Industrial Symbiosis and Land Use

Lucija Azman Momirski 1

1 Assoc. Prof., PhD, University of Ljubljana, Faculty of Architecture, Zoisova 12, 1000 Ljubljana, Slovenia
lucija.azman@fa.uni-lj.si

Abstract. An industrial ecosystem can function analogously to a biological ecosystem. Part of an industrial ecosystem is industrial symbiosis, which engages “traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water and by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity.” Opinions differ among researchers on the need for geographical proximity for industrial symbiosis to succeed. Two models of industrial symbiosis exist: the self-organized industrial symbiosis model and the planned industrial symbioses model, which is an eco-industrial park. The paradigmatic example of the first model is the town of Kalundborg, Denmark, and the second model is a conscious decision to identify various industrial companies that can share resources at the same location. A precise inventory of various industrial uses, which includes waste products, offers answers to where and to what extent cooperation between industries could take place. Land-use management can contribute to a developed holistic approach for industrial symbiosis, which promotes the instruments of land-use planning and adaptive management of the territory.

1. Introduction
An industrial ecosystem can function analogously to a biological ecosystem. Part of an industrial ecosystem is industrial symbiosis, which engages “traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water and by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity” [1]. Opinions differ among researchers on the need for geographical proximity for industrial symbiosis to succeed. Two models of industrial symbiosis exist: the self-organized industrial symbiosis model and the planned industrial symbioses model, which is an eco-industrial park. The paradigmatic example of the first model is the town of Kalundborg, Denmark, and the second model is a conscious decision to identify various industrial companies that can share resources at the same location.
The resulting relationship between the companies of Kalundborg was the result of negotiations and an independent industrial agreement that was only signed on the condition that it was economically viable [2]. The Asnæs plant manager was convinced that economic initiatives were sufficient to develop most of the links between the companies in Kalundborg, which is also supported by other authors [3]. The condition that both technical and economic factors occur simultaneously is difficult to achieve in a preplanned process. Industrial symbiosis was not recognized externally at Kalundborg because it was an exchange between business partners. When this process became apparent, a coordinating body was established in a second step, which speeded up the number and complexity of new exchanges [4].

Because industrial development is a form of economic development, interest in industrial symbiosis applications in the form of eco-industrial parks has developed for various purposes, including revitalizing urban and rural sites, the transformation of brownfield sites, and promoting sustainable development [4]. The study of eco-industrial sites in the United States and Europe has shown that there are few successful initiatives based on the exchange of waste and energy and that they are difficult to organize [3]. The USPCSD (1997) has also published the definition of an eco-industrial park: it is a community of companies working together and with the local community to effectively share resources (information, materials, water, energy, infrastructure, and natural habitats), leading to economic gain, improved environmental quality, and equity in improving human resources for the economy and the local community [4]. An industrial zone that establishes an effective exchange of raw materials and energy between economic entities (analogous to a low-waste or waste-free zone) is called an eco-industrial zone or eco-industrial park. The eco-industrial / economic zone is thus the place where the processes of industrial symbiosis can take place. The USPCSD has tried various approaches to eco-
development, from regional databases to waste parks, the subsequent transformation of existing parks, the development of inner cities, rural development, and the improvement of concepts for new cities [3]. In Japan, an eco-industrial park is an eco-city.

2. Research questions
Traditionally, municipalities have planned special areas for industrial, commercial, agricultural, recreational, and other purposes as well as for residential areas. However, the planning processes have not aimed toward industrial symbioses, but simply any industry and/or any other activity. It is also important to emphasize that industrial symbiosis is usually referred to as a business model, but less so as a spatial phenomenon that can be developed through less or more complex methods. Some studies [5] prove that many successful eco-industrial sites are built on greenfields.

