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OVERVIEW OF EUROPEAN ECO-INDUSTRIAL PARKS: EVALUATION OF INDUSTRIAL SYMBIOSIS POTENTIAL

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Abstract

Eco-industrial parks (EIPs) and other eco-industrial developments have different histories, sizes, locations and organizational forms. In order to characterize them several classifications and models have been elaborated. In this work for the first time the existing European EIPs are overviewed with the help of four classifications. These classifications are based on (1) the stage of the development of the area, (2) the starting point, (3) the activity of the EIP and (4) the location of the companies involved in the EIP. However, these classifications are not sufficient to seek for the symbiotic relationships and therefore evaluate the industrial symbiosis potential in the EIPs. Because of this, there is a need to propose a systematic approach and create a tool supporting industrial symbiosis in the EIPs. For this purpose in this work much attention is particularly paid to the presence of symbiotic relationships and the potential to establish them in the studied EIPs. Next, an appropriate algorithm, being a tool for industrial symbiosis evaluation, is elaborated. It shows that the number of industrial enterprises and the diversity of the companies involved in the EIP are important factors to establish industrial symbiosis. The algorithm indicates that only four out of eighteen European EIPs studied are likely to develop industrial symbiosis in the future. This algorithm could be applied by management teams of the existing and planned EIPs.

Key words: anchor company, classification, eco-industrial development, industrial ecosystem symbiotic relationships

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1. Introduction

The concept of industrial ecology, which ultimately became a branch of science, is an answer to the challenge that faces human civilization to assure sustainable development that is such development that would preserve raw materials, energy sources, biodiversity and clean environment for the future generations. The first basic ideas of industrial ecology were already discussed in the scientific articles in the mid-fifties and they are actually older than the concept of sustainable development, which was verbalized by Bruntland's commision in 1987 (Erkman, 1997). Frosch and Gallopoulos (1989) made "industrial ecology" popular and worldwide recognizable due to their work presented in Scientific American, which occurred to be one of the most frequently cited articles by other researchers working in the area of this branch of science. In short, it is said that industrial ecology could transform the industrial system by means of learning from functioning of the natural environment. The question thus arises how to implement this concept into everyday industrial practice. Establishing eco-industrial parks was propagated as an efficient method to teach the industry (Lowe, 1993), so the actions of the individual enterprises and interactions between them, were similar to that, what nature has done for $4.5 \cdot 10^9$ years.

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One of the definitions of an eco-industrial park (EIP) is given by Lowe (2001). He states that “An Eco-Industrial Park is a community of manufacturing and service businesses located together on a common property. Members seek enhanced environmental, economic, and social performance through collaboration in managing environmental and resource issues”. The second part of this definition should be of particular interest because it concerns the collaboration among the enterprises aiming at preserving natural resources. The question can be asked, in what manner the improvement to the performance in managing the environmental issues is to be realized. EIPs and other eco-industrial developments are the emanation of the ideas of industrial ecology and establishing symbiotic relationships is the way to achieve this enhanced performance pointed out in the definition above.

Ex definitione symbiosis is the relationship between two partners (organisms), from which both derive some benefits (Ashworth, 1991; Liwarska-Bizukojc et al., 2009). This definition concerns symbiosis in the general meaning. Industrial symbiosis is a particular type of symbiosis, which can be defined as a collective, multi-industrial approach to improve economic and environmental performance through the use of waste or by-products as the substitutes for the raw materials (Costa and Ferrão, 2010). In brief, the waste streams, exhausted by an enterprise should be successfully and feasibly used by another company.

Furthermore, various forms of energy that is heat or electric energy can also be transferred, when an enterprise possesses them in excess. Energy has the significant meaning as all enterprises are dependent on its supply and utilise it in various forms. That is why power plants are often present in the EIPs. They are especially welcome, if they produce so-called green energy that is from biomass, wind or sun. A power plant often facilitates the creation of the EIP and becomes an anchor company in them (Wang et al., 2005).

Symbiotic relationships often emerge from the spontaneous collaboration among the companies representing different branches of industry (Costa and Ferrão, 2010; Cutaia et al., 2016; Korhonen, 2001). Additionally, the representatives of government, industry, universities and other institutions are able to support the development of industrial symbiosis joining their activities in the creation of the favorable conditions for this purpose (Costa and Ferrão, 2010). The development of industrial symbiosis depends on an enabling context of social, informational, technological, economical and political factors (Costa et al., 2010). It should be emphasized that industrial symbiosis is a process and requires years to be developed (Gibbs and Deutz, 2005). It is then difficult to expect that any exchange of energy and/or materials takes place immediately.

Boons et al. (2011) described the dynamics through which industrial systems evolve changing the interactions among the companies. Also, environmental and geographical conditions influence the development of industrial symbiosis, for example reduction of fossil fuels use can be achieved when thermal waters are available or solar energy is economically feasible to be utilized. On the other hand geographical settings can be also understood in the broader economical context, including the cooperation within international organizations and global economical conditions. In the narrower economical context one must mention policy intervention and subsidizing. Finally, the social issues, including trust and everyday cooperation among the employees of different firms, sufficient flow of information, must be included as the factor influencing the development of industrial symbiosis (Gibbs and Deutz, 2005).

In further considerations we would like to assume that only the collaboration between the companies, from which both partners derive some benefits, can be regarded as the industrial symbiosis. What is more, industrial symbiosis is going to be understood as the technical cooperation in two areas that is the exchange of mass and energy flows among the companies. The assumed definition of industrial symbiosis is in agreement with the definition of the EIP presented by Lowe et al. (2001), according to which industrial symbiosis involving physical material, water and energy exchange among entities, should be realized in the EIP.

Although seeking the symbiotic relationships is of highest importance, the cooperation among the members of the community to enhance economic, environmental and social performance can be realized in the other ways, too (Fleing, 2000; Gibbs et al., 2005; Mouzakitis et al., 2003; SIAM, 2005; Singh et al., 2007; Câmpean et al., 2017). The good example here is the common purchasing of widely used goods or materials and the utilization of the common infrastructure (Dow, 2005). Other examples are information or skills centers, where employees from different enterprises share information and/or elevate their qualifications. All in all, there is a variety of the common activities among entities belonging to the EIPs and various organizational forms of them. This diversity of the initiatives called the EIPs encouraged scientists to create for them several different systems of classification.

