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Eco-industrial parks: stimulating sustainable development in mixed industrial parks

A.J.D. Lambert [a,*], F.A. Boons [b]

[a] *Faculty of Technology Management, Technische Universiteit Eindhoven, TM/AW Pav. H.03, P.O. Box 513, 5600 MB Eindhoven, The Netherlands*

[b] *Studiecentrum voor Milieukunde, Erasmus Universiteit, P.O. Box 1738, 3000 DR Rotterdam, The Netherlands*

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Abstract

In several industrialised countries, there have occurred initiatives to establish eco-industrial parks. Originally, these were mainly based upon the exchange of resources between heavy industries in industrial complexes. These initiatives are generally referred to with the concepts of industrial symbiosis and eco-industrial parks. Since then, the concept of eco-industrial parks has been extended to another relevant type of industrial park, the so-called mixed industrial park, which consists of various small- and medium-sized enterprises (SMEs), sometimes complemented by a small number of larger industries. Because of the resulting growing ambiguity in the significance of eco-industrial park initiatives, a typology is desirable for entangling the confusion that is introduced. It is argued that mixed industrial parks are poorly investigated although they have a major environmental and spatial impact. Starting from a general consideration of eco-industrial park initiatives, this paper describes the societal and environmental problems that are related to the mixed industrial parks, proposes solutions and discusses the counteracting factors. While our argument relates strongly to the traditionally industrialised countries, it is also relevant to newly industrialised countries, as they are faced with similar problems, or will encounter them in the near future.

Keywords: Eco-industrial park; Industrial ecology; Environmental and country planning; Small- and medium-sized enterprises; Mixed industrial park

1. Introduction

In the Netherlands, as well as in the United States and Canada, the discussion on eco-industrial parks has explicitly started since about 1995. Many elements in this discussion are related to subjects that have been considered earlier separately, such as ageing, country planning, utility production, and waste handling. One of the roots of this discussion is in the concept of *industrial ecology*, which in turn was an attempt to face the problems that were related to resource consumption, waste production, and emission, by an integrated approach. In developing this concept, the challenge for *sustainable development* played a significant role. The need for unleashing the economic progress from the consumption of finite resources and from the discharge of waste is crucial to sustainability. To obtain this, measures were advocated that combine economical and ecological advantages. Although the basic ideas of industrial ecology were already discussed in papers of the mid-1950s, which have been reviewed by Erkman (1997), the first paper that explicitly formulated the principles of such an approach and that brought these ideas to a broader audience was by Frosch and Gallopoulos (1989). Industrial ecology intends to transform the industrial system by learning from the functioning of the natural environment. In the natural system, all components are integrated and no waste is produced. It needs a systematic analysis of materials flows inside the so-called technosystem, which includes the human-controlled production and consumption processes and which is positioned against the ecosystem. The basic characteristics of industrial ecology are formulated as follows (Erkman, 1997):

1. It is a systematic, comprehensive, integrated view of all the components of the industrial economy and their relations with the biosphere.

* Corresponding author. Tel.: +31-40-247-4634; fax: +31-40-244-4602.

E-mail addresses: a.j.d.lambert@tm.tue.nl (A.J.D. Lambert), boons@fsw.eur.nl (F.A. Boons).

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2. It emphasises the biological substratum of human activities, i.e. the complex patterns of material flows within and outside the industrial system, in contrast with current approaches, which mostly consider the economy in terms of abstract monetary units, or alternatively energy flows.
3. It considers technological dynamics, i.e. the long-term evolution (technological trajectories) of clusters of key technologies as a crucial (but not exclusive) element for the transition from the actual unsustainable industrial system to a viable industrial ecosystem.

This innovative approach has been frequently used by both investigators and industries for making inventories of material flows inside the technosystem and for optimising the material flows with respect to the environmental and economic performance of production processes and enterprises. It has also given theoretical background to the current tendency towards "closing the chain". Although complete closing of the chain of materials flows in the technosystem is utopian, the waste reduction might be considerable and will result, e.g. in closure of landfills in Germany not later then the year 2020. However, the discharge of some dilute emissions such as carbon dioxide, and the creation of small amounts of high-risk wastes that have to be stored in a controlled way, are unavoidable for the time being. Regulation has resulted in bans and restrictions on waste disposal and the costs that are related to waste processing are increasing. This has been a strong incentive for the coming of age of a formerly somewhat obscure, but presently a well-established and innovative branch of industrial activity: the recycling industry.

Based on the framework of industrial ecology, the concept of industrial symbiosis emerged. This concept was introduced by Lowe and Evans (1995), based on studies on spontaneously emerged industrial complexes in which the different industries exchanged material flows on a large scale: Houston Ship Channel in Texas, and Kalundborg in Denmark. In the USA, a prestigious project was initiated by the Environmental Protection Agency of the Federal Government. This was called the eco-industrial park project. In this project under responsibility of the President's Council on Sustainable Development (PCSD), experiences should be gathered by co-operating universities, consultants, project developers, local authorities, etc. and dispersed on interested parties for establishing eco-industrial parks. In a 1996 workshop, information was exchanged on 15 sites in the USA and Canada (PCSD, 1997). In this workshop, the definition for the term eco-industrial park was established. Two definitions were selected, the one focusing on societal performance, the other on technical performance:

1. A community of businesses that collaborate with each other and with the local community to efficiently share resources (information, materials, water, energy, infrastructure and natural habitat), leading to economic gains, gains in environmental quality, and equitable enhancement of human resources for the business and local community.
2. An industrial system of planned materials and energy exchanges that seeks to minimise energy and raw materials use, minimise waste, and build sustainable economic, ecological and social relationships.

Although these definitions largely coincide, there are differences, as the second one has an explicit emphasis on physical flows (materials and energy), while the first definition focuses on organisational and societal processes.

In this paper, we will explain that this distinction is not accidental, but rather reflects the different problems that arise in different kinds of industrial parks. The focus on materials and energy exchange has its roots in the chemical industries. This principally refers to "classical" *industrial complexes* that consist of concentrations of materials and energy intensive, so-called heavy industries which intrinsically are mutually interrelated. These complexes can be situated close to each other, but they are often in a zone, for instance alongside a waterway or close to an ore deposit. The other approach is principally inspired by the problems related to *mixed industrial parks*, which usually house a variety of small- and medium-sized enterprises (SMEs). The challenges there are indeed far more diverse and not confined to the exchange of the many relatively small and diverse flows of materials and energy.

