Eco-industrial parks: toward industrial symbiosis and utility sharing in practice

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Abstract: The creation of eco-industrial parks has been adopted as an official national policy in the Netherlands. Many local projects have been supported by the national government, both financially and with expert advice. The policy is targeted at both infrastructure projects and at achieving symbiosis and utility sharing. Yet only a limited number of local projects are actually designed to bring about symbiosis and utility sharing. In this paper, we analyse eight cases of eco-industrial parks. The central question is what factors determine the degree of success in achieving symbiosis and/or utility sharing in eco-industrial parks. Business and location-specific features and the way in which the actual decision-making process is organised appear to be crucial factors. This finding implies that there is a need to bridge the tools and instruments of industrial ecology that focus on the physical flows of matter and energy to approaches and tools that concentrate on decision-making, business strategies, organisational characteristics and corporate environmental management.

Keywords: industrial ecology; industrial ecosystems; industrial symbiosis; eco-industrial parks.

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1 Introduction

Designing eco-industrial parks is one of the concrete applications of industrial ecology [1]. As several theorists argue, the development of eco-industrial parks, when successful, can lead to significant improvements in the collective environmental performance of companies [2–6]. However, the empirical foundations of eco-industrial parks are still somewhat weak since there is little quantitative data available (see for example [7–10]). Many debates rest on the illustrative example of the industrial park in Kalundborg, where industrial symbiosis (exchanges of resources and energy flows between the companies located in the park) have been achieved. In this Danish city various industries and even farms exchange material and energy flows that otherwise would remain as waste, thus forming a complex system of links (industrial symbiosis) between at least nine different types of economic activity. Examples include the exchange of scrubber sludge between a power station and a wallboard plant and treated sludge between a pharmaceutical plant and neighbouring farms. Other exchanges include waste heat or steam from a power station.

In more extensive discussions of this example it has been claimed that such eco-industrial parks can generate both economic and environmental gains [11–13]. Material cycles can be developed toward the vision of closed cycles in industrial parks through symbiosis. The collective environmental performance of an industrial park can further be enhanced with various utility sharing options, such as joint exploitation of waste water treatment plants, combined heat and power or a collectively owned windmill. The exchange of material flows between firms is not entirely new; especially in the chemical industry economic complexes have already existed for a long time. The difference is that these complexes exist within relatively homogeneous classes of industry linked through their flows of products and by-products, whereas in examples of eco-industrial parks, such as Kalundborg, new and *unexpected* combinations involving heterogeneous classes of industry occur.

The case history of Kalundborg is interesting in that it developed spontaneously [11]. It has triggered efforts all around the world to achieve similar results through a planned process of policy making, often organised by local authorities responsible for urban planning (development of greenfield sites and revitalisation of brownfield sites). The Netherlands is no exception. There consultancy firms play a major role in developing eco-industrial parks, acting as intermediaries in applying national policies in practice. In another study [14] we concluded that the various planning methods developed by these consultancy firms proved to have serious shortcomings: the definition of sustainability is unclear; there are no quantitative standards; information on symbiosis and utility sharing is inadequate; the economic and organisational implications are largely ignored and the environmental impact is insufficiently monitored. It is therefore likely that opportunities are being missed due to insufficient focus on potential environmental benefits through symbiosis and utility sharing. Consequently, the envisaged environmental performance in the planning methods is lower than might be expected on the basis of the theoretical claims derived from the literature on industrial ecology and the Dutch governmental programmes.

Yet one of the explicit aims of Dutch environmental policy since 1997 has been to support the establishment of eco-industrial parks. In this study we focused on the practice of establishing of symbiosis and utility sharing.

2 Dutch policies promoting eco-industrial parks

In 1997 the Dutch government published a policy document on Environment and Economy, which stated that economic growth, greater competitiveness and increased employment could be combined with a reduction of the environmental burden, reduction of the input of fossil fuels and non-renewable raw materials and better management of space, nature and biodiversity. The new policy called for the intensification of cooperation between government and business on a number of issues, so-called 'spearheads' of the policy. One of those 'spearheads' was the promotion of 'eco-industrial parks' or "areas where companies will work together and with government with the goal of contributing to sustainable production and/or more efficient use of space" [15].