In the last three decades many eco-industrial developments emerged all over the world. With regard to the eco-industrial developments located in Europe only few of them fulfils the definition of the EIP by Lowe et al. (2001), according to which the existence of the symbiotic relationships (exchange of mass and energy streams) in the EIP is required. On the other hand, some of the eco-industrial developments, for example Kalundborg Symbiosis (Denmark) or the Styrian Recycling Network (Austria), are good examples of industrial symbiosis but they, in fact, are not eco-industrials parks and they are reluctant to be named like that (Ayres and Ayres, 2002; Desrochers, 2002). The issues, whether the symbiosis is present in the studied EIP or not, shall be discussed further.

The main aim of this study is to confront the activities of the operating EIPs in Europe with the idea of industrial symbiosis to answer the question, whether it is realized in them. Furthermore, the potential to create the symbiotic relationships in these EIPs is going to be analyzed. This work focuses on two issues. The first issue is the overview of the existing classifications of the EIPs and their application to characterize the EIPs in Europe (section 2 and 4), which has not been done before. Secondly, we are going to evaluate the activities of these EIPs in the context of the industrial symbiosis and indicate, what the potential to establish symbiotic relationships is in them (section 5). For this purpose a unique algorithm is designed.

2. Systems of EIPs classification

The aim of this section is to overview the existing classifications of EIPs. They can be based on various features. Below four different classifications, including various EIP models, are presented and discussed. The simplest typology is based upon the stage of the development of the area, on which the EIP is located (Lambert and Boons, 2002). Therefore, there are greenfield EIPs, which are established on the new and industrially unused area and brownfield EIPs, which are located in the area formerly used for industrial or other activities. The latter usually replace an old factory or restructure the existing industrial parks (Heeres et al., 2004; Lambert and Boons, 2002; Taddeo et al., 2012). They are often built on the ground formerly degraded by other industrial activities.

In this case the ground usually requires the substantial efforts to clean the environment that is land reclamation, removing waste disposals and treating ground and/or surface waters. The history of the brownfield area, referring particularly to the previous industrial activities, influences on its environmental state and selection of the future EIP members as some companies may not wish to start their businesses on the contaminated area. At the same time in the greenfield parks these restrictions do not exist. As a result, the scope of companies, which would like to join the park, is automatically broader.

The restructuring of the existing and operating industrial park into a new EIP (brownfield type) means that the companies have to adapt to the existing infrastructure (Roberts, 2004; Sakr et al., 2011; Taddeo et al., 2012) in contrast to the greenfield parks, in which the infrastructure can be built dependent on the demands of the investor.

If a degraded and abandoned area is to be used for the creation of the brownfield EIP, theoretically, one can imagine that it could be cleared away to such point that the development of the area is started from scratch. However, in practice, such approach is rarely economically and technically feasible because it takes long time. For example land reclamation in the area, where soil was contaminated with mercury or hydrocarbons, may take several tens years. Thus although free of any old buildings and other remnants, this area is still brownfield and the limitations of the industrial or any other development on the contaminated area must be taken into account. Due to the technical and environmental limitations it is generally easier to create the EIP in the greenfield area. For example it is easier to introduce the idea of green architecture and create high quality environment in the greenfield area. On the other hand, it is more tempting from the point of view of sustainable development and aesthetical issues to establish the park in the brownfield area, as the terrain is revitalized, redeveloped and ceases to be abandoned. What is more, the funds for this purpose may be easier achieved from European or national programs, what can be quite attractive for developers. In the brownfield parks, in which the participants are made to adapt to the existing situation, the planners are more restricted than in the greenfield parks. Industrial participants of such a potential EIP can less willingly join to the initiative. In this way, due to the lesser interest of industrial parties, the development of industrial symbiosis may be aggravated (Sterr and Ott, 2004).

The classification of the EIPs into greenfield and brownfield is useful and relatively easy to make, however, it says nothing about the activities of the members of the park, interactions among them and in consequence it cannot be used to reliably estimate industrial symbiosis potential.

Another EIPs typology emerges from the works of Chertow (1999) and Lowe et al. (1998). As the criterion the starting point of the EIP was proposed and thereby six models of the EIPs can be distinguished. Thus, (1) the EIP can be created from zero (so called *ex nihilo* model). Here, usually the public sector or a developer initiates the action to create the EIP. The potential participants are invited to the newly established industrial area and attracted by the profitable financial conditions. This model is somewhat close to the greenfield EIP. Anchor tenant model (2) is another form of the EIP proposed by these authors (Chertow, 1999; Lowe et al., 1998). In this case a large company initiates the creation of the EIP and attracts other businesses offering common infrastructure, raw materials for the production and markets to sell the goods produced by the potential investors. These parks are usually created around a well-operating large enterprise and operate with the success, what will be shown further.

In business model (3) the investors are attracted to achieve the profitable cooperation. In this model a developer is the initiator of the EIP. Stream model is based upon the exchange of material and energy streams and natural raw materials. It is usually introduced to the already operating industrial park (Lowe et al. 1998). Business stream model (4) is just a combination of stream and business model. Finally, redeveloping model (5) is proposed. This model is valid for the already operating parks. In this case the analysis is performed to redefine the cooperation among the participants of the EIP. The mass and energy balances are performed to initiate establishing new symbiotic relationships. These models touch various aspects, not only the starting point (e.g. *ex nihilo* model), in fact, but also the activity of the EIPs (e.g. business model, stream model) and their organizational form (e.g. anchor tenant model). Because of this, it is difficult to unequivocally address an EIP to an individual category to the EIP. For example, an eco-industrial development can be simultaneously *ex nihilo* park and business park or anchor company park and stream park. It seems to be the weakness of this classification.

Nevertheless, another typology of EIPs, proposed by Chertow (2007) twelve years later is somewhat connected with the aforementioned one from Chertow (1999) and Lowe et al. (1998). It is a planned EIP model and self-organizing symbiosis model. The first one assumes a conscious effort (usually a stakeholder group) to locate companies of different industrial branches in one geographical site and make them exchange the streams and utilize the common resources. In the second one the initiative to create the cooperation, including symbiotic relationships originates from the companies (usually private) themselves (Chertow, 2007). As the six "starting point" models in each case are always somewhat referred to the initiator, stakeholder or managing body, the attribute either "planned" or "self-organizing can be also issued to all of them.

Mouzakitis et al. (2003) proposed a typology introducing five categories of the EIPs, dependent on "the kind of eco-industrial activities". These categories are (1) green & sustainable construction, (2) environmental research & technology, (3) design around environmental theme, (4) mixed use & exchange patterns and (5) industrial ecosystems. The authors of this classification assumed that more than one category could be associated with the individual park. It indicates that this approach is to the certain extent different than the aspects of homogeneity and heterogeneity of the enterprises in eco-industrial parks. Despite this, some connections between these two issues are noticeable and thus are going to be mentioned further in this section.