Additionally, we will discuss examples of both approaches, and we will stress that the appropriate planning and management of mixed industrial parks will become an urgent problem in the near future. Although many examples are taken from the Netherlands, which is indeed a densely populated and highly industrialised country, the associated problems are characteristic to the industrialised world and are emerging in newly industrialised countries as well.

2. Typology of eco-industrial parks incentives

We have already mentioned the distinction between industrial complexes and mixed industrial parks that will be further discussed in the remainder of this paper. Apart from this, a third approach is often studied in the literature. This involves the regional approach, which is frequently advocated in, e.g. Germany and Austria (Schwarz and Steiniger, 1997). Here, recycling networks are stimulated, based on industries that are not located on the same site, but that are present in a particular

administrative or geographic region. The most known example and well-documented example is the regional network in Styria, one of the "Länder" (states) of Austria. We will not go deep into regional network incentives, but it should be mentioned that industrial complexes might occupy complete regions and have an impact on the industrial activities in an even larger area.

Interfering with this given typology, eco-industrial park incentives can be subdivided in greenfield and brownfield projects. Greenfield projects refer to the establishment of a new industrial park and the formulation of requirements at beforehand. Brownfield usually refers to the restructuring of existing industrial parks. These are commonly associated with problems such as ageing and soil contamination. Often, one can observe a mix of both, as ageing proceeds relatively rapid, and industrial parks are gradually expanding. Above that, there is often a combination of existing, ageing industrial parks, and new parks in their vicinity, which offers the opportunity for expanding firms to move and to leave room for revitalisation activities.

Summarising the initiatives that have been developed under the banner of eco-industrial parks, we can draw up the following typology:

1. *Industrial complexes:* geographically concentrated industrial activities, mainly process industries, with tight couplings of a relatively small number of materials and energy intensive production processes.	a. *Greenfield:* the development of a new complex of industrial activities with tight physical couplings, taking into account the ecological impact of the complex in designing it. *b. Brownfield:* the revitalisation of an existing industrial complex using reduction of the ecological impact as one of the goals.
2. *Mixed industrial parks:* industrial activities, mainly SMEs, which are concentrated in dedicated areas, of a very diverse nature with no or little coupling of production processes.	a. *Greenfield:* the development of a new industrial park, addressing ecological issues in the different stages of the development process. *b. Brownfield:* the revitalisation of an existing industrial park taking the reduction of environmental impact as one of the goals.
3. *Eco-industrial regions:* industrial activities in a larger geographical or administrative area, usually referring to a diversity of industries, but often with a definite specialisation. Also called: *virtual ecoindustrial parks*	a. *Greenfield:* developing and industrialising a region according to a welldefined concept that includes the reduction of environmental impact. *b. Brownfield:* restructuring an existing industrialised region, often based on definite regional qualities and accounting for environmental performance.

This paper is mainly restricted to industrial districts and parks and their specific aspects. The main characteristics of both are discussed, and the threats as well as the opportunities in their evolution towards sustainable industrial communities are investigated. We will discuss examples and characteristics of both types, but will focus on mixed industrial parks, reflecting the growing importance of incentives with respect to eco-industrial parks that consist of various economic activities. Our central question is how sustainable development can be stimulated in such industrial parks.

First, we will briefly describe what sustainable development is in relation to industrial parks (Section 3). We then go on to describe current initiatives in industrial complexes and mixed industrial parks, and analyse the extent to which they live up to that definition (Sections 4 and 5). Finally, we draw some conclusions on what has been achieved, and how to move further (Section 6).

3. Sustainable development of industrial parks

Sustainable development is not a goal; it is rather a social process in which the principles of sustainable development are taken as a starting point for assessing ecological, social, and economic aspects of decisions in an integrated way through interactive learning processes among societal actors. From this perspective, advancing sustainable development is a matter of initiating and, if necessary, facilitating these learning processes. This perspective on sustainable development has been developed under the heading of action learning networks (Roome, 1997; Carley and Christie, 1993) and network development (Boons and Berends, 2001). The process of sustainable development consists of a continuous stream of smaller co-operative efforts through which a group of actors advances its understanding of how to assess social, economic and ecological aspects of their decisions in an integrated way.

Ideally, each of the co-operative efforts contributes to the further development of the group of actors towards sustainability, and the socio-technical system they are part of. In practice, the process of sustainable development is difficult to materialise. There are two main problems:

- While it is relatively easy to initiate more or less

superficial, short-term social changes, after some time actors often 'fall back' into their old patterns. This is partly due to the fact that individual actors are embedded in an institutional context, which needs to be involved in the change process. Otherwise the unaffected context 'forces' actors back into their old behavioural patterns (Dieleman, 2000).
- Change is often incremental and leads to system optimisation rather than system change. As change needs to emerge from the existing system, it is not useful to propose radical alternative systems, but on the other hand, incremental change should lead to system changes rather than system optimisation. This creates the need to involve all system actors in the change process.

By taking networks of actors as a starting point in advancing sustainable development, both problems could be overcome. The concepts of industrial symbiosis and eco-industrial parks offer the opportunity of implementing these insights. In order to do so, the following elements should be present:

1. Sustainability is not only about ecological impact; rather, it is about the continuous appraisal of ecological, economic and social aspects of decisions, taking the carrying capacity of the earth as a crucial constraint.
2. Although sustainable development progresses through continuous action, there needs to be a strategic vision to complement operational activities.
3. There is a need to simultaneously address technological and social issues. Issues such as the trust between involved parties, the difficulty of organising collaborative effort, and individual firms remaining flexible within the tighter couplings of an industrial symbiosis need to be addressed alongside technological issues.