The first step was the establishment of a taskforce, which produced a supplementary report entitled 'The Helping Hand' [16]. The report provides insight into the process that leads to the development of eco-industrial parks. It also presents a lengthy list of options for making industrial parks more sustainable, which is intended to serve as a source of inspiration for the development of a vision of sustainability [14].

In Dutch policy the development of eco-industrial parks is stimulated from two perspectives: sustainable business processes and the sustainable design of business parks. The perspective of 'sustainable business processes' is concerned with the physical flows (electricity, heat, water, raw materials and residual substances, persons, goods and waste) resulting from business activities in industrial parks. From this perspective cooperation between companies is intended for creating new possibilities for maximising the efficiency of the use of existing energy and material flows. The 'sustainable design' perspective focuses on the area (consisting of business premises, infrastructure and the various facilities) within which the business processes take place. By cooperating in the design, development and management of industrial parks the stakeholders try to develop business parks with a greater added value in the short term and the longer term.

To assist in this effort and to stimulate new forms of cooperation the Ministry of Economic Affairs made funds available for the eco-industrial parks programme. This programme has been implemented by Novem, a governmental implementation agency for environmental policies in the Netherlands. The subsidy scheme for eco-industrial parks is targeted at projects that are carried out in the period prior to the actual investment. The scheme covers two types of projects [17]:

- the projects to draw up a master plan for the development
- the technical or organisational feasibility projects designed to flesh out promising sustainable solutions into concrete project and contract proposals.

The subsidy scheme makes a distinction between greenfield sites, brownfield sites and the expansion of existing sites. With respect to the options for subsidies a strict link is made between the type of project and the type of site. For new sites a subsidy is only provided for technical feasibility projects. In existing industrial parks development projects, technical and organisational feasibility projects are also eligible for subsidies. The environmental themes are use of space, waste, energy, goods transport, passenger transport, water, raw materials and ancillary products, and park management. Of these, use of space, waste and energy are regarded as priority themes, which means that projects relating to these themes are particularly welcome.

The final closing date for the subsidy scheme for projects to make industrial parks more sustainable was October 1, 2003. In the period 1999 to 2003 subsidies were requested for more than 300 projects. More than 200 projects were granted subsidies totalling around €8 million. In the meantime 85 projects have been completed and another 130 are still underway. The projects relate to at least 25% of the total surface area of industrial parks in the Netherlands [17].

Consultancy firms generally play a central role in these projects as project manager. Some firms have also developed their own planning methods for these projects. In earlier research the University of Utrecht assessed the level of ambition of six of these planning methods [14]. The study found that although the quality of the industrial parks that are being developed is higher, the improvement in environmental performance will probably be modest. Generally speaking, the main emphasis in the planning methods is on spatial measures. There is little further elaboration of the concept of sustainability, and it is certainly not a priority. Too little consideration is given to opportunities for symbiosis or utility sharing. The result is that the envisaged environmental gains are smaller than might be expected on the basis of the theoretical claims in the scientific literature.

In this paper we therefore pose the following central question: "What determines the degree of success in achieving symbiosis and/or utility sharing in eco-industrial parks?" To answer this central question we combine theoretical and practical research. The theoretical aspect involved a literature study, and for the practical element we carried out eight case studies of situations where an effort was made to achieve symbiosis and utility sharing. These eight cases were selected as the most far-reaching among the 85 projects that have been completed.

