent

On a theoretical level, multi-scale analysis can be used to classify these systems. Chertow (2009) proposes three different scales of analysis: spatial (geographical extension), temporal (evolution of industrial characteristics) and organisational (dimension and public/private nature of companies). In particular, the spatial scale is considered one of the defining features; its relevance comes into play in matching flows of materials, energy, water and information across the involved entities. Spatial boundaries can be defined at a micro level (companies), meso level (local area, or cluster), and macro level (regional; national) (Roberts 2004). Another classification is related to their origins: they can develop spontaneously, through the initiative of companies (self-organised) or be guided by local government (planned) (Chertow 2000).

PB approaches have been focused at first on the study of industrial systems (s.c. “Industrial Metabolism”) (Simboli et al. 2012; Deutz and Gibbs 2008), and then on the implementation of ecosystems in the technosphere. The most relevant among the latter are related to the concept of Industrial Symbiosis (IS), based on the synergistic use of flows (e.g., energy losses, scraps, by-products or residuals) among the organisations involved (Chertow 2000). The benefits deriving from the adoption of such solutions may concern all dimensions of sustainability: reducing pollution, contributing to the creation of new businesses and enabling higher efficiency in the use of production capacity and labour. This can also promote changes at a technological, organisational, and socio-economic level (OECD 2012; Côté 2000; Lowe et al. 1996).

PB approaches have gained important spaces in the scientific world; however, cases of their practical application are still limited. The difficulties in the implementation are in part associated with the complexity and the changing nature of the starting contexts (Chertow 2000). The application of the PB approaches to IE has led to the emergence of new models, which, under various concepts (Industrial Ecosystems, Eco-Industrial Parks, etc.), have been devoted primarily to productive settlements (such as for example, Kalundborg's emblematic case), in which different dimensions of the local economy start to become part of the symbiotic network. With the advancement of knowledge, there has been a progressive thematic specialisation of these approaches as well as the introduction of new models, e.g devoted to specific contexts such as urban, energetic, rural, etc. (Yu et al. 2013); however, much debate is still ongoing on how to make IS suitable and effective in each of them (Taddeo et al. 2012; Jensen et al. 2011). Specific technical/structural factors may affect the implementation of such approaches; in addition, each context includes entities which define the dynamics of change within the system, through explicit (power and decision-making rules) and embedded (socio-relational) mechanisms (Simboli et al. 2012; Doménech and Davies 2011) whose role is not predictable.

4 Urban contexts

4.1 Features, forms and evolution

In the urban planning theories, the various forms of urban contexts are traced back to some historical reference models: Greek, Roman, Medieval, Renaissance cities, etc. These models shared the existence of a residential dimension, established in a territory, the prevailing economic (subsistence) activities of which were those of craftsmanship, commercial and agricultural nature. Consequently, the environmental load associated with these contexts was limited. In the industrial era, urban contexts changed their distinctive features: increasing population, territorial dimensions, buildings size, traffic, economic activities and, consequently, resources and energy consumption. The renewed focus on the sustainability of human settlements has prompted scholars and government bodies to give new space to the natural environment in city planning and building (e.g., green cities; passive houses, etc.). More recently, the drifts associated with the neighbourly development of residential and industrial dimensions have given rise in some cases to real megalopolis or hybrid forms of coexistence, which have in part supplanted the pre-existing agro-rural activities. In other cases, the development has been more gradual and the three dimensions have found a more balanced way of interaction, while in others the industrial dimension has gradually disappeared. In any case, the evolution of the residential dimension has been closely linked to the economic and socio-political dynamics of the reference territory. Scholars qualify such contexts as "post-industrial cities". They present variable size, a strong link between the various dimensions of the territory, in which they are located, and fall into those that are called "multifunctional" or "hybrid" settlements (Van der Berg 1987).

4.2 Urban Metabolism as an IE approach for urban contexts

IE provided its contribution to the study of urban contexts through a specific field of studies, which have gradually been affirmed under the name of "Urban Metabolism" (UM). The use of the metaphor for metabolism in the analysis of cities can be traced back to a famous study conducted in the US in the middle of the 1960s by Wolman (1965); the concept of UM, intended as “the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste” was definitively affirmed in the mid-2000s (Kennedy et al. 2007). Unlike other approaches, such as those devoted to industrial settlements (such as IS), the concept of UM incorporates both the analysis of the state of the art of urban contexts and the development of improvement scenarios. The study of the dynamics of material and energy flows within urban areas (Fig. 3) is useful in evaluating the potential optimisation of the production and consumption processes that occur in it.

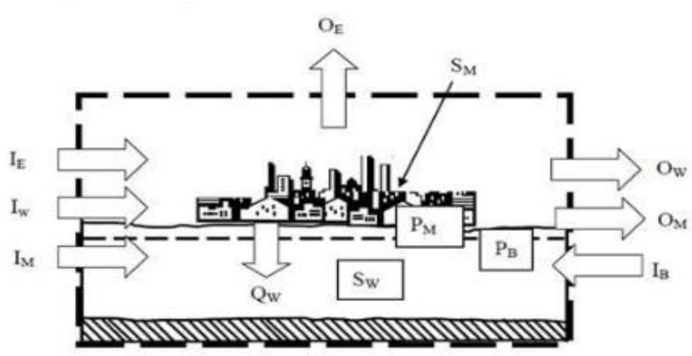

Fig. 3 Material and energy flows within urban areas: input flows (I), output flows (O), internal flows (Q), storage (S), production (P) of biomass (B), minerals (M), water (W) and energy (E) (Kennedy et al. 2014)

In practice, the study of an UM involves the quantification of the inputs, outputs and storage of energy, water, nutrients, materials and wastes for an urban region. The characteristic elements of the specific urban system, such as the type of buildings, the urban vegetation and the transport technologies, can influence considerably the metabolic rate of the city, where the efficiency of the metabolic process is measured as the ratio between outputs and inputs. However, modern cities feature a linear metabolism with large input flows of energy and materials deriving from the biosphere or other systems of the technosphere. These flows, once released in the form of outputs, do not return to their place of origin, but tend to accumulate in other parts of the biosphere (Holmes and Pincetl 2012).