The first category focuses on the actions on landscaping, architecture design and is often connected with the polluted land reclamation. Its main feature is the change of landscape and architecture. Rarely can any symbiotic relationships be established in this park. The second one is rather an environment research centre, which, if exists without any enterprises in the vicinity, has no chance to effectively establish symbiotic relationships. The tasks of these centers are environmental protection promotion, environmental education, research and development, development of environment-friendly technologies. The EIPs created around the environmental theme for example waste management or renewable energy production, are naturally devoted to have symbiotic relationships. Also these relationships can be established in the mixed use parks, which are characterized by the diversity of enterprises. Their main feature is the cooperation of the enterprises by means of various goods exchange. The last form mentioned by Mouzakitis et al. (2003) is the industrial ecosystem, which is the ideal form of industrial symbiosis. Mouzakitis et al. (2003) think that only Kalundborg and Styria Recycling System (the latter is called a virtual EIP) deserve to be named industrial ecosystems. This classification allows for the determination of the dominating profile of EIP activity and, as a consequence, allows only for the rough estimation of the potential to establish symbiotic relationships.

Moreover, upon this classification the issue of homogeneity and heterogeneity of participants and their activities in the studied EIP can be also addressed, especially with regard to type 3, 4 and 5. The issue of homogeneity/heterogeneity is considered as a one of Key Drivers in the transformation of existing industrial clusters (parks) into EIPs (Taddeo et al., 2012). The chemical industrial parks are usually characterized by a high heterogeneity level, which facilitates the formation of synergies (Reniers et al., 2010).

Chertow (2000) proposed the taxonomy of five different material exchange types, taking the degree of establishing symbiotic relationships (level of symbiosis) and location of the companies into account. She distinguished: type 1 – through waste exchanges, type 2 – within a facility, firm or organization, type 3 – among firms co-located in a defined eco-industrial park, type 4 – among local firms that are not co-located and type 5 – across firms organized virtually across a broader region. The ideal example of the latter type is Styria Recycling System. Despite the fact that the companies are dispersed around the region of Styria, they established efficient symbiotic relationships for the purpose of waste materials recycling. This classification mainly concerns one important but narrow feature of the industrial symbiosis, namely the localization of the symbiotic relationships and it extends the development of the industrial symbiosis beyond the typical EIPs.

This issue of collocation and geographic proximity was also thoroughly discussed by Lombardi et al. (2012) and Lombardi and Laybourn (2012). Traditionally, it can be considered as the key to form the physical exchange of water, energy, by-products, i.e. to establish symbiotic relationships. Also in the definition of an eco-industrial park the collocation of enterprises is a priori assumed. Furthermore, geographic proximity is an important factor of calculating of costs in any business. In some cases the resources can be degraded during the transport, which is not the unique problem of creation of industrial symbiosis (Lombardi and Laybourn, 2012; Lombardi et al., 2012). However, Lombardi and Laybourn (2012) controversially stated that geographic proximity is neither necessary nor sufficient for industrial symbiosis. To support this thesis they exemplified the experiences with NISP. There, for example, transport costs occurred to be substantially smaller than the benefits obtained from the exchange of material, namely synergies or symbiotic relationships. Successful symbiotic relationships can be found in the non-collocated Styrian Recycling Network too.

To sum up, none of these typologies clearly show, to what an extent the ideas of industrial ecology, understood in terms of establishing symbiotic relationships among the enterprises, are or can be potentially realized. In the opinion of the authors of this work only these parks, in which symbiotic relationships exist, can be called eco-industrial parks. Thus, there is a need to analyze the activities of these organizations and conclude to what an extent the idea of the EIP is realized there. A tool that could be useful here was proposed by Liwarska-Bizukojc et al. (2009). It is a conceptual model based upon the ecological relationships, from which a minimum condition to establish the symbiotic relationships in the EIP is derived. The model allows for the classification of the enterprises in the ecological manner. Following ecological nomenclature, the enterprises are classified into industrial producers, consumers and decomposers.

Generally, industrial producers transform raw materials into utilizable products with the simultaneous waste generation. Energy producers are a specific kind of industrial producers, too (Liwarska-Bizukojc et al., 2009). Service companies are an example of the industrial consumers, as they only generate waste and do not manufacture any material goods. Any enterprises, whose main business activity is the treatment or neutralization of any waste streams, are industrial decomposers.

The minimal condition assumes that at least one industrial producer or decomposer must be involved in the EIP in order to establish symbiotic relationships. The detailed study concerning this concept is presented by Liwarska-Bizukojc et al. (2009). Out of this classification of the enterprises it is possible to indicate the existing or potential symbiotic relationships among various enterprises engaged in an organization that aspires to be an EIP.

3. Methods

Gibbs and Deutz (2007) thoroughly researched the variety of organizations in Europe that can be classified as eco-industrial parks. Their list comprises 26 various initiatives from the well-known and operating Kalundborg Symbiosis (Denmark) to the planned investment in Vreten (Sweden). However, not all of them are eco-industrial parks because supporting programs, project and non-profit organizations were also included in this list. In that time their status was different, i.e. operational, pre-operational, planned and attempted. This list inspired us to check, whether there are any symbiotic relationships or whether these relationships are stimulated in the initiatives classified by Gibbs and Deutz (2007) as EIPs, and what the potential to establish these relationships is. As the term "EIP" in this context might be misleading, we decided to use in the analysis presented here, if applicable, the name "eco-industrial development", which is also proposed by Gibbs and Deutz (2007).

In this study twenty eco-industrial developments of the operational and preoperational status from the list by Gibbs and Deutz (2007) were subjected to detailed analysis. The analysis was made in two stages. First, the classifications overviewed in section 2 were attributed to the eco-industrial developments from the list of Gibbs and Deutz (2007). Second, the symbiotic relationships and potential to create them were sought for these eco-industrial developments, which are or may physically be eco-industrial parks.

Thus programs, projects or non-profit organizations were excluded from this analysis. With regard to two developments no up-to-date information was found using the mentioned further sources of information, which suggests that these projects failed. These are Closed Project Tuscany and Montagna-energia valle di Non in Italy. Thus, finally in this work eighteen eco-industrial developments were taken into account in the full two-stage analysis. The evaluation of the potential to create symbiotic relationships was based upon the conceptual model of the EIP presented by Liwarska-Bizukojc et al. (2009). In Table 1 these developments were analyzed and their forms of activities were shortly described and classified. Various sources of data from web sites to personal contacts with the people in charge during our study visits in the selected EIPs were used.