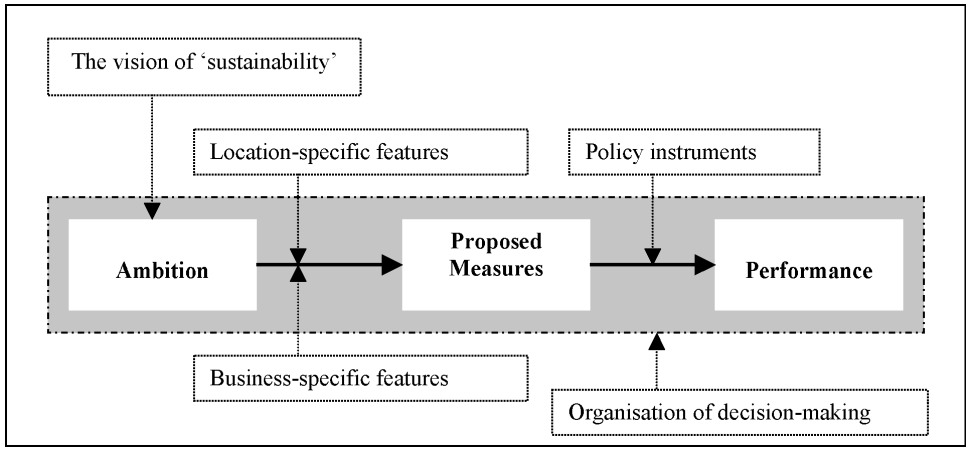
On the basis of the literature study we developed a framework of analysis which explains the possible explanations for success in achieving symbiosis and/or utility sharing in eco-industrial parks. Section 3 of this paper discusses the framework of analysis and the research methods employed. Section 4 describes the most important features of each of the individual cases. The cases are then assessed on the basis of the framework of analysis in Section 5. Finally, Section 6 presents the most important lessons learned from the study.

3 Research method and case selection

For an analysis of the eight Dutch cases we needed a framework. Analysing the establishment of eco-industrial parks in practice requires an integrative environmental sciences approach, at least including the disciplinary perspectives of natural sciences

(claims derived from industrial ecology), business administration (analysing the environmental performance of businesses within their economic and social networks) and policy studies (analysing successes and failures in policy implementation) (see [18–20]). The focus of our framework of analysis was on the process 'from ambition to performance'. The point of departure in the study was that the following factors influence the process from ambition to performance: the vision of sustainability, the location- and business-specific features of industrial parks and the companies in the industrial parks, the policy instruments employed and the organisation of the decision-making process (see Figure 1).

Figure 1 Framework of analysis



'Ambition' relates to the initial ideas about the type of industrial park to be developed and the goals that the developers are seeking to achieve. How the concept of 'sustainability' is put into practice serves as a frame of reference to show the significance of perceived options. Not all measures designed to increase sustainability are feasible in all industrial parks. The location-specific features of the industrial park and the business-specific features of the companies in the industrial park affect the types of measures that can be chosen and therefore have an impact on the performance of industrial parks. Policy instruments may be employed to ensure the proposed measures are carried out. The organisation of the decision-making process influences the entire process of translation from ambition to performance via the proposed measures.

3.1 The vision of sustainability

The vision of sustainability that is adopted influences the level of ambition that is sought, as well as the measures chosen to try and move toward sustainability and the environmental gains one hopes to achieve [21]. It must be clear what is expected of an eco-industrial park and which explicit criteria have to be met in order to assess sustainability. A discernible amount of environmental improvement must be achieved if we are to justifiably call any industrial park 'sustainable'. When we impose the rigorous standards of industrial ecology, we can only call an eco-industrial park sustainable when

sustainable symbioses in relation to the environment are evident. Industrial ecology propagates an economy that develops towards a vision of a cyclical system of energy (cascades) and materials (cycling) in which the only energy input is the sun and all materials are continuously being recycled [12,22].

By reasoning that the closing of material cycles is the highest conceivable environmental goal, we go along with the industrial ecologists to some extent. In our paper on Dutch planning methods for eco-industrial parks we showed that these methods often pay little attention to the operationalisation, definition and fulfillment of the sustainability goals. The definition of an eco-industrial park is often kept as open-ended and as broad as possible. As a consequence the options for 'symbiosis' and 'utility sharing' are not sufficiently considered [14]. In this study we wanted to study the impact of this bias. In our case studies we will make a distinction between distinct levels of ambition:

- 'low': the measures are targeted at individual companies
- 'average': the measures relate to achieving utility sharing
- 'high': the measures relate to both realising symbiosis and achieving utility sharing.

3.2 Location and business-specific features

The existence of particular location and business-specific features is decisive for whether or not symbiosis and/or utility sharing will be achieved. Location-specific features relate to characteristics of the industrial park where symbiosis and/or utility sharing take place. Business-specific features relate to the characteristics of the company seeking to achieve symbiosis and/or utility sharing in an industrial park. With respect to the location and business-specific features the study makes a distinction between physical features that foster symbiosis and/or utility sharing and so-called social features.

