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The conceptual model of an eco-industrial park based upon ecological relationships

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ABSTRACT

The necessity to follow the rules of sustainable development in the everyday industrial practice has led to the formulation of the concept of an industrial ecosystem mimicking the natural ecosystem. Following this analogy, the conceptual model of an eco-industrial park, which is an organised form of the industrial ecosystem, was presented in this paper. The model comprises of (1) the structure of the ecosystem, (2) the classification of the enterprises as producers, consumers and decomposers, (3) mass and energy flows and (4) types of interactions. The classification of the enterprises introduced here as well as the analysis of mass and energy flows indicates that the diversity of the enterprises in eco-industrial parks is desired. Furthermore, the minimal condition to create the symbiotic relationships between the enterprises is established, claiming that at least one industrial producer or decomposer must be involved in the eco-industrial park. The application of this model will facilitate the design and development of eco-industrial parks and enable the identification of symbiotic relationships between the entities of such a park and other types of industrial ecosystems. In order to show the applicability of the proposed model and its potential for the practical implementation two case studies are presented.

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1. Introduction

The term "sustainable development" was globally recognised in 1980 when the International Union for the Conservation of Nature (IUCN) published the "World Conservation Strategy". It was then formally introduced into the general usage in the report of Brundtland Commission "Our common future" and the issues concerning the description of the scientific and technological activities towards sustainability have occurred to be of primary importance [1,2]. Subsequently the analogy between the natural environment and human environment has gained much interest. Due to the fact that natural ecosystems are effective at recycling their resources, they are identified as primary examples for the efficient recycling of materials and energy in industry. As a result the natural ecosystem has become a model for industrial activity [3].

In accordance to Frosch and Gallopoulos [4] in "Strategies for manufacturing" an industrial ecosystem is a system, in which "the consumption of energy and material is optimised, waste generation is minimised and the effluents of one process (…) serve as the raw material for another process". The concept of an industrial ecosystem presented by Frosch and Gallopoulos [4] was based on the flows of materials through the life cycles, otherwise known as industrial metabolism. In order to understand and transform the principles of the natural ecosystems into the industrial ecosystems, many studies of industrial ecology have been performed [5–8].

The example of an organised form of the industrial ecosystem is an eco-industrial park, of which there are several definitions in literature. Côté et al. [9] defined an eco-industrial park as "an industrial system, which conserves the natural and economic resources; reduces production, material energy, insurances and treatments costs and liabilities; improves operating efficiency, quality, worker health and public image; and provides opportunities for income generation from use and sale of wasted materials". Lowe et al. [7] define an eco-industrial park as "a community of manufacturing and service businesses seeking enhanced environmental and economic performance through collaboration in the management of environmental and resources issues including energy, water and materials. By working together, the community of businesses seeks a collective benefit that is greater than the sum of the individual benefit each company would have realised if it optimised its individual interests". Roberts [10] simply called an eco-industrial park as "the next stage in the evolution of traditional manufacturing estates". The definitions presented above indicate

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that in an eco-industrial park the industrial symbiosis involving physical exchange of materials, water and energy between the entities should be realised [7]. The seaside industrial town of Kalundborg (Denmark) is the archetypal example of an industrial symbiosis, but is not referred to as an eco-industrial park. Nevertheless, the characteristic features and relationships mentioned in the definitions of an eco-industrial park can be found in Kalundborg.

The taxonomy of eco-industrial parks using the material exchange types as the criteria to distinguish between their various models was proposed by Chertow [11]. He examined 18 potential eco-industrial parks and suggested their classification. These are type 1: through waste exchange; type 2: within a facility, firm or organisation; type 3: among firms collocated in a defined eco-industrial park; type 4: among local firms that are not collocated (Kalundborg); and type 5: among firms organised "virtually" across a broader region [11]. Another approach was presented by Baldwin et al. [12]. They analysed various models of the eco-industrial parks: (1) Kalundborg, (2) Styria, and (3) Massachusetts on the basis of evolutionary framework.

On the contrary to these two different modelling approaches [11,12], the conceptual model of the eco-industrial park presented in this paper was built upon the terms and principles used in ecology. The ecological terms used so far to describe the industrial ecosystems only partially explain the status and functioning of eco-industrial parks. For example Côté et al. [5] focused mainly on the different types of symbiotic relationships, whereas Korhonen [8] described four principles (roundput, diversity, locality and gradual change), upon which the activity of eco-industrial parks should be based. Also Ayres and Ayres [3] discussed the biological analogy in reference to the industrial ecosystems. They described this analogy, especially with regard to the cycling of materials, nutrients and energy in the ecosystem, as a model for the relationships between facilities and companies. The typology of natural and industrial ecosystems was presented there [3].