Perspectives of analysis

At a first level of analysis, UM is usually studied through the use of aggregate measures, such as the annual consumption of electricity or water, as happens for the human metabolism, in which aggregate indicators (such as the daily consumption of energy or oxygen) are taken into account (Kennedy et al. 2014).

During the period 1981-2000, as recognised by Zhang et al. (2015), two main methods have been proposed by UM researchers: the *black box model*, in which the internal components of the system were not considered; and the *subsystem model,* in which the black box was “opened” to reveal its components. Black box models reflect the overall inputs and outputs of a city and its activity intensity and scale to provide a macroscale indicator. Black box models can be used when little data is available and provide an overview of urban metabolic efficiency and the degree of sustainability. In contrast, subsystem models describe details of the flows among subsystems and the factors that influence these flows; this requires much more detailed data. The advantage of subsystem models is that they provide more direct support for diagnosing problems and suggesting measures to solve them, such as how to increase the efficiency of energy and material flows, how to increase the quality of life, and how to sustain development (Zhang et al. 2015). The most recent models have been adopted in order to further refine the analysis of the internal functioning of urban systems by accepting the paradigm of complexity. This setting is reflected in the recognition of certain distinctive features of urban dynamics, such as systemic interactions, feedback mechanisms (and therefore the consideration of circular flows and not just linear ones) and network relations (Cotè et al. 2015). In light of the above, the research on UM seems to have evolved, moving from linear input-output models of resource, towards the representation of the cyclical processes and their measure. In this direction, recent efforts are being made to integrate the perspective of evaluation of the s.c. "life cycle-based" approaches to IE (e.g., Life Cycle Assessment) in the study of territorial and urban contexts (e.g., Szita Tóthné and Roncz 2016; Goldstein et al. 2017).

5 Research gaps and potential contexts

The gradual "specialisation" that is affecting the territorial/PB studies in the IE field has been partially justified by the need to exploit the synergies of relevant contexts and, at the same time, to develop analytical models and solutions that take into account some specific variables. However, this process presents some conceptual and methodological limitations that we would like to highlight and try to face in our study:

I) IE studies the economic systems analogically to the biological ones, i.e., as complex systems, open to external exchange (closed economic systems are currently only theoretical), whose persistence is strongly linked to the diversity of species who live in it; as aforementioned, it is precisely such diversity that assures a circular and non-dissipative use of material and energy drifts. An "a priori" introduction of sectoral or typological boundaries to the contexts studied can limit severely opportunities for potential synergistic interactions among the entities involved, included the neighbouring ones (Jelinski et al. 1992). In addition, contexts change over time and the adoption of a too rigid approach would limit the possibilities of incorporating solutions and synergies that emerge during its evolution.

II) The symbiotic solutions that could be implemented in a given context are sometimes influenced by its size and the dimensional scale of plants, processes and detectable flows. If large settlements can independently reach the minimum level of activity able to allow a technically and economically sustainable management of waste and by-products, this does not apply to small-scale settlements, where the viable alternatives are more limited.

The analytical framework that we propose concerns those "hybrid" and small-scale urban contexts in which the residential, rural and industrial dimensions are strongly integrated; in the IE perspective, such perspective can benefit from some special conditions that characterise these contexts: a *first* benefit comes from the geographical proximity among the three involved dimensions; a *second* advantage could arise from the complementarity that characterise the three dimensions (production-transformation-use); a *further* advantage can be related to the univocal governance and legislation of the system, attributed to the same territorial body (Taddeo et al. 2017). In particular, around the topic of proximity there is a relevant debate in the literature. On the one hand, there are those who claim that proximity is a crucial aspect in IS because it would limit the transport costs and impacts and would facilitate socio-relational interactions between the parties / entities (Sterr and Ott 2004; Velenturf and Jensen 2016). On the other hand, there are those who say that companies in an IS must not necessarily be co-located (Laybourn and Morrissey 2009). However, it should be briefly considered that an IS is based on exchanges of low value-added flows (e.g., wastes); long-distance transfers can generate extra costs, as well as additional environmental impacts. Therefore, proximity, in general, plays in favor of a great efficiency of IS exchanges; neverthless, when dealing with recovery and recycling issues, no particular spatial scale should be assigned a priori, because economic transactions or e.g. other socio-politic reasons can prevail (Lyons 2007; Hewes and Lyons 2008).

As operating territorial examples, we refer to the rural and urban economies of southern Europe, district models, satellite cities, urban regions, and to all those mixed/multiple land use models that characterise the urban planning and local planning models of the post-industrial era (Fig. 4). We consider useful to place this discussion in the UM field of research, as in these models the residential dimension typically assumes a primary and focal role over the other two, from an economic, urbanistic and social point of view.