Several research questions identify the goal of understanding the connection between industrial symbioses and land use:
1. Can Kalundborg serve as a model for land-use planning in the development of industrial symbioses in other cities? It is argued that the development of Kalundborg’s industrial symbiosis is a greenfield development.
2. The categories of agricultural land use have shrunk to a small number of categories. They have been precisely defined for centuries. The basic categorization simply distinguishes between rural and urban land use. It is argued that the classification of land use of industrial areas could be based on waste indicators, which would support further development of industrial symbiosis.

3. Data and methodology
The first research question is examined by:
– Research on expanding the Stadtoil industrial area in Kalundborg;
– Comparing the Stadtoil industrial area in Kalunborg in 2005 and 2017; and
– Studying the city plan of the Municipality of Kalundborg.

The second research question is examined by:
– Research on information on waste and waste management in Slovenia. Waste management regulations prescribe a reporting obligation for companies that deal with waste, which must complete this form every year and submit it to the institutions in charge.
– Proposing a definition of land-use categories for industrial symbiosis sites; and
– Applying land-use categories for industrial symbiosis sites for the site in the Municipality of Kranj.

4. Results and discussion

4.1. Kalundborg IS and land-use planning
The Municipality of Kalundborg is located in northwest Zealand. The administrative region of Zealand has an area 7,273 km² and a population of 816,460. The Municipality of Kalundborg has an area of 604 km² and a population of almost 49,000. The largest urban area in this predominantly rural municipality is Kalundborg (Figure 1), with around 16,500 inhabitants [6]. In addition to Kalundborg as a paradigmatic business model for the development of industrial symbiosis, Kalundborg was also a case study for a land-use planning methodology involving chemical sites for decision-making in local and regional administrations [7].
The Statoil refinery (which changed its name to Equinor in May 2018) is located south of the city of Kalundborg, about 2.5 km from the center and near the coast with a relatively large harbor. The refinery is regulated according to the Risk Directive, and it submitted an application to the county in 1991 for construction of a new processing plant and new storage facilities. Taking into account the alternatives and assuming that no decision has yet been made on the expansion, the following alternatives were considered, taking into account the overall benefits of the risk represented by the operation of this new expansion (Figure 2):

1. No expansion in West Zealand County (zero option or basis), Code B
2. Expansion at the Kalundborg site. This alternative has four variants:
   a. South of the refinery (north of Asnæs Skovvej) Code K1
   b. East of the refinery, Code K2
   c. West of the refinery, Code K3
   d. South of Asnæs Skovvej, Code K4
3. New refinery at Stigsnæs, Code S

This study concludes that there is no precise definition for industrial areas’ land use: dangerous facilities have so far been covered by land-use planning legislation consisting of procedures in which accident hazards are not explicitly taken into account in land-use policy. A general goal of land-use planning for chemical sites is to manage industrial risks in such a way that the benefits of land development are maximized and the various categories of costs and undesirable consequences are minimized. The aim of the study was to provide a general methodological framework for supporting decisions at the location or major changes in chemical complexes and surrounding land-use patterns.
The methodology introduces land-use planning as a multi-criteria decision. This makes land-use planning in the presence of large-scale hazardous facilities a problem of “multi-criteria decision analysis” (MCDA). For a MCDA problem, the choice of an alternative should be made from a number of given alternatives (small or very large), each alternative being evaluated by more than one criterion. The methodology divides the planning process into seven steps, in which one can go through the steps several times, and it aims to support the end user in formulating possible solutions for the land-use problem. The process is not linear, but instead circular. By cycling in one step or between two steps, the decisionmaker gradually gains a better understanding of a complex topic. However, the methodology aims to create or facilitate a platform to help the final selection by professionals in the relevant institutions. To achieve this, the approach uses the concept of dominance.