To achieve symbiosis and/or utility sharing it is important that there are two or more companies established in the industrial park with *complementary needs* for energy, water and/or (residual) substance flows [23]. To achieve symbiosis it is important that the composition of companies in the industrial park is sufficiently diverse [23]. However, this required diversity may also create obstacles for success in two ways. First, increasing diversity of companies involved may at the same time lead to increasing divergence of interests, strategies and preferences [24]. Second, connecting two very different types of companies (from different sectors) also implies new business risks that may lead to 'unhealthy dependencies' [25]. Further, one must acknowledge that residual substance flows may also be used outside the region, in fact regional and supra-regional solutions may very well be competing, both in terms of economy and ecology.

Diversity in the local industrial structure is not important for utility sharing as companies have similar supply and demand patterns for energy, water and (residual) substances. Related to this location-specific feature is the fact that a business-specific feature of the companies must have stable (residual) substance, water and/or energy flows [26]. Supply and demand of the companies must be aligned on one or more of the following points:

- the quantity of demand must be the same as the quantity of supply (quantitative)
- the quality of the supply must correspond with the quality of the demand (qualitative)
- mutual exchange of energy, water and (residual) substances between companies calls for simultaneity [1]
- the physical distance between the companies must be small [23].

Besides these physical location and business-specific features, there are also a number of distinct social features:

- The companies must *trust each other* [26].
- There must be an *anchor company* in the industrial park. An anchor company is a large industrial company that will attract other companies. Such a company could represent a core around which complementary partners can be sought [27]. Martin et al. suggest that creation of an eco-industrial park will be easier if there is a company that can take the function of a 'central node' [26]. Korhonen has illustrated that local power plants applying the method of co-production of heat and power (CHP) may be able to serve as anchor tenants, because, when equipped with advanced combustion techniques, they can simultaneously use wastes from households, agriculture, food industry, forest, pulp and paper industry and also produce energy for all of these sectors i.e. electricity, industrial process team and district heat [28].
- There must be a *pioneer* in the industrial park. A pioneer displays vision and is convinced that the principles of industrial ecology are correct. This pioneer is prepared to take the initiative, enjoys the confidence of partner companies and has a financial interest in the development of an eco-industrial park [27,29].
- The *mental distance between the parties concerned must be short* [23]. The basis of the cooperation in the industrial park in Kalundborg lies in openness, communication and mutual trust between the partners [26]. This requires an active business networking strategy [30].
- There must be a *core group of companies with a distinct environmental profile* in the industrial park [27]. A properly functioning environmental protection system is often regarded as an important factor for establishing the cooperation needed in eco-industrial parks [21].
- The companies in the industrial park must have a *high degree of organisation.* In the Netherlands companies are usually organised in industrial federations or business associations. A well-organised industrial federation or business association is able to represent the joint interests of the users of the industrial park and provide ideas for cooperation [21].

- The companies are *tied to the vicinity.* The degree to which a company has a bond with its location plays a role in achieving symbiosis or utility sharing. When a company achieves symbiosis or utility sharing by doing so it binds itself to the location where it is established. This reduces the company's flexibility, which can have a negative effect on its competitive position. Achieving symbiosis and/or utility sharing, however, can also produce benefits of agglomeration. Companies that are integrated in a regional production network enjoy the benefits of agglomeration that exist within the network [14].

3.3 The organisation of the decision-making process

The way in which the decision-making process is organised, information is collected and actors are involved in the process influences the process of "translation from ambition to performance" in the industrial park. The study explored a number of important success and failure factors with respect to the organisation of the decision-making process which might explain the difference between the level of ambition and actual performance of eco-industrial parks. Success and failure factors are closely related; the absence of a particular success factor can be a failure factor.

To secure and maintain support for the process it is important that it is elaborated jointly (public and private) and that measures to achieve sustainability are identified jointly [31,32]. It is also possible that the process is defined top-down or bottom-up. Where it is steered top-down by the government there is no consultation between the companies. The options are chosen by the government and then included in policy instruments. In a bottom-up process the companies themselves take the initiative and investigate what improvements they can carry out themselves [14]. In addition, civil organisations should also be involved in the decision-making process at an early stage in order to avoid possible problems and debates [26]. Involvement of these civil organisations can be beneficial to the level of sustainability of the project [28,33].