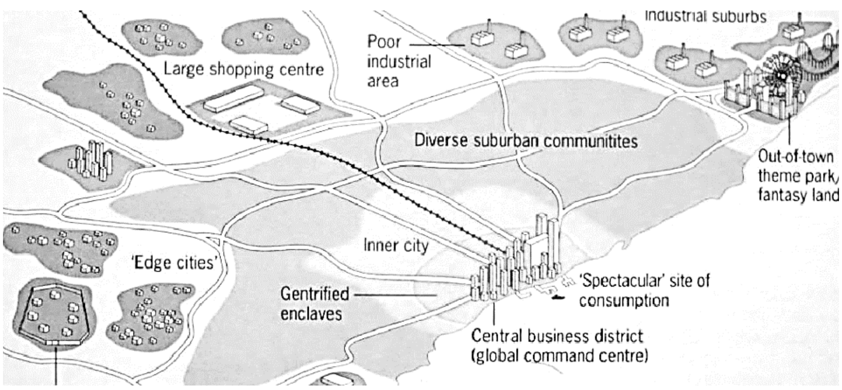

Fig. 4 An example of post-industrial city (Knox and Pinch 2010)

For example, such contexts have been widely disseminated in Italy after the industrialisation stage that characterised the 1960s. During that period, the progressive affirmation of large industrial complexes was the result of economic policy guidelines, which identified the industrialisation of the country as the primary objective to ensure economic growth and social development. Such a strategy was characterised by the presence of a large base production plants, which had the role of a “development pole”. In some cases, the development pole was located near an urban site, equipped with infrastructure and services (in particular, a port, an airport and railways); in other cases, especially in Southern Italy, the large plants were established far from urban sites, with a limited presence of infrastructure.

The 1970s crisis and the renewed global economic dynamics contributed to a review of the production strategies and the interrelations between the economy and the territory. Alongside the large plants, new models of medium and small-sized industrial settlements were promoted, having their centre of gravity in residential settlements. These were called “planned industrial areas” and they involved local authorities (first the municipalities) or other local government agencies and private individuals, to provide primary infrastructure (roads, electricity, water, sewerage, etc.) and to manage the spatial location of companies. Ever since their appearance, the theme of the interaction between these settlements and the surrounding local (natural and residential) systems has raised the interest of different actors from the political, economic and academic world. In some contexts, the establishment of industrial areas near urban centres and agricultural areas has been the source of criticalities, related to the subsequent industrial and urban development. Traditional urban land use policies propose to separate the three systems with the aim of minimising the effects of externalities and mutual interactions (e.g., concerning the use of resources, the solid, liquid and gaseous emissions, acoustic and visual impacts and also, in a broader sense, the social ones). In many cases, such policies have generated the loss of competitiveness of companies and depopulation of rural and residential settlements. IE and UM can help to identify forms of integrated revitalisation of these contexts (Lefebvre 1999).

5.1 The case of Pescara Province

The Abruzzo Region, Italy, can be considered as an example for the development of hybrid urban systems in the post-industrial era. In Abruzzo, few basic productions (e.g., steel and petrochemical plants) were established during the 1960s; as happened in other southern regions, industrialization took place later, in two main ways: some industries (glass, mechanics and then pharmaceuticals and electronics) were settled by exogenous companies as key industry or final producers; in the other cases, the emergence and location of endogenous enterprises was witnessed, as sub-suppliers, third-party manufacturers or as a consequence of the development of local handicrafts. This period was characterised by a land use competition between the emerging industrial activities and the primary (rural) sector, which was the basis of the regional economy until the mid-twentieth century. The urban polycentrism and the small size of cities avoided the establishment of macroscopic settlements, but they were not able to prevent the emergence of residential suburban phenomena and demographic explosions, especially in some "minor" municipalities, involved in large localisation processes.

The territory of the Pescara Province (Abruzzo Region), used as the reference context for this article, comprises a total of 34 residential settlements. Over 20,000 businesses, employing 43,635 employees, are located within the area. Table 1 describes their sectoral distribution.

Table 1 Sectoral distribution and companies located within the Pescara Province

PREVAILING INDUSTRIES	NUMBER OF COMPANIES	TYPE OF ACTIVITY
Trade	*7.729*	
Agriculture	*3.013*	
Manufacturing activities	*2.494*	Machinery and mechanical appliances for production, textile and clothing industry, food and beverage industry, metal and metal products manufacturing, electrical and optical equipment manufacturing
Service	*2.192*	
Construction	*2.167*	

As shown in Fig. 5, the Pescara province is characterised by the presence of 9 main industrial settlements; in some of them, the presence of a residential (light blue area), an industrial (light red area) and a rural (remaining areas) dimension - that define hybrid contexts - can be recognised.