To be more precise these were the following primary sources as web sites (13 out of 18 addresses listed in the appendix), brochures (London Remade, 2004; Dow, 2005), e-mail contacts and study visits (Oekopark Hartberg, Valuepark Schkopau®) and secondary sources as web sites (5 out of 18 addresses listed in the appendix and indicated with asterisks), scientific articles (Gibbs and Deutz, 2007; Labelle, 2001; Mouzakitis et al., 2003) and reports (Fleing, 2000; SIAM, 2005; Rowland, 2002). Some web sites of EIPs can be regarded as primary sources because they were created directly by the management teams of a given park. Their content is differentiated. Using this source of data, it is important to distinguish information of the advertising character from the real data. Sometimes these web sites do not contain all necessary information required to look for symbiotic relationships.

There was a group of web sites that come from other institutions for example scientific institutes or local authorities, and they contained the descriptions of the activities of selected EIPs. These data had to be treated as secondary sources, similar to the scientific articles and reports made by the institutions independent of parks. The information presented there is always selected and processed by other authors. The core of the study was performed between October 2007 and October 2010. It was further updated until 2013.

Table 1. Selected eco-industrial developments in Europe in accordance with the list of Gibbs and Deutz (2007). The description and classification

Eco-industrial development and its location	*Area typology*	*Starting point*	*Activity typology*	*Symbiotic relations & companies location*	*Short description of its form of activity*
National Industrial Symbiosis Programme (NISP), UK	N/D	depends on a project	mixed use & exchange	across firms organized virtually across a broader region	NISP is an innovative business opportunity program that delivers bottom line benefits for the members whilst generating positive outcomes for the environment and society. It is the first industrial symbiosis initiative in the world to be launched on national scale.
Crewe Green Business Park, UK	greenfield	*ex nihilo*	green and sustainable construction	among firms co-located in a defined area	Companies are invited to take part in the project. They must follow strict environmental rules in their activities including the landscape issues
Dagenham Sustainable Industrial Park, UK	brownfield	business stream	mixed use & exchange, environmental research and technology	among firms co-located in a defined area	Hi-tech company present in the park, production companies invited
Dyfi Eco-park, Wales, UK	greenfield	business	design around environmental theme (renewable energy)	among firms co-located in a defined area	Green energy park, no production plants
Ecopark Oulu, Finland	greenfield	business	mixed use & exchange, environmental research and technology	among firms co-located in a defined area	Research centre for green technologies; research and teaching activities.
Ecosite du Pays de Thau, France	N/D	business stream	mixed use & exchange, environmental research and technology	among firms co-located in a defined area	Claims to have introduced new waste management technologies already in the 80's, now this region is advertised for tourist purposes
Ecotech, Swaffham, UK	greenfield	anchor tenant (wind energy power plant)	design around environmental theme (renewable energy)	among firms co-located in a defined area	Leasing of conference rooms, offices, some green energy plants (wind turbines)
Emscher Park, Germany	brownfield	N/D	design around environmental theme	N/D	Landscape park; transformation of the former industrial area; it is an entertainment centre
Oekopark Hartberg, Austria	brownfield	business stream	mixed use & exchange, environmental research and technology	among firms co-located in a defined area	Mainly financial and service businesses are engaged in the project, however there are few examples of industrial symbiosis due to the presence of the manufacturers
Kalundborg, Denmark	brownfield	stream	industrial ecosystem	among local firms that are not co-located	Many symbiotic relationships among companies engaged; the pattern for the industrial symbiosis
London Remade eco-industrial sites, UK	N/D (project)	stream	design around environmental theme (waste management)	among local firms that are not co-located	It is a non-profit organization funded by the London Development Agency. It seeks to address the economic aspects of recycling and regeneration in London.
Parc Industriel Plaine de l'Ain (PIPA), Lyon, France	brownfield	redeveloping model	mixed use & exchange	among firms co-located in a defined area	Various manufacturers (including chemical) and service companies engaged, few symbiotic relationships possible.
Righead Sustainable Industrial Estate, Scotland	N/D (project)	business stream	mixed use & exchange, environmental research and technology	among local firms that are not co-located	A two-years project to investigate the mechanisms required to implement the sustainable development on the operational Industrial Estate; various businesses involved, including small manufacturers and service companies
Sphere EcoIndustrie d'Alsace, France	greenfield	N/D	design around environmental theme	among firms co-located in a defined area	Created by the city of Wittelsheim and Mines de Potasse d'Alsace company; active in the environmentally-sound use of materials, recycling, and environmental rehabilitation
Styrian Recycling Network, Austria	greenfield	stream	industrial ecosystem	across firms organized virtually across a broader region	Large variety of enterprises, which spontaneously created the symbiotic relationships
Environment Park in Torino, Italy	brownfield	business stream	mixed use & exchange, environmental research and technology	among firms co-located in a defined area	Various manufacturers; biohydrogen and solar energy plants

ValuePark® Schkopau, Germany	brownfield	anchor tenant (polyolefins producer)	mixed use & exchange	among firms co-located in a defined area	Anchor tenant model park around Dow Chemicals factory, several symbiotic-like relationships
Vreten, Sweden	greenfield	business	mixed use & exchange,	among firms co-located in a defined area	There are business circles formed by the companies to implement the collective operations. It was initiated by a waste disposal services provider to improve sorting of trade waste.

4. Characteristics and classification of the EIPs in Europe

Four classifications mentioned in section 2 were introduced to characterize the eco-industrial developments studied. Although all these classifications have a variety of limitations and shortcomings discussed above, this characterization was made to form a background, on which the new approach to classify the EIPs and judge their potential to establish symbiotic relationships upon the algorithm presented further in this work was to be presented. Furthermore, such complex description of the European EIPs with the simultaneous use of all these four classifications has not been made before.

The classification based upon the stage of the area development shows that the EIPs studied were created both on the former industrial areas (7 brownfield entities) and new areas (6 greenfield entities) (Table 1).

Five EIPs considered in this work are difficult to classify as greenfield or brownfield. The main reason is that these developments are not located in a defined area. For example, NISP is a national program that delivers environmental, social and economic benefits to the member companies across the United Kingdom. It engages twelve regional teams responsible for the promotion and recruitment to the industrial symbiosis program. It is then obvious that the companies involved in NISP are located in different areas and NISP cannot be called an EIP upon the aforementioned definition by Lowe (2001).