The development of an eco-industrial park calls for substantial investment. It requires, for example, infrastructure for material and energy flows and the construction of shared facilities. Problems relating to the costs and the investment risks can endanger the continuity of the process. Besides the project costs, the division of the process costs must also be considered [16].

3.4 Policy instruments

The possibility of steering the process towards symbiosis and utility sharing depends on who owns the land for the industrial park. In the Netherlands the owner is often the government (local authorities), but it may also be a property developer or a company. Both national and local government can promote establishment of eco-industrial parks [34–36]. Their policy instruments may differ in terms of enforceability.

The most compelling policy instrument considered in the study was legislation. An example of legislation for eco-industrial parks could be the adoption of the concept of the umbrella licence, which implies licensing a group of firms instead of single firms. The point of departure of the umbrella licence is that a ceiling is established for the various forms of environmental burden (such as noise, air pollution) within the area

covered by the licence and that the cumulative environmental burden may not rise, and must in time decline. However, within the area licensed companies can exchange or substitute dissimilar forms of environmental burden. Companies may agree on compensation, but this is their own responsibility (which makes it different from emission trading, where the market is established by government). This may give companies more flexibility, but it can also make the process more complex. It is important to remember that the legal procedures will have to be followed particularly closely. The continuity of the decision-making process on the development of the eco-industrial park may be at risk if problems arise during the legal procedures.

Another local policy instrument would be to impose requirements on companies locating in the industrial park and setting out the agreements reached in private law contracts. The owner of the land could use this policy instrument and hence reject companies whose business activities do not fit in with the eco-industrial park. Financial incentives can also be used as a policy instrument. Besides financial incentives in the form of providing funds (such as the project subsidies referred to earlier), the owner of the land being used for the industrial park can use the price of land as a policy instrument [37].

Park management is a policy instrument which is used for the active management of the industrial park and to maintain its quality at the desired level in the long term. The stakeholders in the industrial park can make agreements about its design and/or management [38]. These agreements can cover aspects such as the clustering of companies, the provision of infrastructure facilities, the management and maintenance of roads and aspects of facility management.

The fourth policy instrument involves facilitation through the input and exchange of knowledge and experience. There is a widespread need for the exchange of knowledge, practical examples, information about schemes etc. There is a great deal of knowledge available, but it is very fragmented. There is an important task here for the government to ensure that "the wheel does not have to be reinvented every time", but also to provide its own information about incentives and laws and regulations [16]. The final policy instrument is promotion and acquisition. In many cases it is very important for sustainable development of new or existing industrial parks that companies that fit in with the concept of the site also locate there.

3.5 Performance

The level of success itself is measured indirectly. It has not been our objective to make detailed assessments of the economic and ecological effects of proposed and implemented measures. For this study, assessing performance by using information provided by companies and authorities involved is sufficient to answer the key question whether proposed measures have actually been carried out. With respect to the level of performance, two levels will be identified and applied in Table 1:

- '–': none of the proposed measures were carried out
- '+': all or most of the proposed measures were carried out.

This framework of analysis provides us with a number of potential explanations for the success in achieving symbiosis and/or utility sharing.

3.6 Case selection

To select potential cases we used summaries of the projects that received subsidies in 1999 and 2000, published by the funding agency Novem. As we discussed in Section 2, about 200 projects received a subsidy, about 85 of them being completed in early 2003. Most of the projects from 1999 or 2000 were feasibility studies, in most cases addressing other issues than symbiosis and/or utility sharing. This analysis resulted in a list of 20 potential cases of symbiosis and/or utility sharing projects which were 'mature' enough to allow an analysis which would include conclusions about actual performance. This list of potential cases was then submitted to an expert at the funding agency Novem. We decided to draw up the final selection in association with Novem, because this organisation has considerable knowledge of current practices relating to eco-industrial parks. In this way we selected eight cases which were potentially at the most advanced stage in terms of symbiosis and/or utility sharing. These eight projects encompass both new and existing industrial parks. From the original selection ten cases were not selected because we intended to select only eight cases and two projects were not included as there have already been frequent studies devoted to these projects (the INES Mainport and Rietvelden/De Vutter (see [39,40]).

The data (input) needed to produce the descriptions of the cases came from a literature search and from interviews with the main stakeholders in the collaborative process. Data collection took place in mid 2003.