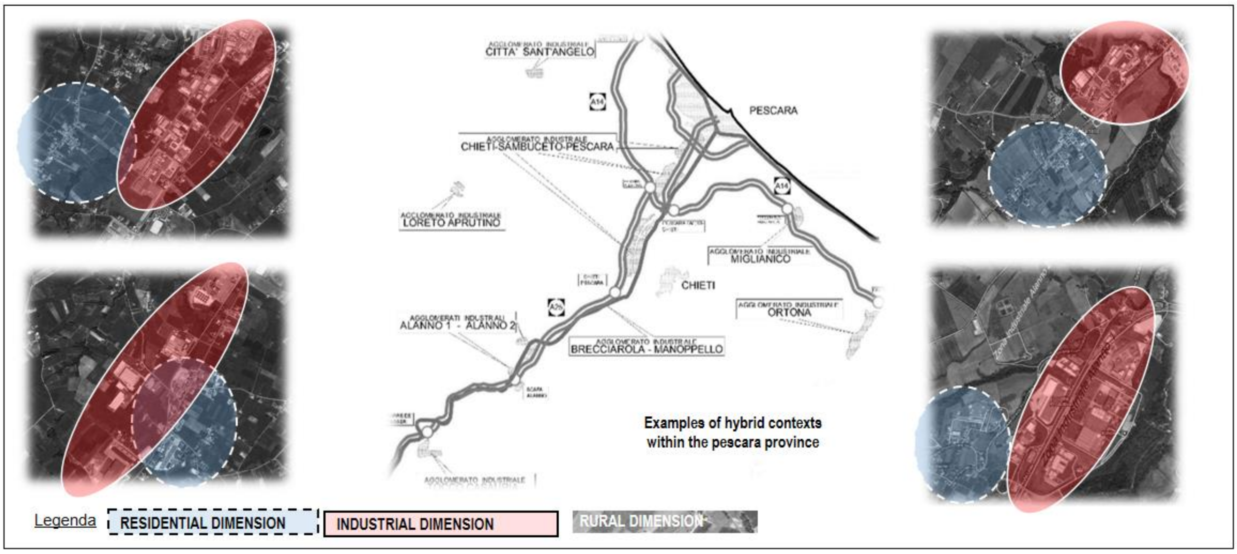

Fig. 5 Some examples of hybrid urban contexts of the Pescara Province

6 The analytical framework

The framework that we propose for the study of such multifunctional/hybrid urban contexts is made up of the three main dimensions described above: residential, industrial, rural (cultivation and livestock breeding). Each of them is characterised by the presence of multiple activities and related inputs and outputs of material and energy flows. The graphic version is represented by a block diagram, where the anthropic activities (production/processing and use/consumption processes), are placed within the boundaries, while the environmental matrices (atmosphere, biosphere and lithosphere) are considered as external (Fig. 6).

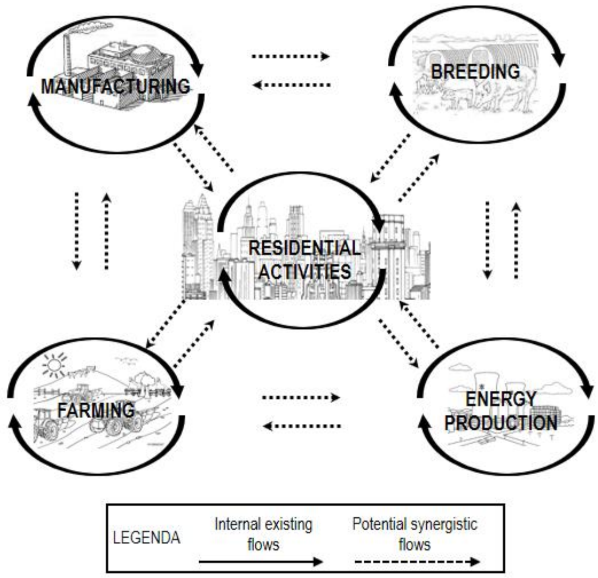

Fig. 6 An example of multiple dimensions involved in an urban system

The structure of the model was inspired by the schemes proposed in the analysis of intersectoral flows by Villarroel Walker and Beck (2012). The typical activities and flows of each of the analysed dimensions are described below.

Residential dimension (RES): UM studies (Kennedy et al. 2007) outline that urban centres are generally characterised by the presence of use (e.g., for durable goods) and consumption activities (e.g., for food) as well as by construction activities (public and private buildings, houses), services (public and private) and trade. The model does not include industrial production activities, which may be present in large cities, but are very limited, or almost absent in small settlements. However, infrastructures and utilities related to the supply of gas, electricity and water as well as for the municipal waste collection (mainly solids and liquids) are included (Fig. 7).

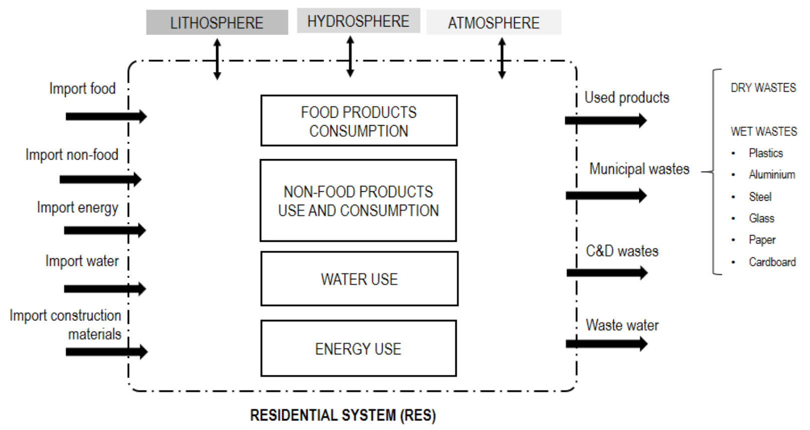

Fig. 7 Typical activities and flows of the residential dimension (Kennedy and Hoornweg 2012)

Industrial dimension (IND): the "planned" industrial systems, considered as the referential industrial model for the hybrid urban contexts, are typically not characterised by the presence of large plants for basic or extractive production; they are mostly characterised by the presence of manufacturing facilities, which have been localized in such areas due to fiscal incentives or local development policies or are the result of the growth of a local craft fabric. However, construction quarries and food processing plants using local inputs, are included. Typical flows are therefore those related to production inputs (raw materials and semi-finished products) and outputs deriving from the established processes (finished products, semi-finished products, waste and scraps) and from support facilities and infrastructures (Simboli et al. 2014; Taddeo et al. 2012), as represented in Figure 8.