4. Industrial complexes

4.1. Introduction

Heavy industries have since long been involved in optimising efforts with respect to environmental performance, because many processes are environmentally relevant. The process industries were the first to be addressed with requirements on their environmental performance. This was triggered by catastrophes and the perceptible ecological damage caused by these types of industry. On the other hand, essential improvements appeared possible, and a lot of tools have been developed by these industries for resource savings and the reduction of emissions. In times with elevated energy prices or uncertain supply of materials, resource conservation measures are implemented. Apart from good housekeeping and end-of-pipe measures such as filters, process integration is practised since long. Techniques such as heat integration, water cascading, and recycling of spilled materials to processes have been applied and are often essential to the operation of basic processes, such as in oil refineries. Materials exchange networks between the different processes within a single enterprise, as well as between multiple enterprises, is usual. The cost savings that can be obtained by such measures are often impressive. Because the heavy industries have since long been spotlighted as important polluters, the problem of improving the image of the companies has also played an important role. Also, heavy industries have traditionally been concentrated, e.g. in harbour districts, near iron and coal deposits, and along ship channels. A massive need for transport, by ship, train, or pipeline, also stimulated both settlement of companies in each other's neighbourhood, and exchange of resources. This process is well documented for the Rijnmond area in the Netherlands, which involves the extensive complexes of chemical industries in the Rotterdam harbour district (Stichting Historie der Techniek, 2000). From the 23 companies that settled there in the 1960s, as many as 16 gave up the presence of an existing complex (the vicinity of producers of raw materials and of users of products). Apart from this, the impressive infrastructure, including pipelines with nearby industrial complexes in the Netherlands, Belgium, and Germany, played a decisive role. This massive materials and energy exchange is characteristic for a well-developed industrial complex and clearly surpasses much smaller complexes such as in Kalundborg, which are frequently referred to in the literature. Individual process industries can even not survive without any process integration or exchange of residual materials.

Apart from this, concern with environmental and human safety is crucial to the process industries. Thus, because of the very nature of this kind of industry, a lot of relevant skills is available there and much can be learned from that for application in other economic activities, including mixed industrial parks.

4.2. Industrial symbiosis

Let us discuss now the essential aspects of materials and energy exchange between enterprises, which is often referred to as *industrial symbiosis*. Symbiosis (literally: living together) includes the existence of physical exchange aimed at mutual advantage.

From a technical point of view, three interesting opportunities can be discerned with respect to physical flows inside the complex:

- Collective setting available of utilities.
- Collective processing of waste streams.

- Mutual exchange of materials and energy.

Apart from these, two more options are present that are related to external exchange:

- Applying residual products from remote companies.
- Delivering residual products to remote companies.

These options are visualised in Fig. 1.

Such a symbiosis might lead to various environmental advantages, such as a decreased waste production and resource consumption, and the advantage of scale, e.g. in waste collection and waste processing. For instance, the selectivity of sorting the waste streams can be extended. The system tends to be cheaper because redundancy is counteracted. Nevertheless it can be more flexible because more internal degrees of freedom are present: flows can change direction, if required.

To the externally generated stream of residual products, an additional stream gains importance, namely that of discarded products. Because of tightening regulations, an increasing share of these products will be recollected and processed, aimed at materials recycling. Within this framework, dedicated recycling industries are emerging. This touches the materials processing industries. Allocating recycling industries in the vicinity of the existing process industries decreases the need for transport and can mitigate the nuisance caused by the recycling processes.

4.3. Process integration

Within the process industry, a lot of techniques have been developed and applied during the past decades. These measures vary from conscious operation, usually referred to as good housekeeping, via stand-alone measures such as thermal insulation, up to integrated solutions. The latter involve energy conservation measures such as the application of combined heat and power generation, the application of heat pumps aimed at upgrading the residual heat, and heat integration. Heat integration is usually accomplished by the utilisation of networks of heat exchangers. These exchange heat from hot flows toward flows that have to be heated. Heat integration is especially interesting in those cases where is a combined need for heating and cooling. This method has been first applied in the oil refinery industry. Here, the outgoing product flows (petrol, kerosene, etc.) have to be cooled and the feed (crude oil) has to be heated simultaneously. Ample mathematical programming and software tools are available for optimising such networks, which are based on work of the early eighties, see, e.g. (Cerda and Westerberg, 1983; Linnhoff and Hindmarsh, 1983; Papoulias and Grossman, 1983). A more actual survey of this field is by Biegler et al. (1997).

Energy integration is, however, not confined to a particular process or plant. The same techniques can be applied for supporting site integration.

On the other hand, the techniques that have been developed for heat integration can be extended to the integration of materials flows. One of the first topics that has been investigated in this field, has been the integration of water flows. In contrast with energy flows, where quality is closely related to the temperature, the quality of water flows embraces multiple parameters, such as the concentration of various undesired substances. The principal problem here is meeting the supply of wastewater flows from industries with the need for different qualities of water in other industries. Different centralised water treatment steps can be involved, combined with mixing and even decentralised water treatment operations, such as those based on reverse osmosis. A review of these techniques on the plant level is by (Buehner and Rossiter, 1996). This is often called “water pinch method”, after “pinch technology” for heat integration. The optimisation tools that are available in this field, are an extension of those that have been developed for heat integration. An extension to site integration is given in Keckler and Allen (1999). Extensions to general mass flows have been elaborated as well, for instance by El-Halwagi (1999).

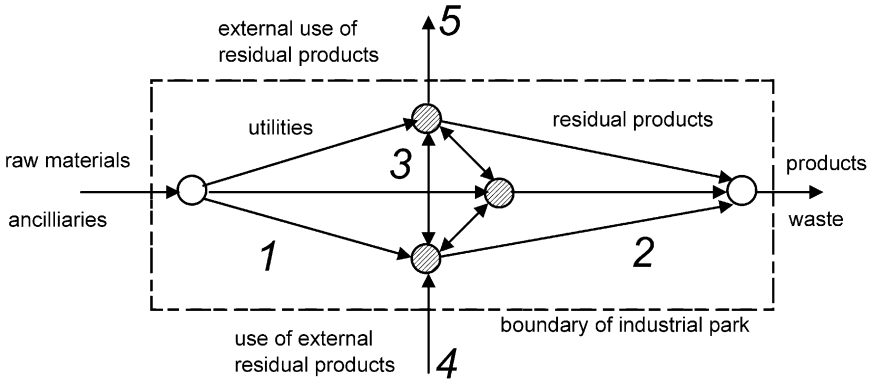

Fig. 1. Industrial symbiosis.

One of the problems in plant integration is the batch-wise operation of many processes, which upsets the balance between supply and demand. Storage of materials, the establishment of bypasses, and even the attuning of processes should be necessary then.