For the study, the selected area of Kalundborg was divided into a number of smaller parts called cells. A land-use pattern was defined for the affected area if the land-development type was determined for each individual cell in that area. A land-use pattern represents an alternative approach, and the number of possible land-use patterns represents the number of alternatives available. This last number depends on two sizes: first, the number of cells covering the area in question, and, second, the number of alternative land-development types available for each cell. The number of cells in a range depends on the shape and dimensions of each cell. Each form and dimension is acceptable through the methodology, and the properties of each cell are to be determined by the relevant interests of the spatial planner. Nevertheless, the methodology developed has taken various cell types into account. The second element in the generation of alternatives is the land-development types available for each cell. Land-development types were defined (protected, agricultural, residential, industrial, and existing residential). Relocation was possible with compensation, and each cell received an alternative type of land development.

The cells were divided into three general categories:
- Cells that cannot be modified in their current use (excluded from further consideration);
- Cells not currently used for residence, suitable for one of the following four types of land development: protected land (no further development allowed); agricultural use (only agricultural activity allowed); residential use (implies a certain population density and a certain economic value); and industrial use (implies a different type of building and economic activity leading to the economic and population characteristics described); and
- Cells currently used for residence (accessible for each of the four types of land development with the following remark: the conversion from residential use to nonresidential buildings should include compensation for current residents).

The methodology is defined even more precisely, but the study does not show the choice of the best alternative because it mostly focuses on the methodology itself. However, following the spatial development of the location in the satellite images, it is obvious that the refinery has expanded in the area south of the refinery and north of the Asnæs site. Such a development makes sense because it fills in the area between the current industrial sites that are not located in the immediate vicinity of residential areas. The current plan of the Municipality of Kalundborg, which entered into force on March 7th, 2018, defined the area (frame number 032, Figure 3) as a business area considering specific uses such as offices and the service industry, industry, ports, transport and logistics companies, and the supply system. This description is further expanded with industrial and production activities, oil refineries, tanks, distribution facilities, administration, warehousing, workshops, harbor facilities with cranes, berths, and transport facilities. In the description, land use and the program for construction or buildings intertwine.
The current spatial plan of the Municipality of Kalundborg has multiple definitions for spatial regulations. The northern part of the framework area north of Asnæs and east of the north–south road must be exempted from construction. In the north-eastern part of the area, the maximum number of the building stories is four and the maximum building height is up to 18.0 m. In the rest of the area, the height limit is 8.5 m with the possibility of greater height if the company’s operations require it. At the Statoil refinery, a safety zone of 300 m from production facilities and tank volumes must be respected. Within this zone, housing, institutions, or businesses may not be constructed without the permission of the Danish Emergency Management Agency. No form of construction can be expected within a 50 to 100 m zone from production facilities and tank volumes. East of the Statoil refinery as well as east and south of United Kingdom Oil Spill Storage, a constraint zone of 500 m is stipulated. Within this zone, residents or institutions may not be located without the permission of the authorities.

The spatial plan defines safety measures well, but there is no indication that the land use would take into account the rules of industrial symbiosis or that industrial symbiosis indicators would in any way affect the intended land use. In order to support sustainable (spatial) development, it is essential to provide suitable and sufficient areas for industrial development. Kalundborg’s industrial symbiosis development is clearly a greenfield development that cannot be seen as a model for land-use planning, especially not in urban areas where there are many degraded areas that are also potential sites for the development of new commercial and industrial areas. The sustainable development of industrial activities therefore concentrated exclusively on the production process, but not on sustainable spatial planning and soil protection.
4.2. Industrial symbiosis and land use
In order to ensure integrated sustainable development, it is necessary to provide land for new eco-industrial zones in degraded or poorly used commercial or industrial areas and other degraded urban areas. One step further from this finding is to structure the industrial zones into various categories.

In Slovenia, the Waste Ordinance (Official Gazette of the Republic of Slovenia, nos. 37/2015, 69/2015) and other waste-management regulations impose a reporting obligation for waste generated and handling of waste. The data are collected within the statistical region and are based on data on the location of the waste. The following considerations are taken into account: 1) the company’s waste is processed by the company itself; 2) the company’s waste is allocated to the transferee (another person) in Slovenia; 3) the company’s waste is transferred to another EU member state; or 4) the company’s waste is transferred to a third country (outside the EU). The waste receiver in Slovenia can only be a waste collector or processor. Of the waste generated in Slovenia in 2016, 46% came from production and 44% from services.