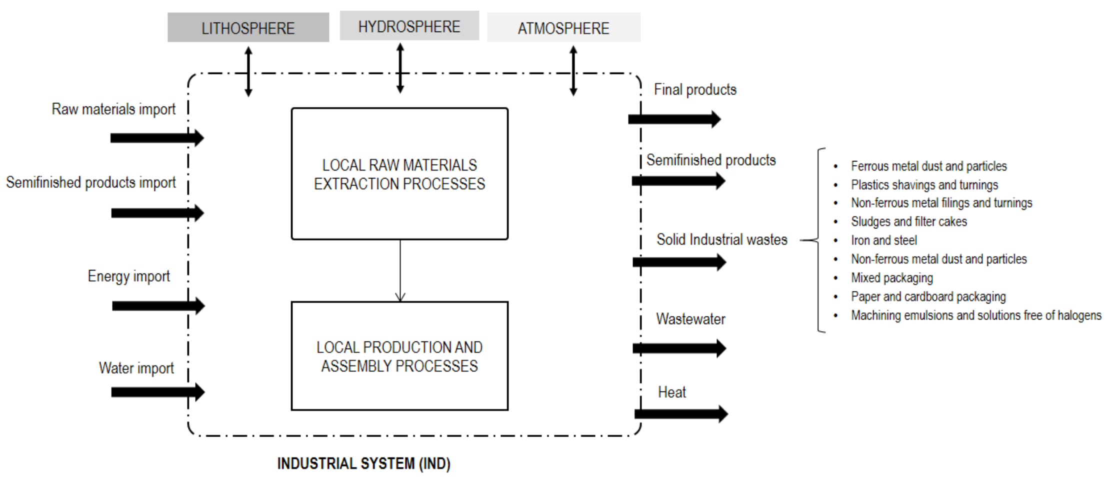

Fig. 8 Typical activities and flows of the industrial dimension (Simboli et al. 2014; Taddeo et al. 2012)

Rural dimension (RUR): southern Italian hybrid urban contexts usually originated from local agro-rural settlements; thus, cultivation and farming activities are almost always present and carried out as the main or secondary activity by a large part of the local population (sometimes in a cooperative way). In some cases, food processing or storage facilities are present. Typical input flows are therefore linked to the supply of seeds and seedling, fertilisers, plant protection products, animal feed, fuel for agricultural machinery, water for irrigation and, as recent studies have shown, a number of auxiliary materials, mostly agricultural plastics - HDPE, PP, EVA, PVC, and PC- that are used as film mulches, drip irrigation tapes, row covers, tunnels, silage bags, hay bale wraps, containers, trays and pots (Simboli et al. 2015). The output flows from the subsystem are mainly vegetable and animal products (and the relevant waste, which can reach 30-35% of the total), wastewater and waste of auxiliary materials (Fig. 9).

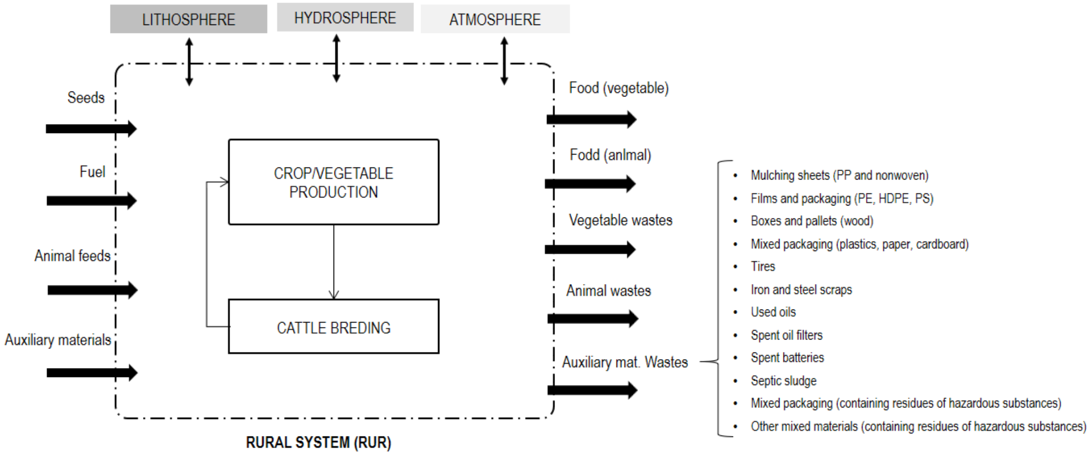

Fig. 9 Typical activities and flows of the rural dimension (Taddeo et al. 2017; Simboli et al. 2015)

A fourth dimension, concerning energy and waste management activities (WES), is considered in the model, as well. This is not included as part of the starting context, for the following reasons: i) in small urban contexts, waste treatment activities are rarely carried out by the municipality, but they are often managed by supra-municipal bodies and includes almost exclusively municipal wastes; ii) as aforementioned, energy production activities are unlikely to be present in such contexts, and if they are, they are often managed by national public bodies or private multinational companies and they do not have direct links with the local social and business dimensions. Exceptions may be those activities related to waste management or energy production that may emerge following an "eco-industrial" perspective of the system, as a whole. Their potential synergic interactions with other sub-systems will be identified and analysed in the discussion section.