Software tools that are based on techniques from process integration are also available for site integration. One of these tools is the Designing Industrial Ecosystems Tool (DIET), which optimises the exchange of materials, water, and energy between a given group of industries and that is based on mathematical programming. The application of such tools requires the availability of data on material flows of the different industries. A prerequisite for this is open communication between the different industries and research institutions or some co-ordinating site management. In practice, however, the companies are not familiar with multi-lateral agreements, although exchanges on a bilateral basis have been existent since long. These are, however, principally based on incidental agreements between firms and they are mainly governed by cost reduction arguments.

Nevertheless, this mechanism was powerful enough for establishing closely interconnected industrial complexes. The most investigated example is *Kalundborg* in Denmark. It consists of four major industries: a power plant, a petrol refinery, a pharmaceutical plant, and a wallboard plant. Steam, fuel gas, and residual heat are exchanged between the different industries. Residual heat is also used for district heating, in agriculture, and fish farming. The gypsum from the scrubbers of the power plant is applied in the wallboard plant. Some other residual products are used externally. Kalundborg has been referred to in many papers, see Lowe and Evans (1995), Gertler and Ehrenfeld (1996) and Ehrenfeld and Gertler (1997). Kalundborg even acts, to some extent, as *the* model for eco-industrial parks. Investigators concluded that the principal characteristic of the Kalundborg complex is its more or less spontaneous development, based on economic principles and by the virtue of well-established contacts between the different companies. This, however, is usual in the establishment of eco-industrial parks. We have observed this in the Rijnmond example and this is also observable in most of other industrial complexes. The real problem is going beyond such symbiotic systems in two manners.

First, the transition from ad hoc to a structured approach, including the optimisation and control, and the attraction and selection of additional plants for perfection of the system. This requires structured organisation, aimed at co-operation of the involved companies, and participation of the other stakeholders such as the local authorities and other interested parties.

Second, there are many residual products that can be usefully applied but that are not because of economic reasons. Residual heat is a typical product that is amply available, but its application requires investments such as ducts, heat pumps and so on. Such solutions are infeasible if economic aspects prevail.

For this reason, a structured approach by itself is not a guarantee for success. A promising initiative has been the INES (INdustrial EcoSystems) project in the Rijnmond district of Rotterdam (Baas, 1998), which started in 1994 with a letter of intent of the responsible persons of over 80 process industries. These include 7 refineries, 11 companies involved in inorganic chemistry and 13 in petro-chemistry. We mentioned already that they have chosen each other's vicinity for reasons of materials exchange. Other stakeholders that became involved were the local authorities and the Ministry of Economic Affairs, and expertise institutes such as universities and consultancy firms. The project intended the stimulation of the exchange of residual products between these industries by the selection and implementation of solutions that would offer both environmental and economic benefits. The whole trajectory was originally intended to be accomplished within three years. The phases of the project were:

1. Inventory of the major physical flows.
2. Clustering of the enterprises according to the results of the inventory.
3. Formulation and selection on the basis of feasibility studies of definite projects.
4. Technical and economical elaboration of the selected projects in increasing detail.
5. Implementation.

Since then, a lot of measures have been proposed. Some minor improvements, such as redirection of solid waste from incinerators to electric power plants, and the utilisation of low-pressure natural gas, have been implemented indeed. The only major project that has been realised is the outsourcing of the compressed air system by four companies. The collective air-sharing system started in 2000 and has been until present the only implemented multilateral project. The calculated reduction in CO_2-emission by this project is 2775 tonnes/year, corresponding to only a few megawatts. This is virtually negligible compared to the potential reduction in energy consumption by the exchange of residual heat. All the proposals were finally cancelled because of economic reasons, such as payback times of over 30 years.

Actually, the continuity of INES (presently: INES Mainport) is guaranteed for the time being. Although new studies are performed on water integration and a formal exchange facility for residual products, the concrete results of the project still remain modest. One of the conclusions of the INES studies was: "industrial ecology is common practice in the chemical industry,

and is mainly initialised and supported by the companies", see (INES Mainport, 2000).

4.4. Outsourcing and clustering

One of the tendencies in industry is the restriction to the core activities and, consequently, the outsourcing of ancillary processes. This results in the self-sufficient operation of these processes, e.g. in independent companies. These companies, in turn, can provide services to multiple industries and can be taken over by specialised companies. This tendency is, for instance, the real clue to the success of the already discussed air-sharing project in the Rijnmond district. The supply of utilities is involved by this tendency and it opens the way to combine the production and distribution of utilities for many industries on a particular site, which might increase efficiency and flexibility.

The same tendency, however, might lead to the subdivision of more or less integrated industrial companies in business units that are operating virtually independent of each other and even acts as if it were competitors. This strongly counteracts the exchange of information and of utilities, as juridical and economic constraints become restrictive in such cases.

A large producer of electronic products that had formerly a policy of integrating its ancillaries and supplies, changed its policy in favour of outsourcing. The company owned plants that were involved in producing plastics, or cardboard packaging, were sold to dedicated firms. Also much of the utility supply, such as groundwater resources, combined heat and power plant, waste processing plants, and comparable activities were made independent companies, or were transferred to companies that considered these activities as their core business. Outsourcing even might stay at the basis of eco-industrial park initiatives that are based on industrial symbiosis. One of the interesting examples is a Dutch beet sugar factory that will make its ancillaries share with other producers, particularly if no sugar is produced, which is the case 10 months a year. Another example is a major waste dump that already produces electricity, biogas, fertiliser, and sorted materials, intends to establish a dedicated industrial park that is based on these resources. Recently, various types of agro-industrial production parks are advocated. Although residual heat from industry is incidentally used in agricultural production such as in greenhouses and fish farms, proposals for further integration the supply (feed and fertiliser), the agricultural activities, and the food processing industries. Because agricultural products and by-products are usually bulky and perishable, the need for logistics (transport, conditioned storage) is impressive. Integration and utility sharing is promising in this field (Innovatienetwerk Groene Ruimte en Agrocluster, 2000), although objections might arise against the massive exploitation of animals, and the impact on the social structure of the countryside.