Applying the starting point classification proposed by Chertow (1999) and Lowe et al. (1998) it occurred that business stream model dominates in European eco-industrial developments (Table 1). Five out of eighteen developments classified here can be attributed to this model. Also “pure” stream and “pure” business models are often met and anchor company model fits the best to two developments that is Ecotech Swaffham and Valuepark® Schkopau (Table 1). In some other entities the initiative of two or three companies and/or institutions became a driving force to develop the cooperation and, as a result, create parks of business-stream model (Table 1). Here, a good example is Oekopark Hartberg, where Hartberg Municipality, power plant and waste company contributed to the creation of this EIP. It should be also noticed that the other two models *ex nihilo* and redeveloping model are attributed to Crewe Green Business Park, Parc Industriel Plaine de l’Ain (PIPA) in Lyon, respectively. The aim of Crewe Business Park activities is to conserve, enhance and accentuate existing landscape features in order to create a high quality environment. Parc Industriel Plaine de l’Ain was transformed into the EIP from the active industrial park, which was established in the 1970s of the 20th century.

The third classification applied in this work was proposed by Mouzakitis et al. (2003) and focuses on the activities of the EIPs. This classification assures a quick identification of the main profile(s) of the activity of the eco-industrial development. Although Mouzakitis et al. (2003) allowed for the attribution of more than one category to an individual EIP, in this study in order to more transparently track the activities of the EIPs, we selected one or maximal two categories to the individual EIP. The EIPs studied were predominantly in the category mixed use and exchange. Ten out of eighteen developments were attributed to this category (Table 1). It means that among the enterprises belonging to these EIPs collaboration consists of the exchange of at least one by-product or energy/heat. This is very positive information because it indicates that these entities may have a potential to establish the symbiotic relationships in the future.

The functioning of European EIPs is often associated with the presence and activity of an environmental research and technology unit. It was observed in seven cases (Table 1). What is more important, the research units are established usually in these EIPs, in which the exchange of mass or energy streams occurs (Table 1). For example, in Dagenham Sustainable Industrial Park there is Environmental Technology Resource Centre for London, Oekopark Hartberg – Joanneum Research, Valuepark® Schkopau – Fraunhofer Institute (Merseburger Innovations- und Technologiezentrum Fraunhofer Pilotanlagezentrum). Experts, including scientists, work also in the other entities, for example NISP, although they are not organized in the independent and separate research unit. It should be also noticed that there are five EIPs, which focused their activity on one environmental theme (Table 1). These are usually recycling or renewable energy. For example, Dyfi Eco-park was designed around the renewable energy sources, mainly water power and photovoltaic panels, whereas London Remade focuses on waste management.

The latter classification used in this work concerns the location of the companies involved in the EIP. In most of the EIPs studied, that is twelve, the companies are co-located in a defined area (Table 1). The location of the companies in the neighborhood is a desired feature from the point of view of their further cooperation and industrial symbiosis (Lombardi et al., 2012; Lowe, 2001). It saves money spent on transport and reduces environmental pollution connected with it. In the EIPs, where the companies are co-located in a defined area and at the same time mixed use and exchange pattern exists, the chance to strengthen the cooperation and establish symbiotic relationships increases. Nevertheless, in two EIPs (it is better in this case to call them eco-industrial developments than EIPs for the reasons below) classified as industrial ecosystems Kalundborg and Styrian recycling network the companies are not co-located in a defined area but they are organized across a broader region. This lack of collocation causes that these two do not fulfill the definition of the EIP by Lowe (2001) and they actually cannot be called eco-industrial parks. On the other hand, they show that the lack of the physical proximity of the companies did not prevent from establishing industrial symbiosis, as their name "industrial ecosystem" indicates a really high level of establishing symbiotic relationships paradoxically not often met in the developments calling themselves eco-industrial parks**.**

5. Evaluation of the potential to establish industrial symbiosis in the EIPs in Europe

In this section the eco-industrial developments in Europe were analyzed with regard to the conceptual model of the EIP presented by Liwarska-Bizukojc et al. (2009). This was done in order to demonstrate either existing industrial symbiosis or potential to establish industrial symbiosis. In this model the companies involved in the EIP were divided into three categories: the industrial producers, decomposers and consumers. As it was mentioned in section 2, in order to establish industrial symbiosis in the EIP at least one industrial decomposer or even better one industrial producer should be involved (Liwarska-Bizukojc et al., 2009). It is unlikely to establish industrial symbiosis among the industrial consumers only. In the study we made a closer look into the activities of the companies belonging to the EIPs listed in Table 1.

Five out of eighteen eco-industrial developments presented in Table 1 were excluded from the analysis because they are actually not physical beings but symbiosis programs (NISP, London Remade Ecoindustrial sites, Righead Sustainable Industrial Estate, Emscher Park) or they are in the phase of planning (Dagenham Sustainable Industrial Park). The remaining EIPs were studied in order to seek the existing or potential symbiotic relationships. The results are collected in Table 2. Due to the dynamic political and economical situation, the status of the industrial symbiosis in the EIPs studied or even the existence of the EIPs can be the matter of change.

Analyzing the results in Table 2 it is revealed that the symbiotic relationships can be found unequivocally in three developments that is Kalundborg, Styrian Recycling Network, Oekopark Hartberg. The first two are well known and widely described examples of the industrial symbiosis (Ayres and Ayres, 2002; Boons and Janssen, 2004; Fleing, 2000). In Oekopark Hartberg symbiosis concerns one material stream that is waste paper collected in the park and city Hartberg. Cellulose from waste paper is utilized for the production of thermal insulation and then this insulation is used by the house-builder. The detailed description of this case was presented elsewhere (Liwarska-Bizukojc et al., 2009). Following the development of Oekopark Hartberg during three years (2007-2010), the increase of the number of enterprises, investments and organized events in this park was easily noticeable. It is a good prognostication for the further development of this park and the chance to extend the cooperation (industrial symbiosis) among the enterprises belonging to it.

The question arises with regard to the other EIPs listed in Table 2, whether there is any possibility to evaluate their potential to establish industrial symbiosis. For this purpose, the following algorithm is proposed (Fig. 1). It uses the conclusions drawn upon Liwarska-Bizukojc et al. (2009) conceptual model of an EIP. Two main pathways in this algorithm were included. The first pathway concerns the case, in which an industrial producer is present in the EIP. In the second one only the presence of an industrial decomposer is assumed. A lack of either industrial producer or decomposer makes the industrial symbiosis impossible to occur. The first pathway is further developed for the cases when more than one industrial producer is involved and the simultaneous presence of industrial decomposer(s) and producer is considered. The situation of more than one industrial producer and decomposer are involved in the EIP facilitates establishing symbiotic relationships (symbiosis very possible). In the second pathway, in which only the presence of the industrial decomposer(s) is considered, the potential to establish symbiotic relationships is lower but possible.