Taking the above-mentioned achievements into account, there is still a need for the complementary description of the industrial ecosystem and its special form: the eco-industrial park. The main aim of this work is the formulation of the conceptual model for an eco-industrial park, which would be able to evaluate the possibility of creating the symbiotic relationships in such a park. In order to do this the terms and definitions used in ecology are going to be transformed and adapted for the description of an eco-industrial park. Upon this approach we wish to answer the question of practical meaning: what is the minimal condition to create symbiotic relationships in an industrial ecosystem? The presented conceptual model shall allow solutions to this question. Therefore, its application will facilitate the designing and development of the eco-industrial parks, enabling one to seek the symbiotic relationships between the entities of such a park as well as in other types of industrial ecosystems.

2. The conceptual model of an eco-industrial park

The conceptual model of an eco-industrial park, which is claimed to be an industrial ecosystem, was build upon the conception of the natural ecosystem. In this model each entity, i.e. the enterprise incorporated into an eco-industrial park, is treated as a living organism. Depending on its activity each enterprise is adequately classified with the help of the elaborated industrial classification. Each enterprise has its own metabolism, therefore the principles of mass and energy flow are also taken into account. At the same time between the enterprises different interactions are established. Although symbiotic relationships are desired in the eco-industrial parks, in this model three types of interactions: positive, neutral and negative are considered, which properly reflect the relationships existing in nature.

2.1. The structure of ecosystems

Natural ecosystem is a functional ecological unit in which the biological, physical and chemical components of the environment interact [13]. Ecosystem consists of two main components, i.e. community, which is sometimes called biocoenosis and habitat (biotope). Community is defined as the total living biotic components of an ecosystem including plants, animals and microbes, whereas the ecological term habitat refers to a place where species normally reside and is often described in terms of physical features [13]. Also in the industrial ecosystem the industrial community and the industrial habitat can be distinguished.

Assuming that each enterprise is a living organism, as it was previously found, the following definition of an industrial community can be formulated. The industrial community is the team of legal persons (i.e. industrial companies, service and trade businesses) acting in the defined space of the environment (industrial habitat).

The members of the industrial community can be described as "living organisms", because they need food, i.e. substrates (organic or inorganic input materials), energy of different kind (renewable or non-renewable sources) and have simple or complicated industrial metabolism. As a result of its activity two kinds of products are formed. First of all, there are main products defined as the desired products of market value. The second group of products is by-products, i.e. waste. Some by-products can be potentially used as an input material for another enterprise within the recycling of matter.

The industrial habitat comprises of a certain area with the infrastructure and resources. The following analogy between natural and industrial habitat can be made: soil or area – area, water – water supply and sewer system (storm and sanitary), air – air, unlimited solar energy – energetic network (different types of energy used, usually limited). However, the industrial habitat also comprises of information (telecommunication) and transportation (roads, railway and airports) systems, which have no direct analogy to the natural habitat. Nonetheless, the information transfer is observed in the natural ecosystems in the community, and not in the habitat. This is for example chemical communication between organisms with the use of pheromones or sound signals.

2.2. Classification of enterprises

Côté et al. [9] introduced many ecological terms in order to describe an eco-industrial park. However, in many cases the analogy between ecological meaning and new meaning referring to industrial ecology was not clearly indicated. For example, according to Côté et al. [9] taxonomy is the process of classification of businesses and activities. In comparison to this, the definition in "The encyclopedia of ecology and environmental management" describes taxonomy as the theory and practise of describing the diversity of organisms and of ordering this diversity into a system of words, called classification that convey information concerning kinds of relationships among organisms [13]. Taxonomy is the specific classification of organisms based on species. However, in this model another classification, also used in ecology, but based on function, is applied. The presented below classification refers to the energy source and type of the nutrition of the organism.

Functionally two components of the ecosystem can be recognised (autotrophs and heterotrophs) and usually four constituents, i.e. abiotic, producers, consumers and decomposers [13,14]. Following this functional classification, the enterprises, which are a biotic part of the industrial ecosystem, can be divided into industrial producers, consumers and decomposers. The classification of enterprises presented here is connected with the mass and energy balance and should facilitate the preparation of these

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