4.5. Conclusions

Industrial complexes are usually spontaneously developing exchange networks for utilities, residual products, etc. Most of the heavy industries attain economic benefits with materials exchange. However, a further extension of such networks to lower grade residual flows, such as residual heat, usually fails because of the large preparation time in relation to the internal dynamics of the system, the high investment costs, and uncertainties in the market and, particularly, the energy prices. Most promising are the opportunities for clustering in greenfield areas. This is not only true for the process industries, but also for the food processing industries. Here, it can be observed that the distinction between agriculture and industry is gradually fading away.

The outsourcing of non-core businesses, particularly the setting available of utilities and ancillary processes, offers opportunities for more flexible exchange of physical flows between different companies.

- these initiatives mostly deal with economic issues, not with sustainability;
- a strategic focus is often missing;
- social issues are to some extent less problematic, due to the nature of industrial complexes.

5. Mixed industrial parks

5.1. Background

Although the heavy industries have been clustered for long, the picture for most of the other firms is quite different. This concerns, e.g. the labour or knowledge intensive industries, craftsmanship, services of local importance, and related activities. Most of these enterprises are small- or medium-sized, although some of them are subordinated to large holding companies. The role of clustering has always been modest here. Some concentration because of the presence of specialised expertise, cheap labour force, or the vicinity of particular resources such as pure water, originally played a role in traditional industries such as the production of textile, cigars, leather and other.

Originally, individual enterprises emerged in or near residential areas. Frequently, these were dangerous, they emitted hazardous substances, or they caused nuisance such as noise, stench, dust, and transport. From the company's point of view, expansion appeared virtually impossible, particularly because residential districts

gradually enclosed the enterprises, and regulation with respect to nuisance became stricter.

Primarily aimed at enhancement of the quality of urban life, the visionary architects Le Corbusier and Giedion postulated the paradigm of separation of the different urban functions in the year 1928. This idea has been widely accepted since then, which resulted in the forerunners of the presently existing mixed industrial parks. The first industries that settled there were those that were not compatible at all with residential areas. Somewhat larger industries took advantage of transport facilities such as railway connections or inland navigation channels. Examples of these are processing plants for agricultural products, production plants for building materials, construction plants, foundries, etc. These often form the cores of the older mixed industrial areas. Frequently, these industrial areas survived the degradation of the original infrastructure.

Gradually, an increasing share of economic activities moved from the residential area to industrial parks, up to local services and even retail trade. This development has been strongly enhanced by the introduction of car transport for employees and customers, and truck transport for goods. As a result, a score of mixed industrial parks emerged. This development was further accelerated by municipal policy and by the autonomously functioning market mechanism. All these tendencies contributed to the development of mixed industrial parks.

These are characterised by the following:

- They are usually occupied by many small- and medium-sized enterprises (SMEs).
- Most of the enterprises have a local or at most a regional importance.
- There is a restricted dependency of the particular properties of the site.
- The enterprises experience virtually no advantage of each other's vicinity.
- The population of the enterprises usually changes rapidly.
- There is redundancy, i.e. multiple similar enterprises might be present, such as printing companies (Côté and Smolenaars, 1997).

The importance of mixed industrial parks for the economy and the employment is considerable and still growing. Their impact on the country planning, however, is sometimes alarming.

5.2. Site management

Because the enterprises in the mixed industrial parks are small- or medium-sized and are active in a variety of branches, there might be competition on the one hand, indifference and difference in interest on the other hand. Coherence is poor. This reflects itself also in the way they are established. In the Netherlands, the park is usually made ready for building by the municipality or a regional authority. Subsequently, the available lots are issued to the candidates. Most of the candidates (approximately 80%) appear to be of local origin. Once the lots are issued, some collective management is virtually absent in most cases, not to mention selection, clustering, and zoning. Even trivial topics such as social security, traffic control, fire protection, and signposting are not adequately regulated, not to mention industrial symbiosis and a proper clustering of related enterprises. The layout of the mixed industrial parks is usually rather chaotic and poorly planned. Its presentation is chaotic as well, not to say ugly.

Even a structured platform for deliberation between the interested parties, which is a necessary condition for eco-industrial parks, fails in most of the cases. Even collaboration between the enterprises, which appears to be a key issue in the process of establishing eco-industrial parks, is often absent because of a lack of confidence and of interest. The presence of anchor tenants can be stimulating. These are some enterprises that are really interested in a process of upgrading and that recognise the problems of the site as a whole. In some brownfield cases the relatively large-sized and environmentally relevant enterprises that originally made out the core of the site, can act as an anchor tenant.

Site management is advocated as a logical sequel to organisation, as it is intended for the co-ordination of collective issues. Inquiries of the resident firms have revealed a ranking of collective issues that are considered poor and that need improvement. Security issues are frequently mentioned here. Although some resident industries in the food or process sector set residual heat available, the need for the exchange of residual products is considered of minor importance. Most of the interest in this field is in collective purchasing of utilities such as energy, the collective recollection and processing of packaging materials and solid waste, and, possibly, the collective generation of energy. The firms want to contribute only on a voluntary base. This, however, might lead to an ineffectiveness of the intended measures, because uncommitted enterprises can evade any step towards an eco-industrial park. On an existing mixed industrial park of 290 ha, 20 (5%) of the 400 existing firms are joined in a collective recollection scheme, which is considered a success (ter Stege, 2000).

With respect to the layout and effective use of surface area, requirements can be set by regulation: a minimum height, a minimum density of build-up area, and rules for parking lots (on roofs or in cellars). Besides this, the collective use of parking lots, collective transport, the collective use of buildings, and the establishment of other collective facilities are often mentioned but rarely practised as possible solutions. In practice, increased

ground use efficiency seems — if on a voluntary base — only being restricted by raising ground prices.

In larger, regionally focused, mixed industrial parks, the clustering of transport facilities can be attractive. In some cases, facilities that enable the transfer of goods between ship, rail and truck, have been realised indeed, e.g. a container terminal for collective use that was formerly owned and used by a single company. This can also be considered as outsourcing, as it is based on economic, not on ecological considerations. Nevertheless, site-management is a prerequisite for industrial parks that are developing collective facilities.