4 Results of the case studies

In this section we will first briefly describe the eight cases. The eight examples are located throughout the Netherlands, as shown in Figure 2. The study examined the following cases:

- Ecofactorij Eco-Industrial Park in Apeldoorn
- Agro Industrial Complex in Dinteloord
- Business Park South Groningen in Ter Apelkanaal
- The Kleefse Waard Eco-Industrial Park in Arnhem
- The Trompet Eco-Industrial Park in Heemskerk
- Emmtec Industry & Business Park in Emmen
- Wavin Eco-Industrial Park in Hardenberg
- VAM MERA Eco-Industrial Park in Wijster.

Figure 2 Eco-industrial parks with focus on symbiosis and utility sharing

4.1 Ecofacorij eco-industrial park in Apeldoorn

The Ecofactorij in Apeldoorn is a new industrial park. The Ecofactorij can be described as a mixed industrial park for companies classified up to environmental impact category 4 (for explanation of the impact categories, see [41]). Around eight or nine companies can be established on the site [42]. The level of ambition for the Ecofactorij industrial park is very high. For energy, the target is that the site will run entirely on non-fossil fuels. Other targets are that at least 75% of the water must be produced in a sustainable manner and waste flows must be minimised.

The ambitions for the Ecofactorij go further than what can be enforced with Dutch environmental regulation. The local authority therefore established an environmental points system. There is a basic package of minimum conditions for companies locating in the industrial park. Points are only awarded for measures in what are known as the 'plus package'. The score determines the size of the bonus a company can receive, which may entitle the company to a reduction of the land price, a subsidy and/or priority in locating in the industrial park. The subsidy or discount on the land price is only granted once it has been established that the condition has been met. The ambitions of the individual companies are set out in 'long-lease conditions', which means they have a private law status [43].

In May 2003 there was still a wide gap between ambition and performance at the Ecofactorij industrial park. There were only two companies actually established there. The difference between ambition and performance can be explained by the fact that the process was prepared by officials without involving stakeholders (companies, civil organisations). This top-down process had a negative effect on support for the decisions of the local authority in Apeldoorn. Both the Chamber of Commerce and local NGOs have commenced legal proceedings against the local authority. These legal obstacles could probably have been avoided if these parties had been involved in the decision-making process.

4.2 Agro Industrial Complex Dinteloord

The Agro Industrial Complex Dinteloord (AICD) was one of the first attempts to create an agro- industrial complex in the Netherlands. The process is still ongoing. After a standstill of around two years due to administrative problems (see below), it now seems that the industrial site of De Suiker Unie (Cosun) will go ahead. The total site covers 220 hectares, of which 50 hectares are built on. Around 80 hectares are water and an area of the same size is zoned for agriculture.

De Suiker Unie is the initiator of the project and also owner of the site. In an attempt to strengthen the competitive position of the company and of the region De Suiker Unie started investigating whether better use could be made of the plant, not only in terms of raw materials or energy, but also space, water, by-products, residual substances, production machines, knowledge and manpower. The company started the project with the aim of producing in a cheaper way and in a more eco-friendly way, while at the same time developing new and sustainable products and processes [44]. It researched various Product-Market-Technology combinations (PMTs) that might lead to more effective use of De Suiker Unie's plant.

The project started in 1996. In 1998 it was expected that the first companies would be established at the AICD in 2000, but in 2003 there are still no companies there. The difference between performance and ambition can be explained by the fact that the administrative context at the start of the process was difficult. De Suiker Unie had great difficulty in convincing the province and the municipal authority to allow suitable companies to locate at De Suiker Unie's site. From a planning perspective the current location of De Suiker Unie is not adequate. In addition, circumstances have changed in one of the local authorities, which has seriously complicated the decision-making process. The changing context was the consequence of the redrawing of municipal boundaries and has led to the loss of political and administrative support for the AICD in one of the local authorities.

4.3 Business Park South Groningen in Ter Apelkanaal

Business Park South Groningen (BZG) in Ter Apelkanaal currently encompasses 19 hectares (net 15 hectares) and a site of 30 hectares is being developed. The industrial park is suitable for companies in environmental impact categories between 1 and 4. An exception may be granted for companies in environmental (nuisance) category 5 [41].