Table 2. Characteristics of eco-industrial developments (excluding projects and programs) regarding their symbiotic potential

EIP	*No. of firms*	*Industrial producers*	*Industrial decomposers*	*Industrial consumers*	*Existing symbiosis*	*Other cooperation*
Crewe Green Business Park, UK	35	Manufacturer of packages and labels	Common waste collection system	Most entities	no	Recycling, reuse of rainwater
Dyfi Eco-park, Wales, UK	12	Renewable energy, software company	-	Consulting firms	no	Green energy, ecological construction of buildings
Ecopark Oulu, Finland	several	High tech companies	-	Research, education,	no	Creation of a network of

				R&D companies		environmentally orientated companies
Ecosite du Pays de Thau, France	N/D	-	Lagoon treatment of wastewaters, plastics recycling, recycling of shellfish production wastes.	R&D on environmental technology and biotechnology	no	-
Ecotech, Swaffham, UK	several	Wind energy power plant	-	All other companies	no	-
Emscher Park, Germany	N/D	Solar energy plant	-	-	no	Re-use of land, to prevent its further degradation
Oekopark Hartberg, Austria	about 30	• Powerplant (solar, wooden pellets) • Cellulose insulation manufacturer • Construction materials and wooden houses manufacturer	• Waste company cooperating with municipality • Waste company (recycling)	All other small and medium enterprises	yes (Streams exchanged: waste paper, wooden pellets, heat and electricity)	-
Kalunborg, Denmark	7 involved in the symbio-sis	• Power station • Plasterboard company • Pharma-ceutical plant • Enzyme producer • Oil refinery	• Sludge company • Waste company	Industrial Symbiosis Institute	yes (Streams exchanged: heat, steam yeast slurry, biomass, gypsum, cooling water, technological water, wastewater sludge)	There are symbiotic connections into the local farmers and other industries (fertilizer industry, concrete and cement industry) outside Kalundborg
Parc Industriel Plaine de l'Ain (PIPA), Lyon, France	90	Chemical, textile, pharmaceuticals and food factories	Wastewater treatment, recycling	Logistic, packaging, contracting	Not yet	A wide variety of activities
Sphere EcoIndustrie d'Alsace, France	8	-	Recycling	"Green" design, help in the introduction of ISO 14001	No	Creation of the environment friendly region
Styrian Recycling network, Austria	about 50	Agriculture food processing, plastics, woodworking, building materials factories	Waste management companies	-	Paper and cardboard, gypsum, iron scrap, used oils, tires, saw dust, residual wood, bark, waste textiles	-
Environment Park in Torino, Italy	about 75	Fuel cells construction materials, solar panels production (2 companies)	-	Software and firmware company, research company, mechatronics research company (spin-off TU Torino) several consulting companies	-	-
ValuePark® Schkopau, Germany	16	Chemicals and plastics companies	Wastewater treatment plant	Transport and logistics companies, research institute	Most of companies create synergy with the main company, i.e. polyolefin producer	Common system of different utilities (i.e. water, cooling water, nitrogen)
Vreten, Sweden	80	-	Waste disposal and sorting companies	Cleaning, building renovation, transport	-	Formation of "business circles", six environmental themes: energy, supply chains, waste management, cleaning, transport, construction

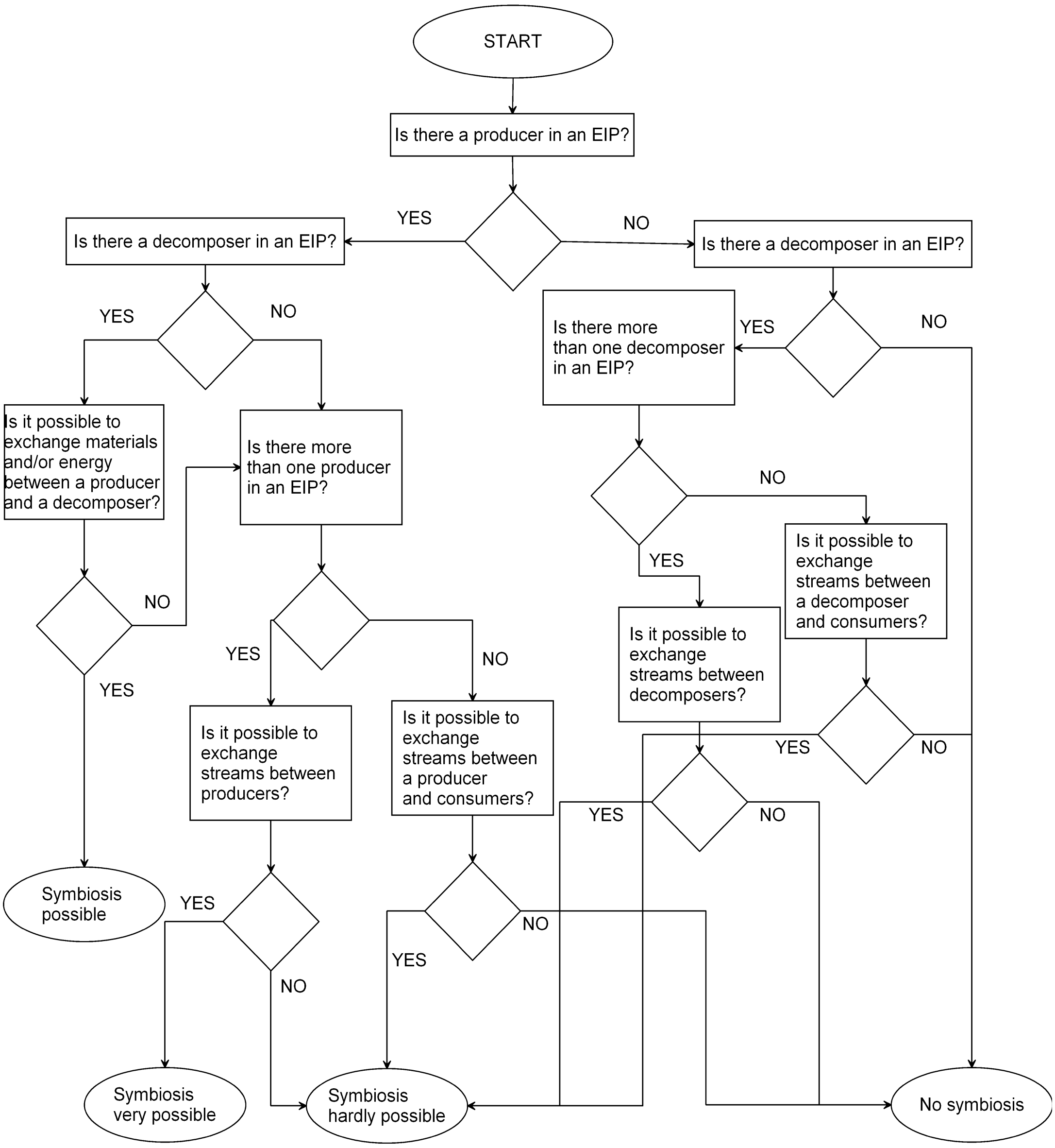

Fig. 1. Algorithm to evaluate the potential of the industrial symbiosis in the EIP