7 Discussion: potential synergies detectable

It should be emphasised that among the three dimensions of the urban contexts, especially if located in the same spatial area, some exchanges may be present regardless of eco-industrial synergies; some examples are described in Table 2:

Table 2 I/O commercial relations among the tree dimension

	RUR	RES	IND
RUR	*-Internal exchanges-*	RUR can provide RES with agricultural/crop and livestock products for consumption	RUR can provide IND with agricultural/crop products, livestock products and by-products, for further processing
IND	IND can provide RUR with agricultural products (fertilisers, packaging, machinery)	IND can provide RES with consumables and durable products for use	*-Internal exchanges-*

However, other synergies can be highlighted by considering also the waste and scraps flows that can be generated in the three dimensions and by integrating the model with the WES, that it is placed on the "boundary" of the system in the representative model. Given the experiences gained by the authors in the previous studies, the WES dimension can play an important role of "interface" among the dimensions of a given hybrid urban context and also with other neighbouring urban contexts. Furthermore, the presence of WES can also facilitate the compliance with regulations that in some regions do not yet allow waste and scraps to be directly transferred from one entity to another not authorised for their processing (Directive 2008/98/EC).

The potentially synergistic flows emerged as a result of the preliminary analysis conducted are described below (Table 3) and they are identified by progressive numbers, which also allow for an easier identification in Figure 10.

Table 3 Some of the potential synergies emerged

1)	*Vegetable waste resulting from RUR agricultural phases or from IND processing or RES consumption processes can be reused for animal feed in RUR;*
2)	*Vegetable waste arising from RUR farms, or from RES or IND can be used for composting in the WES and then return to RUR;*
3)	*Plant waste and waste resulting from RUR agricultural phases or from RES or IND can be used to produce biogas in the WES and then return in the form of heat or energy in the RES (or RUR or IND);*
4)	*Wastes deriving from RUR's agricultural phases or from RES or IND can be used to produce biofuels in WES and then return in the form of fuels in the RES (or RUR, for agricultural machinery);*
5)	*Differentiated RES waste (aluminium, steel, glass, paper, plastics) can be treated (collected, selected and shredded) in the WES to be recycled in IND or even for urban furniture production for the RES*
6)	*C&D waste from the RES can be processed (selection and shredding) in the WES and then be reused as in road works (as background or for asphalt production) within the system;*
7)	*Waste from other sources of RES, RUR or IND can be treated (incinerated) in the WES for the production of heat or energy to be redistributed to the system;*
8)	*Disposal of certain types of packaging, metal or plastics, derived from RUR (e.g., agricultural bins) or RES (e.g., waste containers) can be repaired and returned to the RUR;*
9)	*IND heat dissipation can be used for greenhouse heating in RUR;*
10)	*RUR or IND hot water or steam can be used for fish farming or greenhouses heating in RUR;*
11)	*Vegetable waste (dry fraction) of RUR -e.g., from prunings- or of IND -e.g., sawdust- can be used for the production of pellets to be used for domestic heating in RES or industrial plants in RES or IND;*

12) Wastewater can be treated and reused for irrigation in RUR or for use in the RES and IND

13) Recyclable waste from IND can be treated in the WES and return as secondary raw material the IND processes (closed-loop recycling) or to be outsourced (open-loop recycling).