In Business Park South Groningen an 'eco cluster' of four companies has been formed around the fat rendering company Ten Kate, which exchange (residual) substances and energy among each other. Besides Ten Kate, the partners are the US company Applied Food Biotechnology (AFB), the German company DGF Stroess VlaPro (DGF) and the Dutch company Avebe. Applied Food Biotechnology (AFB) produces flavouring agents for pet food, DGF Stroess VlaPro (DGF) is a producer of gelatine and Avebe is a starch factory. Ten Kate supplies proteins to AFB and to DGF Vla Pro, DGF Vla Pro supplies fats to Ten Kate. In association with the energy company Essent, Avebe supplies steam and electricity to the three other companies by means of a combined heat and power plant [45].

The exchanges that take place between Ten Kate and Vla Pro and AFB generate annual cost savings of around two million euros for the companies. The environmental gain from the measures is a reduction of approximately 5,000 transport movements and energy savings of roughly 6 million kilowatt hours. In addition, the exchanges save an unspecified amount of water. The generation of wastes has been dramatically reduced. What waste there is comes from cleaning activities [45].

The interesting feature of this case is the fact that existing chain partners coincidentally established themselves in the same industrial park. The process has been driven by the companies themselves (bottom-up process).

4.4 The Kleefse Waard eco-industrial park in Arnhem

The Kleefse Waard has a total area of around 45 hectares and accommodates approximately 25 industrial companies, ranging from sole traders to companies with roughly 200 employees. Companies classified up to and included in the environmental impact category (for explanation, see [41]) six can locate on the site.

The reason for the initiative to cooperate was the decision by Acordis (formerly Akzo Nobel) to close its factory for industrial rayon for tyres. The closure of this plant created overcapacity in the existing facilities in The Kleefse Waard and left many vacant buildings. Acordis actively searched for companies that could use the vacant premises and the overcapacity and set up a separate private company for this purpose, Industry Park Kleefse Waard b.v (IPKW). This company is the owner of the land, the buildings and the utilities. In addition, the company also manages the utilities.

With respect to the companies it wanted to locate at the site. IPKW b.v. had a strong preference for companies that wanted to use the available facilities, such as the combined heat and power plant and the waste water treatment plant and were also prepared to buy a standard package of services, which includes, for example, security and fire fighting services.

It is impossible to make any judgment on the environmental gains achieved by the proposed measures as there are no data available. Since 1998 a total of five new companies have located at The Kleefse Waard and are connected to the existing facilities. The companies trust each other. This can be explained by the fact that some of the companies formerly belonged to the same enterprise and the site has had a long history. Because cooperation had proved successful in the past the newcomers trusted the other companies and had confidence in the services being provided.

4.5 The Trompet eco-industrial park in Heemskerk

Industrial park The Trompet will be a newly developed greenfield site just outside the city Heemskerk. The gross area of the site is 18 hectares. The site is described as a 'mixed industrial park'. In 1992 the local authority of Heemskerk adopted the 'Land Use Plan Heemskerk 2015' in which it decided to try and develop the industrial park in a sustainable fashion [46].

In The Trompet the proposed measures will yield more than 50% reduction of CO_2 emissions compared with a conventional industrial park. The environmental benefit in terms of water, raw materials and waste cannot be expressed as a reduction in relation to conventional industrial parks [46].

The development of The Trompet has been a long process. The project started in 1992 and the first companies registered in July 2001. This long period can be explained by the lack of expertise of the organisation concerned with respect to the concept of sustainability and the efforts that are needed to move toward the implementation of the concept in practice.

4.6 Emmtec Industry and Business Park in Emmen

Emmtec Industry & Business Park is an industrial park situated in the municipality of Emmen. Emmen's zoning plan for Bargermeer, of which Emmtec Industry & Business Park is part, is designated for companies classified in an environmental (nuisance) category [41] up to and including 6. In addition, there are companies on the site which provide support services for the production companies. The site area of the site is 130 hectares and there are 18 companies located there. The most important sectors represented are large-scale production companies, service companies, maintenance companies, commercial services and utilities [47].