This would require the streams to be exchanged among industrial decomposers and consumers or among industrial decomposers. As this exchange is less plausible from the technical point of view, due to the characteristics of waste streams excreted by industrial decomposers, the symbiosis is then unlikely. Even if these features described above were fulfilled in a given moment of the development of the EIP, it must be remembered that the existence of industrial symbiosis is vulnerable to the continuing presence of these aforementioned important types of companies because the establishing of the symbiotic relationships, as mentioned earlier, takes time. With the presented algorithm the analysis is performed just for the given moment in the history of EIP development.

It must be also clearly stated that this algorithm does not take the quantity and quality of the input and output streams among various companies into account. It claims to be only the first step to check, whether there is a potential to establish symbiotic relationships. Thus, only the presence of specific types of the enterprises is analyzed. As the inventory analysis of input and output streams, together with their amount and composition, in a given EIP is a laborious and costly step, this algorithm should be helpful to estimate, whether it is worth doing it.

The proposed algorithm can be used by managing teams of EIPs. They can easily determine the potential of the creation of symbiotic relationships provided they have sufficient data as these presented in Table 2. It is next required to attribute one of these terms: industrial producer, industrial consumers or industrial decomposer to the enterprises present in the EIP and follow step by step the proposed algorithm obtaining the outcome: symbiosis very possible, possible, hardly possible or no symbiosis**.**

In all of them at least one industrial producer or decomposer is present, however, the potential to establish symbiotic relationships is not the same in these entities. It must be also mentioned that the initiative in Vreten probably goes in another direction towards business park. No data are available about it from the primary sources and scarce from the secondary sources. Apart from the minimum condition the diversity of companies is another factor, which has to be taken into account in the evaluation of industrial symbiosis potential (Chertow and Lombardi, 2005; Korhonen, 2001; Taddeo et al., 2012). Thus, it should be stated again that the potential increases, if both industrial producers and decomposers are present in the EIP or if more than one industrial producer is present in the EIP. It corresponds with the results of algorithm “symbiosis possible” or very possible. Upon this statement resulting from the algorithm only four out of ten EIPs fulfilling the minimal condition for the industrial symbiosis are most likely to form symbiotic relationships in the future. These are Crewe Green Business Park, Parc Industriel Plaine de l’Ain (PIPA), Environment Park in Torino, Valuepark® Schkopau. A short description of these EIPs is presented below.

The aim of Crewe Business Park activities is to conserve, enhance and accentuate existing landscape features in order to create a high quality environment. Conservation of wildlife and natural habitat is of highest importance in this park. The high standard of the attitude to the environment is expected from the developers, so the local authority controls building form, height, site layout and choice of materials. The overall ratio of building to total site area is about 25%. Sites are offered on a 125 year leases (Cheshire East Council, 2012)

The businesses invited and engaged in Crewe Business Park are dominated by service companies (industrial consumers). One manufacturer of packaging (industrial producer) is also involved, however there are no symbiotic relationships between it and any other enterprise engaged in the park so far. The common household waste collection system is a form of co-operation between the industrial consumers and decomposers. In this system large waste items are collected separately. So are electric and electronic waste, including old fridges, freezers and fluorescent tubes. The Crewe Business Park is to a certain extent included into the local environmental management system and therefore some services are offered to the participants. It is claimed that the regional environmental policy is based upon the 4 R's: Reduce, Re-use, Repair, Recycle (Cheshire East Council, 2012). In Crewe Business Park industrial symbiosis can be potentially started from the exchange of streams between the manufacturer of packages and labels and the enterprise responsible for waste collection in the park, namely between one industrial producer and one industrial decomposer. Upon the algorithm it means “symbiosis possible”. But, if one takes a more demanding definition of industrial symbiosis or actually symbiotic network, as proposed by Chertow (2007) a “3-2 heuristic” (at least three different entities involved in exchanging of at least two different resources) into account, the proposed action in Crewe Business park would only remain the exchange of the streams. Nevertheless, our algorithm is trying to seek for the potential to establish symbiotic relationships. Out of these relationships, if more of them were established, the full industrial symbiosis would eventually evolve.

The Environmental Park in Torino was initiated in 1996 by the Piedmont Region, the Province of Torino, the City of Torino and the European Union. The initiative was supported by the representatives of various scientists from all over Europe. Its main aim was to introduce the innovative and eco-efficient technologies. This park is supposed to fulfill the mission of the implementation of the innovative technologies concerning energy and environment in small and medium enterprises. The cooperation among the enterprises and scientific institutions is revealed by realizing of the common projects, conferences and other meetings. The main scientific activity in this park concerns the technologies of biohydrogen production together with the pilot plant constructed for this purpose (actually it can be treated either as industrial decomposer or even producer). Also solar energy technologies and energy from biomass are developed (industrial producer responsible for energy production). The latter is represented by the pilot-plant for the pre-treatment of biomass (industrial decomposer). This park was located on the former industrial area. At the same time, a lot of attention was drawn to green architecture, due to fact that it is located in the Valley of Dora River. Potentially, several symbiotic relationships in this park can be established, due to the presence of various production companies, including the manufacturer of solar panels and manufacturer of fuel cells construction materials. It means the presence of the other two industrial producers. Thus, according to the algorithm symbiosis is here “very possible”.

Parc industriel planie de l’Ain (PIPA) was created in the seventies as an industrial park and an anchor company influenced its development. The oil refinery was built in the face of the global oil crisis in the early seventies (large industrial producer being at the same time an anchor company). This attracted a variety of other enterprises, mainly small and medium ones from such branches of industry as chemical, textile, pharmaceutical (the variety of industrial producers). Also, the logistic companies were introduced as well as the scientific research centre. Plaine de l'Ain Mixed Syndicate, which manages this park, is a public institution. PIPA is located on 2992 hectares and at present 90 companies are active here. A special care is taken towards architecture and environmental standards. The symbiotic relationships can be easily formed in this system due to its high level of diversity, heterogeneity of enterprises, and the presence of chemical industry, which has the highest potential in establishing symbiotic relationships. No doubt arises that the result of symbiosis potential evaluation here is “very possible”.