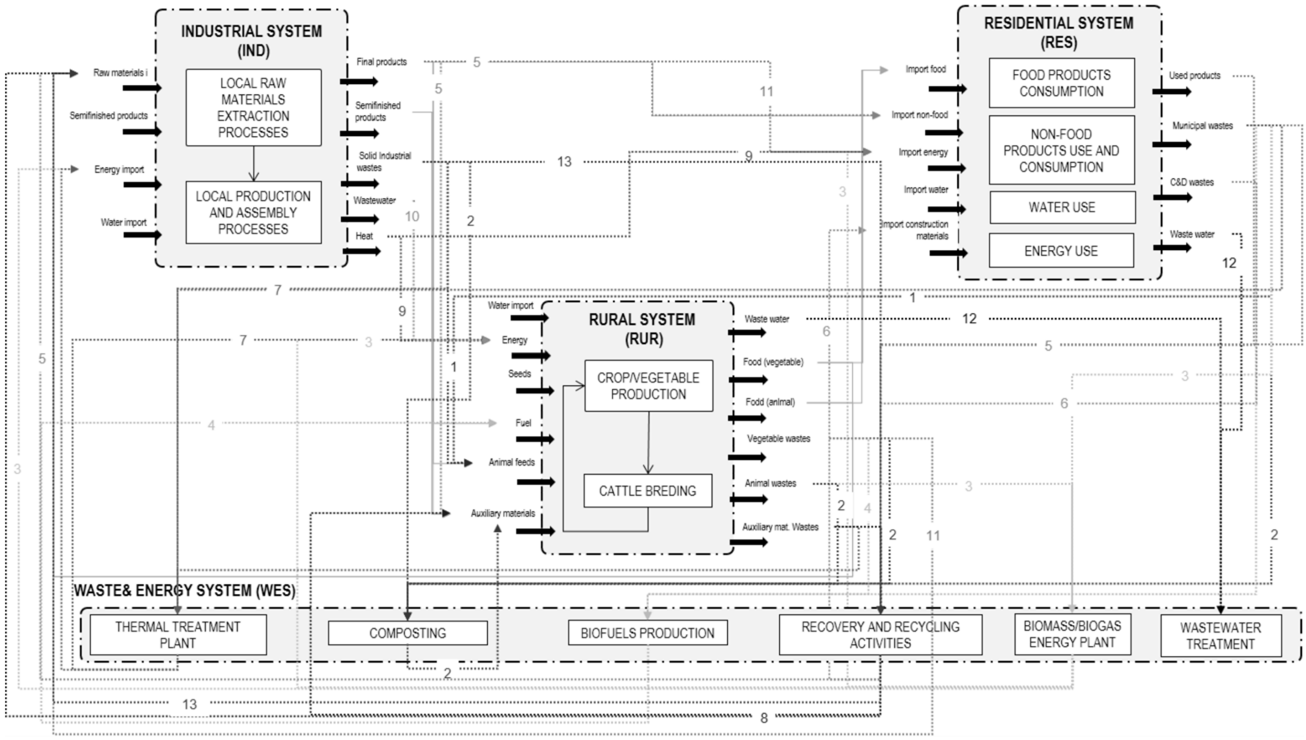

Fig. 10 Potential synergies emerging from an integrated view

It is clear that, in such contexts, it is possible to activate numerous synergies involving two or more of the dimensions which they are composed of. Particularly interesting are the material exchanges, which allow for easy internal and external recycling processes (waste processing and municipal waste resulting from a separate collection, waste of auxiliary materials in the agricultural field), but also for composting (wet fractions) and reuse (C&D waste). At the same time, water treatment processes allow subsequent use for irrigation or washing. More complex are the processes for the production of biofuels and the generation of electricity, heat and biomass, biogas, incineration, district heating, but we need to consider the economies of scale that could be achieved by placing WES in sharing with other neighbouring urban contexts. In some cases, it is possible to activate "closed loop" relations, such as vegetable crop fractions, which are grown in RUR, processed into IND, consumed in the RES and then can return to producing biogas in WES or, in some cases, fertilise the land in RUR.

The framework proposed here could be applied to study many of the hybrid urban contexts placed in areas, such as those of the central-southern Italy, where the planned industrialisation process has resulted in the birth or the development of small production sites close to residential settlements and rural areas, which, due to fragmentation, would be difficult to promote forms of autonomous and sustainable development. IE can provide them with organisational and technological solutions to develop forms of synergistic cooperation that are capable of producing economic, social and environmental benefits.

8 Conclusions

The preliminary analysis covered in this article focused on urban contexts with specific features (i.e., reduced space scale, hybrid nature, which includes a residential, industrial and rural dimension, strong spatial contiguity among the three dimensions) and are still little affected by the PB approaches to IE. The study led to a retrospective investigation for a technical and socio-economic qualification of such contexts, the development of a specific approach based mainly on contributions from UM and IS, a qualitative analysis for the specific synergies that are potentially associated. The article proposes an integrated analytical framework based on empirical data and a literature review, which illustrates the main flows and synergies among the residential, rural and industrial dimensions of these contexts. The integrated vision of the three dimensions, associated with a fourth, specifically dedicated to waste and energy flows, can be useful for efficiently identifying and managing material and energy flows beyond the typical use and consumption of "pure" urban systems as well as for developing improvement actions, favoured by greater heterogeneity and proximity, along with more effective policies for a sustainable approach to local development in a circular perspective. The results of a pilot survey, carried out with reference to the territory of the Province of Pescara, confirm the widespread diffusion of these "hybrid" urban contexts, the three dimensions of which can grow synergistically. There are also significant areas of scientific advancement in research and potential applicative impacts. The next steps of the research include a more rigorous definition and a taxonomy of such contexts and a multiple on-site test of the framework, trying to explore the applications of approaches and tools for assessment of the environmental, economic and social effects deriving from the adoption of an integrated vision.

References

Ayres RU, Ayres LW (1996) Industrial Ecology: Towards Closing the Material Cycles. Edward Elgar, Cheltenham

Bateman B (1999) Place-Based Public Policy in Southeast Asia: Developing, Managing, and Innovating for Sustainability. US-Asian Environmental Partnership. Petree Printing Press, Washington

Bretagnolle A, Daudé E, Pumain D (2006) From theory to modelling: urban systems as complex systems. Cybergeo: Revue européenne de géographie 335: 1-26

Chertow MR (2000) Industrial symbiosis: literature and taxonomy. Annu Rev Energ Env 25: 313-337

Chertow MR (2009) Dynamics of geographically based industrial ecosystems. In Ruth M, Davidsdottir B (eds) The Dynamics of Regions and Networks in industrial Ecosystems. Edward Elgar Publishing, Cheltenham, pp 6-27

Côté R, Tansey J, Dale A (2015) Linking Industry and Ecology: A Question of Design. UBC Press, Vancouver

Côté RP (2000) A Primer on Industrial Ecosystems. A Strategy for Sustainable Industrial Development. Halifax Industrial Ecology Research and Development Group, Dalhousie University

Côté RP, Cohen-Rosenthal E (1998) Designing eco-industrial parks: a synthesis of some experiences. J Clean Prod 6: 181-188

Desrochers P (2002) Industrial ecology and the rediscovery of interfirm recycling linkages: historical evidence and policy implications. Entrep Region Dev 14: 49-65

Deutz P, Gibbs D (2008) Industrial ecology and regional development: ecoindustrial development as cluster policy. Reg Stud 42: 1313-1328

Dinarès M (2014) Urban Metabolism: A review of recent literature on the subject. Documents d'Anàlisi Geogràfica 60: 551-571

Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives

Doménech T, Davies M (2011) The role of embeddedness in industrial symbiosis networks: phases in the evolution of industrial symbiosis networks. Bus Strateg Environ 20: 281-296

Erkman S (1997) Industrial ecology: an historical view. J Clean Prod 5: 1-10

Frosch RA, Gallopoulos NE (1989) Strategies for manufacturing. Sci Am 261: 144-152

Garner A, Keoleian GA (1995) Industrial Ecology: an introduction. National Pollution Prevention Center for Higher Education, University of Michigan 1-35

Goldstein B, Birkved M, Fernández J, Hauschild M (2017) Surveying the Environmental Footprint of Urban Food Consumption. J Ind Ecol 21: 151-165