The list of the main waste operators depends on the type of waste generated by undertakings in carrying out their production or service activities, and how they are treated is a potential categorization for industrial areas with possible development of industrial symbiosis. Selected categories are defined based on the Waste Ordinance (Official Gazette of the Republic of Slovenia, nos. 37/15 and 69/15):
- Waste processors with an environmental permit for waste processing as referred in Article 42;
- Waste manufacturers with an environmental permit for waste disposal, as provided in the first paragraph of Article 42;
- Waste collectors with a certificate of entry in the register of waste collectors in accordance with Article 30;
- Waste managers with a certificate of entry in the register of waste managers as referred to in Article 53;
- Waste dealers with a certificate of entry in the register of waste dealers as referred to in Article 50.

Table 1. List of the main waste operators in selected municipalities, depending on the type of waste generated by undertakings in carrying out their production or service activities and waste treatment.

| Waste | Kranj (n) | Celje (n) | Novo Mesto (n) | Nova Gorica (n) |
|-------|-----------|-----------|----------------|----------------|
| Processing | 16 | 12 | 11 | 5 |
| Disposal | 2 | 3 | 2 | 0 |
| Collectors | 6 | 2 | 4 | 4 |
| Managers | 5 | 20 | 5 | 4 |
| Dealers | 8 | 21 | 5 | 8 |

A comparison between the four selected centers in Slovenia by selected categories (Table 1) shows that this type of enterprise is most developed in Celje, less in Kranj and Novo Mesto, and least of all in Nova Gorica. However, all categories (except one in Nova Gorica) are active and as such are suitable for the categorization of land use.

The next step examined possible locations for developing an industrial symbiosis in the Municipality of Kranj. At the existing site in Laze in the western part of Kranj, there are up to three companies dealing with waste in various categories. Most of the area is equipped with facilities, and the rest is uninhabited forest areas. In addition to a planned road bypass, the zone has satisfactory supply facilities, but only a few free spaces. The ST 20 area is not suitable for business development. The east part of the area belongs to a functional degraded area of industrial activities according to the FF methodology. According to the FA methodology, the entire zone is classified as degraded urban area for two reasons: physical and functional degradation [8].
Figure 4: The Laze industrial zone in the western part of Kranj: 1. Orthophoto in 2006; 2. Orthophoto in 2015 and the expansion of zone facilities; 3. Industrial buildings within the zone; 4. Municipal Spatial Plan.

Active industrial symbiosis could prevent the defined degradations. The corresponding land use, including the phenomenon of industrial symbiosis also defined in spatial documents, would encourage the siting of companies interested in developing this industrial activity in the area. The synergy of the companies—all connected with recycling components and materials—could make it possible to survive and even grow. Moreover, the distances between the companies involved in the symbiosis would remain short and consequently the costs of the byproducts would not become higher than the costs of virgin raw materials, and so the companies would maintain their competitiveness.

5. Conclusion
The power of land-use planning must also be recognized and utilized in the context of industrial symbiosis. Countries, regions, and municipalities can create opportunities and support successful industrial symbiosis and the circular economy in general. Land-use planning is probably the most important tool in this, and it is just as important for the development of industrial symbiosis and for the circular economy as it has been for sustaining biodiversity, recreational use, and maintaining a healthy environment, as well as for many other aspects and activities.

Land use is an instrument of traditional spatial planning. However, social and economic activities in particular areas bring to the fore the relationships among various types of use. A precise inventory of various industrial uses, which includes waste products and their management, offers answers to how and to what extent cooperation between industries could take place. Land-use management can contribute to a developed holistic approach for industrial symbiosis, which promotes the instruments of land-use planning and adaptive management of an area.
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