Valuepark® Schkopau is located in the small town of Schkopau (about 3500 inhabitants) in the central region of Germany (Sachsen-Anhalt) near the city of Halle. It was established in 1998 and its area comprises of 150 ha. The main objective of Valuepark® was to establish the integrated value-creating network of raw material suppliers, downstream investors and service providers so as to encourage benefits from the cost synergies and economies of scale of sharing services and resources. Tens German and international enterprises are involved in the cooperation with the polyolefin producer (large industrial producer and simultaneously the anchor company). It offers to these companies counseling for planning and obtaining permits, a wastewater treatment plant (WWTP), emergency services, analytical services, rail dispatching and different utilities (i.e. water, cooling water, nitrogen, other industrial gases, natural gas).

In Schkopau there are mainly industrial producers involved in the park and one industrial decomposer. It makes industrial symbiosis very probable according to the algorithm proposed in this study. The existing cooperation between the anchor company and other participants of Valuepark® is based upon the use of polyolefins and other chemicals to manufacture the stretch film, modifiers, PVC windows and many other plastic goods (Liwarska-Bizukojc et al., 2009). It is very likely that this economic cooperation will be extended in the future to the ecological dimension, and waste materials or by-products or energy will be exchanged among companies to establish industrial symbiosis. The activity of the industrial consumers in Valuepark® is connected with transport and logistics, whereas the activity of the industrial decomposer concerns wastewater treatment. The latter company can also be potentially included in the symbiotic network. The observation of the activities in ValuePark® for three years (2007-2010) shows the increase of the number of enterprises and closer cooperation among them. This symbiosis in Schkopau is “very possible” and it actually exists. It is worth adding that the web site of Valuepark® delivers updated information and the contact with the manager of Valuepark® is easy.

EIPs can be classified on the basis of (1) the stage of the development of the area, (2) the starting point, (3) their activity and (4) the location of the companies involved in them. These classifications occurred to be very helpful in characterizing and comparing of various EIPs. At the same time they do not give any answer what the potential to establish symbiotic relationships in the individual EIP is. The analysis of the EIP dividing companies into industrial producers, decomposers and consumers is more useful in this context. It supplies information on whether the minimal condition to establish industrial symbiosis resulting from the model of the EIP based upon the ecological relationships is fulfilled or not. This condition says that industrial symbiosis is possible in those EIPs, in which at least one industrial producer or decomposer acts. For example, in two well known eco-industrial developments, actually not EIPs, that is Kalundborg and Styrian Recycling Network, where the material and energy symbiosis take place, this condition is fulfilled. It is also fulfilled in ten out of eighteen of the European EIPs studied. At the same time this study reveals that the minimal condition of industrial symbiosis is not sufficient to evaluate the potential to establish symbiotic relationships. Thus, in this study the appropriate algorithm was elaborated to facilitate this process in the existing and planned EIPs. The algorithm indicates that also the number of industrial producers or decomposers and the diversity of the companies involved in the EIP are important factors in order to establish industrial symbiosis. Upon the algorithm four out of eighteen European EIPs studied are likely to generate symbiotic relationships in the future.

At the same time industrial symbiosis takes time to be established. That is why the conditions formulated out of the model of the eco-industrial park as well as the algorithm presented in this article must be permanently, continuously in time, fulfilled in the system that pretend to establish industrial symbiosis and finally become the industrial ecosystem.

6. Conclusions

Several classifications and models have been developed in order to characterize EIPs. In this work they were applied to characterize European eco-industrial parks, which has not been done before. They occurred to be very useful in describing and comparing of different EIPs and it is proved by this study. These were the classifications based upon (1) the stage of the development of the area, (2) the starting point, (3) the activity of the EIP and (4) the location of the companies involved in the EIP. The overview of the existing classifications and the application of some of them in the study of the European EIPs revealed that upon them it is generally difficult to reliably evaluate both the presence of industrial symbiosis in them and the potential to create it.

Simultaneously, the analysis presented in this work (particularly data in Table 2) proves that the development of industrial symbiosis in European EIPs is very limited. Thus, in this work the appropriate algorithm to facilitate the creation of industrial symbiosis was elaborated. It allows for the fast evaluation of industrial symbiosis potential in the existing and planned EIPs and as a result its application should help in the creation of symbiotic relationships between enterprises.

Appendix

Addresses of internet websites of the EIPs studied:

1 Crewe Green Business Park:
www.crewebusinesspark.co.uk/
http://www.cheshireeast.gov.uk/business/employment_sites_and_premises/employment_sites/crewe_business_park.aspx

2 Dagenham Sustainable Industrial Park:
www.barking-dagenham.gov.uk.
*http://www.lbbd.gov.uk/Regeneration/Dagenham/Pages/LondonSustainableIndustriesPark.aspx

3 Dow Valuepark®: http://www.dow.com/valuepark
4 Dyfi Eco-park: http://www.ecodyfi.org.uk/energy/renewableslist.htm
5 Ecopark Oulu: http://nortech.oulu.fi/eng/Ecopark.html
6 Ecosite du Pays de Thau: *http://gozoblog.com/files/2008/06/ecosite-du-pays-de-thau-colour-sum.pdf *http://ie.tudelft.nl/index.php/Ecosite_Du_Pays_De_Thau
7 Ecotech Swaffham: www.ecotech.org.uk; http://www.greenbritaincentre.co.uk/
8 Emscher Park: http://www.iba.nrw.de/main.htm
9 Environmental Park Torino: www.envipark.com
10 Kalundborg: www.symbiosis.dk
11 London Remade: http://londonremade.com
12 NISP: www.nisp.org.uk. http://www.nispnetwork.com
13 Oekopark Hartberg: http://www.oekopark.at
14 Parc Industriel Plaine de L'Ain (PIPA): http://www.plainedelain.fr
15 Righead Sustainable Industrial Estate: *http://www.forward-scotland.org.uk/Archive-Publications/Righead-Sustainable-Industrial-Estate.html *http://sustainable-energy.meetup.com/cities/gb/v8/righead_industrial_estate/
16 Sphere EcoIndustrie d'Alsace: *http://www.uneptie.org/pc/ind-estates/casestudies/Sphere.htm *http://geoconfluences.ens-lyon.fr/doc/territ/FranceMut/FranceMutScient5.htm
17 Styrian Recycling Network: *http://www.kfunigraz.ac.at/inmwww/styria.html *http://ie.tudelft.nl/index.php/Styria
18 Vreten:* http://www.uneptie.org/pc/ind-estates/casestudies/Vreten.htm

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