5.3. Brownfield parks

In the course of the evolution of mixed industrial parks, enterprises are leaving while others appear. The overall structure of such parks tends to age; i.e. a gradually inadequate adaptation to the requirements of the state-of-the-art is perceptible. This reflects itself in a decreased attractiveness of the park for investors, and also in an inefficient use of the park's infrastructure. Even when industrial parks are still expanding, their oldest are already ageing and often need restructuring or redestination. A 1996 survey reported that about 20% of the industrial park area in the Netherlands suffered from ageing. Ageing referred here to inadequate functioning with respect to accessibility, layout, environmental requirements (e.g. soil contamination and nuisance), and general presentation including social security (Heidemij Advies, 1996). Because of the rapid growth of the urban area and the area of industrial parks, this figure will inevitably increase both absolutely and relatively. Measures aimed at counteracting this situation are:

- Large-scale maintenance.
- Restructuring: a radical upgrading.
- Redestination: a change in destination.

Redestination to residential use or office buildings is frequently practised for the parks that are near to urban centres, railway stations etc. The first redestination plans were related to the industrial parks of the pre-war period, which often became fully enclosed by residential areas. Choosing for redestination was the joint result of their location and the ground prices. Restructuring of the aged industrial parks appeared expensive compared to the establishment of new industrial parks in the greenfield. Ageing industrial parks frequently become occupied by retail trade, such as large-scale shops for furniture, building and garden materials, dress shops, etc. which further counteracts their attractiveness for activities that require a certain degree of presentation.

One of the problems in ageing is the closure or relocation of existing industries. As an example: an intermediately sized industrial park (2 km^2) was dominated by an internationally based tyre plant, a plant for manufacturing fine mechanical devices, and a plant for food processing. A few decades later, two of these key industries have closed. Presently, the biggest employer has become an electronic equipment plant that in turn is cut back gradually. Only the food processing plant, being the most materials and energy intensive company, had expanded and imposed quite other requirements on the site than the disappeared large companies did. Apart from these anchor tenants, a rapidly evolving multitude of smaller companies existed.

5.4. Greenfield parks

Although the land use in brownfield parks is often obviously ineffective, the existing enterprises are restricted in their desire to expand. According to surveys, this restriction is usually experienced by at least 25% of the companies. Once the gradually expanded industrial parks reach their ultimate boundaries (residential areas, waterways, highways, municipal borders, nature parks), there is a desire to establish new, sometimes adjacent sites. These new, greenfield-based industrial parks are closely related to the existing ones, for many firms want to move from the old to the new site, claiming still more area there, even for future expansion or as a strategic stock. For a medium-sized municipality (40,000 inhabitants), without heavy industries, an existing area of 150 ha (1.5 km^2) and existing plans for another 100 ha in the greenfield, are typical. Therefore, the problems of existing and of new industrial parks are closely connected.

In industrialised countries, the agricultural area, which often possesses high cultural–historical and natural values, and should act as a buffer zone between build-up areas, is transformed to industrial area at a high rate. Deregulation, which includes the permission of erecting detached houses in industrial areas, the permission for retail shops to occupy greenfield area, and the emergence of "linear" chains of industrial parks along motorways, aggravates the situation with respect to environmental and country planning. Moreover, the definition of an industrial park is obscured to some extent. In the Netherlands, the land occupation for industrial parks is estimated less than 2% of the country's land area (580 km^2 in 1994), according to official statistics. Such figures, however, reflect only a part of the planning problem. Isolated enterprises, concentrations of retail shops, car repair shops, office buildings, etc. are excluded in these figures. Nevertheless, an additional increase with 210 km^2 (1.5% on a yearly base) is expected till 2020 (Keers, 1998). The growth rates refer to all industrial areas, and traditionally a large share of it is still by industrial complexes. The autonomous growth rates of the mixed industrial parks are not separately monitored, but undoubtedly still more impressive. As industrial parks are increasingly situated on former agricultural

sites, the related infrastructure threatens to disintegrate the countryside even more by urban sprawl.

More than on the static figures, one should focus on the dynamics. In the period 1989–1996, an 18.5% increase can be observed for both industrial park area, and the area that is occupied by services, according to official statistics. The complete built-on area did increase with 6.7% in the same period of time. Illustrative to this relative growth is the area that is occupied by construction sites. For industrial parks, this is 21% of the area in use, in 1996. In absolute sense, this figure equals the area for the construction sites (117 km^2) of all other built-on areas, mainly for residential purposes. These figures are based on the year 1996 for the Netherlands. Since then, the economic growth has accelerated and, consequently, the rate of industrial park construction. The fact, that no recent figures are available, reflects both inadequate monitoring and an amount of public indifference in this field. This reflects itself in a rather unstructured development.

Such a development, although seemingly favourable for the enterprises on the short term, results in serious disadvantages for both the economy and the environment on the long term. The inefficient land use already causes severe logistic problems as it multiplies the intensity of the road traffic. Besides this, the attractiveness of the landscape gradually degrades which also undermines the climate for investments on the long term. It can be observed, e.g. that the visual impact of mixed industrial activities is considerable and amply exceeds, even intentionally, the confinement of the area. As many of the new industrial parks arise somewhere in between existing residential areas, they can act as catalysts for urban sprawl.

These aspects illustrate the need to arrive at a more sustainable approach in both the planning and the management of mixed industrial parks.

5.5. Case 1: Burnside Industrial Park

From the international scientific literature, only few data on mixed industrial parks are available. One of the cases that repeatedly appears in the literature, is *Burnside Industrial Park* near Dartmouth, Nova Scotia, Canada (Côté and Hall, 1995; Lowe, 1997; Côté and Smolenaars, 1997; Côté and Cohen-Rosenthal, 1998). This initiative, called "the industrial park as an ecosystem" started in 1992. It concerns a 30-year old, mixed industrial park of presently 760 ha (7.6 km^2), one of Canada's largest ones, which houses about 1300, mostly small-scale and even micro-scale, enterprises that employ about 18,000 people (24 employees/ha, which is modest). A selection of these enterprises is listed: 36 printers, 21 painting firms, 19 chemical companies, 20 computer firms, 32 car repair firms, 17 metal processing companies (Côté and Smolenaars, 1997). Further mentioned activities involve food processors, health services, communications, construction, retail, and logistics. The few larger firms on this site are involved in furniture production, plastic film production, cardboard manufacturing, and telecommunications. Packaging has been considered here as the most important residual product flow in terms of volume, and a proposal for collective processing of packaging has been worked out, which has not been implemented up to now.