Hewes AK, Lyons D (2008) The humanistic side of eco-industrial parks: champions and the role of trust. Reg Stud 42: 1329-1342

Holmes T, Pincetl S (2012) Urban Metabolism Literature Review. Center for Sustainable Urban Systems, UCLA Institute of the Environment

Jelinski LW, Graedel TE, Laudise RA, McCall DW, Patel CK (1992) Industrial ecology: concepts and approaches. Proceedings of the National Academy of Sciences of the United States of America 89: 793-797

Jensen PD, Basson L, Leach M (2011) Reinterpreting industrial ecology. J Ind Ecol 15: 680-692

Kennedy C, Baker L, BrattebØ H (2014) Analyzing a city's metabolism. In: Mazmanian DA, Blanco H (eds) Elgar Companion to Sustainable Cities: Strategies, Methods, and Outlook, 1st ed. Edward Elgar, Cheltenham, pp 225-282

Kennedy C, Cuddihy J, Engel-Yan J (2007) The Changing Metabolism of Cities. J Ind Ecol 11:43-59

Kennedy C, Hoornweg D (2012) Mainstreaming Urban Metabolism. J Ind Ecol 16:780-782

Knox P, Pinch S (2010) Urban Social Geography. An introduction. Pearson Education Limited, Essex

Laybourn P, Morrissey M (2015) National Industrial Symbiosis Programme: The Pathway to a Low Carbon Sustainable Economy International Synergies. National Industrial Symbiosis Programme, Birmingham

Lefebvre C (1999) L'area urbana di Chieti-Pescara tra periferia e centralità. In: Landini P (ed) Abruzzo. Un modello di sviluppo regionale, 1st edn. Società Geografica Italiana, Roma, pp 91-114

Lowe AE (1997) Creating by-product exchanges: strategies for eco-industrial parks. J Clean Prod 5: 57-65

Lowe E, Moran S, Holmes D (1996) Field Book for the Development of Ecoindustrial Parks. Report to the EPA on Industrial Ecology. Environmental Protection Agency, Washington

Lyons D (2007) A Spatial Analysis of Loop Closing Among Recycling, Remanufacturing, and Waste Treatment Firms in Texas. J Ind Ecol 11: 43-54
OECD, European Commission, Nordic Innovation Joint Workshop (2012) The Future of Eco-innovation: The Role of Business Models in Green Transformation. OECD Background Paper, Copenhagen
Pandit A, Lu Z, Crittenden JC (2015) Managing the Complexity of Urban Systems. J Ind Ecol 19: 201-204
Roberts BH (2004) The application of industrial ecology principles and planning guidelines for the development of eco-industrial parks: an Australian case study. J Clean Prod 12: 997-1010
Schwarz EJ, Steininger KW (1997) Implementing nature's lesson: the industrial recycling network enhancing regional development. J Clean Prod 5: 47-56
Simboli A, Taddeo R, Morgante A (2012) Place-based approaches to industrial ecology. Considerations about the application in long-standing industrial clusters. In: Ioppolo G (ed) Environment and Energy, Franco Angeli, Milano, pp 177-189
Simboli A, Taddeo R, Morgante A (2014) Analysing the development of Industrial Symbiosis in a motorcycle local industrial network: The role of contextual factors. J Clean Prod 66: 372–383
Simboli A, Taddeo R, Morgante A (2015) The potential of Industrial Ecology in agri-food clusters (AFCs): A case study based on valorisation of auxiliary materials. Ecol Econ 111: 65–75
Sterr T, Ott T (2004) The industrial region as a promising unit for eco-industrial development reflections, practical experience and establishment of innovative instruments to support industrial ecology. J CleanProd 12: 947-965
Szita Tóthné K, Roncz J (2016) Economic analysis of regional sustainability – Hungary. In Massari S, Sonnemann G, Balkau F (eds) Life Cycle Approaches to Sustainable Regional Development. Taylor&Francis, New York, pp 172-178
Taddeo R (2016) Local industrial systems towards the eco-industrial parks: The model of the ecologically equipped industrial areas. J Clean Prod 131: 189–197
Taddeo R, Simboli A, Morgante A (2012) Implementing eco-industrial parks in existing clusters. Findings from a historical Italian chemical site. J Clean Prod 33: 22–29
Taddeo R, Simboli A, Morgante A, Erkman S (2017) The Development of Industrial Symbiosis in Existing Contexts. Experiences From Three Italian Clusters. Ecol Econ 139: 55-67
Van der Berg L (1987) Urban systems in a dynamic society. Gower, Aldershot
Velenturf APM, Jensen PD (2016) Promoting Industrial Symbiosis using the concept of proximity to explore social network development. J Ind Ecol 20: 700-709
Villarroel Walker R, Beck MB (2012) Understanding the metabolism of urban-rural ecosystems: A multi-sectoral systems analysis. Urban Ecosys 15: 809-848
Walloth C, Gurr JR, Schmidt JA (2013) Understanding Complex Urban Systems: Multidisciplinary Approaches to Modeling. London, Springer
White R (1994) Preface. In: Allenby BR, Richards DJ (eds) The greening of industrial ecosystems, National Academy Press, Washington, pp v-vi
Wolman A (1965) The metabolism of cities. Sci Am 213: 179–190
Yu C, Davis, Dijkema GPJ (2013) Understanding the Evolution of Industrial Symbiosis Research. A Bibliometric and Network Analysis (1997–2012). J Ind Ecol 18: 280-293
Zhang Y, Yang Z, Yu X (2015) Urban Metabolism: A Review of Current Knowledge and Directions for Future Study. Environ Sci Technol 49: 11247-11263