Although Burnside is one of the earlier explicit initiatives and much work has spent to it, the results are still modest. They mainly include the establishment of an information centre for cleaner production (Eco-Efficiency Centre) and some regulation on the environmental performance of individual companies. The Centre launched the Eco-Business Program in 1999 aimed at simultaneously reducing the environmental impact and obtaining economical advantage. Joining the program was on a voluntary basis. About 52 members have been registered in so far. Part of these firms are directly interested because of their professional involvement in recycling or other environmentally relevant activities. Another incentive has been the establishment of an exchange for used pallets.

Although mapping of the flows of materials and energy of the different companies is crucial to the development of eco-industrial parks, such a mapping was not carried out mainly because, a full set of consistent and reliable data on physical flows has not become available. Data acquisition can be considered as one of the major bottlenecks in even formulating proposals on materials and energy exchange in mixed industrial parks on a multi-lateral level. In the scores of small- and micro-enterprises, physical flows are even not sufficiently monitored for internal use. Setting available consistent data for the purpose of mutual and public interest is rarely practised.

5.6. Case 2: Mixed industrial parks in the Netherlands

The questions that arise with respect to mixed industrial parks in Europe are discussed mainly in scores of nationally oriented professional journals and reports. These are engaged with problems such as: requirement of area for expansion, ageing, soil and groundwater contamination, restructuring and redestination, collective security, collective waste processing, and utility sharing.

However, some data are available from the initiatives that have been taken to integrate eco-park principles in existing *typical* mixed industrial parks. This excludes the intended parks that are based on alternative energy sources, or that are specialised in recycling or environmental technology. Most of these data are from surveys. They include observation, interviews, and the results of questionnaires.

An average mixed industrial park in the Netherlands has been investigated into more detail. This park, although grown in a conventional way, had the intention to meet the standards of an eco-industrial park. It is a municipal industrial park of about 100 ha (1 km^2). It has gradually been extended, and even presently new lots are added to the park. Additionally, a new 0.8 km^2 adjacent industrial park is under construction. Besides that, a third industrial park was recently opened in a neighbouring, formerly rural town that has recently been annexed by the municipality. This fragmentation seems the result of ad hoc policy making. The origin of the park is at a railway junction that was formerly intensively used for freight transport. Presently, the benefits of the junction are not longer used, apart from — marginally — the transport of employees. The original industries, situated near the railway, are a food processing plant (slaughterhouse) and a pharmaceutical plant that was originally based on slaughterhouse by-products. A third important industry is in precision mechanics. A novel enterprise of supra-regional importance produces textile goods for application in cars. Apart from some related firms (cold stores, food transport companies), the present activities in the park are not related to the original activities. Most of the resident firms are of local or regional importance. In total, 124 firms have been counted in the year 2000. These employ about 5000 people.

The enterprises can be arranged according to the following classification:

1. *Miscellaneous* (2). A school and a youth club.
2. *Industry* (39). Machine building and metals construction (16), miscellaneous manufacturing (9), printing industries (6), food processing (3), textile industries (2), plastics processing (2), pharmaceutical (1).
3. *Wholesalers* (11). Most of them are involved in building materials, technical and medical goods. Some industries are also combined with wholesale.
4. *Car* repair shops and trade (20).
5. *Retail trade* (1). A kitchen mall.
6. Miscellaneous local and industrial *services* and *craftsmen* (33). These include building constructors such as painters (5), plasterers, roofers, paviors, building contractors, architects, electricians and installers, and gardeners. Industrially oriented services are involved in advertising, copying, consultancy, call centre, security, courier service, leasing. There also exists a sheltered workshop.
7. *Logistics* (11), including transport and storage.
8. *Recycling* (7), including a car recycling company, recycling companies for construction and demolition debris, and the municipal waste collection park.

Typical to this park is the absence of a specific high-tech segment in the ICT and electronics sector. Another particular aspect is the virtual absence of retail trade other than dealers in cars and campers. The point of departure is an industrial park that has gradually grown over more than half a century, and that has evolved without much planning and vision. Most of the area is presently occupied by the recycling companies and the logistics firms. The many car dealers are present everywhere, and do also occupy lots of area.

The eco-industrial park initiative emerged as a by-product of a major sewer renovation plan that has been initiated by the municipality. It started with a permanent organisational structure of the entrepreneurs in the park. A questionnaire to the enterprises in the park was organised, which was based on experiences in earlier projects. It resulted in a return of 50–60%, which is typical to such surveys. Questions were put on topics varying from energy and waste, to security, collective facilities, and the detection of bottlenecks. Here a lack of coherence between the different companies became apparent. Relatively large enterprises or otherwise environmentally relevant companies appeared co-operative, but the major part of the smaller and micro-companies was not interested. Moreover, potential conflicts of interest were imminent between some major recycling companies for demolition debris, the car dealers, and the other companies, due to the occupied area, the presentation, and the nuisance due to these recycling firms. The typical reaction was the ‘not in my backyard’ attitude: removing these firms to other places to the greenfield, instead of decreasing their negative aspects. This should indeed decrease the mutual nuisance, but with questionable ecological effects.

Apart from the organisation of the enterprises, the involvement of the authorities needed attention, because they were apparently pushing the responsibility to each other. The municipality tended to transfer its responsibility to the enterprises, whereas the enterprises complained the shortcomings of the municipality in cleaning, law enforcement, public lighting, etc.

The practical interpretation of sustainability, not to mention the implementation of concrete improvements, appeared a cumbersome and time-consuming process. Nevertheless, the results of the questionnaire revealed many obvious features that were relatively simple to improve: poor traffic security, absence of footpaths and bicycle tracks, a chaotic lay-out and architecture, a lack of regulation, no adequate information system for visitors (street maps, signposts), absence of public green, inadequate land use, massive open air exhibitions of used cars, caravans, etc. and illegal parking. No tendency toward improvement was observed, however: the land use of the most recent extensions appeared still more extensive than it formerly has been.

In contrast with this ineffectiveness, the impossibility for expansion was frequently indicated by the entrepreneurs as a major problem. One advocated the moving of the car dealers to the greenfield, with still

more space for exhibiting occasions, and the moving of the recycling companies to a dedicated park in the greenfield, rather than the restructuring and a more intensive use of the park. A stricter regulation was never advocated, although complaints on inadequate law enforcement were frequent.

Restructuring, although initially experienced as expensive, could result on the long term in a better layout, a more attractive presentation, a reduction of nuisance, and a maximum advantage of each other's vicinity. Besides that, the operation of collective facilities could be enabled, which is attractive for both the environment and the individual enterprises.

Biomass, mainly from packaging and offices (paper, cardboard, and wood) appeared the most essential waste flow in the park, apart from hazardous waste inclusive spilled oil. Here, collective waste processing could play a substantial role, and the recycling companies that are already present in the park, could play a role here, rather than moving them from the park.

5.7. Analysis

We have described extensively the characteristics of industrial complexes and mixed industrial parks, as well as the possibilities for developing a more sustainable approach to each of these types of industrial park. The following table summarises the main differences as they relate to the possibilities for such an approach:

	Industrial complex	Mixed industrial park
Material/ energy networks	Tightly coupled	Loosely coupled
Process integration	- Widely applied - internally focussed - great potential	- relatively new - externally focussed - marginal potential
Organisation/ management	Linkage through decentralisation (outsourcing)	Linkage through clustering and coordination (site management)

From this table it is clear that industrial complexes have advantages in developing a more sustainable approach to the extent that the potential for process integration is larger. Besides that, due to the fact that linkages are essential to the company, these are easier to organize. In addition, linkage through decentralisation follows a trend that is more generally discernible in business, i.e. that of outsourcing.

In contrast, mixed industrial parks face considerable barriers in developing a more sustainable approach. Process integration is relatively new for most of the involved firms, and needs to be externally focused towards firms with which they have no prior relationship other than geographical proximity. From these results the problem of cooperation; trust needs to be built before firms are willing to link their processes in ways that affect them strategically.

From the descriptions and cases, it also becomes clear that sustainable development often is interpreted in a narrow way, i.e. remains restricted to ecological impact of production processes. The economic aspect of sustainability plays a role, but mainly in providing a constraint in the choice of options in reducing ecological impact. The social aspect of sustainability is often absent from the initiatives that are developed. As a matter of fact, the interrelation between these aspects on a strategic level is also missing. This results in the absence of any development of a strategic orientation on the ecological, economic and social development of the industrial complex/park. Potentially, the mixed park maybe has an advantage in this respect. Because of the fact that it consists of a larger number of quite different firms, the potential for new ideas may be bigger. Developing such ideas, however, requires a fruitful network of cooperation, which needs time and collective learning to develop.

6. Conclusions and recommendations

In this paper, a study on the different aspects of the establishment of eco-industrial parks has been elaborated. For a better orientation in this complicated field, a scheme for the classification of these projects has been proposed. Two major types of industrial park have been distinguished: industrial complexes and mixed industrial parks. In industrial complexes, the exchange of materials and energy flows has always been essential, but incentives towards a further extension of this integration to lower-grade residuals often failed in the implementation stage because of mainly economic reasons. The most profitable opportunities were already implemented since long and incentives with marginal profitability or moderately high risk were canceled, although a considerable reduction in CO_2-emission could be obtained by them. Moreover, the dynamics of the involved industries, including closures and moves, frequently interfered with the long lead-time of the projects.

In the literature, the impact of mixed industrial parks, although increasingly important from both an economic and an ecological point of view, has been underestimated to a great extent. This became evident by the nearly exclusive emphasis in the literature on the Kalundborg example as *the* model for eco-industrial parks. Divergence in the interests of the involved enterprises, poor

organisation, and a lack of acquaintance with co-operation have been identified as the principal causes for the slowing down or failing of most of the initiatives. The following opportunities, although often neglected in the literature, have been identified: (1) the presence of specialised enterprises, notably on waste collection, waste processing, and recycling; and (2) the possibility of clustering of comparable small enterprises.

Because mixed industrial parks tend to drastically replace the agricultural occupation of area in densely populated, industrialised or industrialising regions, the accompanying problems that arise should be consciously faced with. This requires the establishment of a policy that meets the interests of all involved parties, also on the medium and long term, inclusive the problems of adaptation to changing circumstances, and ageing. This policy should be based on ample quantitative data that are, however, only poorly available.

Case studies reveal that although the desires of the enterprises and the authorities with respect to sustainability are clear, the implementation of concrete measures proceeds slowly and has only a marginal effect. The diversity of interests of the different stakeholders, and the obviousness in claiming new industrial area because of modest ground prices counteracts the indispensable restructuring of existing parks as well as a stricter regulation in both existing and new parks.

In the discussion on eco-industrial parks, it is advised to pay more attention to mixed industrial parks, and to find and implement solutions that ensure both the continuity and the sustainability of these parks.

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A.J.D. Lambert received his Masters degree in Applied Physics from Technische Universiteit Eindhoven in 1975 and his PhD in Plasma Physics in 1979. Since then he has been involved in modelling of energy systems, and he is currently involved in research on the relation between production systems, energy, and the environment. He is currently and Assistant Professor at the Technische Universiteit Eindhoven. Dr Lambert has published papers in several international journals, including *Physica*, *Computers in Chemical Engineering*, *International Journal on Production Economics*, *International Journal on Production Research*, *Journal of Cleaner Production*, *Technovation*, *Computers and Industrial Engineering*, and *the International Journal of Manufacturing Technology Management*. He has written a book on Energy and Production. He participates in an international programme on Reverse Logistics.

F.A. Boons received his Masters degree in Policy and Organisation

Sciences from Tilburg University in 1990 and his PhD in Organisational Sociology in 1995. His research involves the development of economic and organisational sociological insights through the study of change processes related to sustainable development. His main focus is analysing the way in which the interaction within networks/systems of organisation leads into the mobilization of change efforts, or the strengthening of the status quo within production and consumption systems. Dr Boons is senior researcher at the Erasmus Centre for Sustainable development and environmental Management (ESM, Erasmus University Rotterdam). He has published papers in several international journals, including *Business Strategy and the Environment*, *Journal of Cleaner Production*, and *Environmental Politics*. He edited a special issue of the *International Studies in Management and Organization*, and co-authored a book on institutional change in Dutch industry related to ecological pressure.