Emmtec Services sells 'sustainability' as a product to the companies. All the knowledge it has accumulated is regarded as a competitive advantage. Consequently, it is very reluctant to provide information, and because of this it is not possible, at this moment, to make a comprehensive survey of the exchanges of energy, water and (residual) substances taking place between the companies. Residual heat is used, cooling and process water is recycled, residual substances are used as raw material and packaging materials are taken back by the suppliers [47]. Due to reluctance to provide information little can be reported about the environmental gains achieved in the industrial park. The companies at Emmtec Industry & Business Park have complementary demands for energy and water. This demand is coordinated in terms of quality, quantity, simultaneity and physical distance. The companies trust each other, which can be explained by the history of the industrial park: the companies were formerly part of the same organisation.

The industrial park possesses important social location- and business-specific features. Acordis, formerly part of Azko Nobel, has played a major role as pioneer and anchor company in the process of creating the site. As a result of a shared past, the mental distance between the companies is short.

4.7 Wavin site eco-industrial park in Hardenberg

Wavin N.V. is a company that split up into several parts some years ago. There were a number of parties involved in that process. The former owners of Wavin were Shell and the water company Waterleiding Maatschappij Oost. The current owner is the venture capitalist CVC.

Wavin is an internationally operating company whose core business is the production of plastic pipeline systems. In the Netherlands, Wavin employs around 550 people at the Wavin KLS plant in Hardenberg. This is also the head office in the Netherlands. The industrial park covers 42 hectares and the site accommodates six different plastic processing companies.

There has been a number of striking successes at the Wavin site: There is collective cold storage, collective energy and waste contracts have been signed and the industrial park as a whole has an umbrella licence under the Environmental Management Act and the Pollution of Surface Water Act. At Wavin in Hardenberg cold storage for process cooling has been used successfully since 1996. Ground water is no longer extracted so that the financial costs are declining and the use of this resource is reduced. The benefits for the companies include cost savings through lower charges for ground water use. The existing infrastructure remains intact, the companies avoid the need for investment in cooling machines and their image has improved. The benefits for the environment are reduction in ground water use, hence preventing dehydration, no discharges of used ground water into the surface water, ground water is saved for high-value purposes, the use of renewable energy and, lastly, the technology is quiet. By using cold storage for process cooling between 200,000 and 250,000 kWh of electricity, 138 tonnes of CO_2 emissions and 3 million m^3 of water are saved each year, there is less pollution of surface water, less pollution (with iron) and the dehydration is zero [48].

A site manager has been appointed to act as the main contact person for government agencies and the companies at the Wavin site. Because of the close cooperation with the government the site has been granted the first outline umbrella licence awarded in the Netherlands. The contracts, site agreements, an extensive range of services provided by facility management companies on the site and regular meetings of the users are important for ensuring optimal coordination and cooperation among the companies [48].

The successful collaboration between the companies at the Wavin site can be explained by the companies' shared history. All the companies were formerly part of Wavin. When Wavin disposed of a number of business units each went its own way under new owners but the cooperation has continued.

4.8 VAM MERA eco-industrial park in Wijster

The industrial park VAM MERA in Wijster in the heart of the north of the Netherlands, has a container terminal for importing and exporting raw materials and waste by rail. Alongside the site is Essent Milieu, which used to be the state-owned waste disposal company VAM. The site was initially developed for a large-scale composting plant for urban household waste from the west of the Netherlands. There is another 65 hectares available. VAM and the municipality of Middenveld want to use this space for other companies operating in the areas of the environment, energy production, recycling

and waste processing in order to create an eco-industrial park specifically for this sector. They are thinking about companies, the activities of which complement those of the VAM or companies that would be interested in the products or product flows of the VAM. However, also companies in the transport and maintenance sector or research institutes whose primary area of interest is waste-related issues could be considered [49].

To generate ideas for the exchange and use of the streams in the future industrial park, an Industrial Ecological Profile (IEP) of VAM was drawn up. This profile systematically identified the water, energy and residual substances and their balances for the various parts of VAM as well as the activities in the various parts. The relationships between the various parts were also surveyed [48]. When the plans were presented it was observed that there were a lot of companies interested in locating at the VAM MERA site. The provincial authorities carried out an assessment and the reactions to the consultation procedure confirmed that there was a lot of interest among the various companies. With hindsight, it has been asked whether the estimates were too optimistic. The site is now ready for occupation but there are no users. This is partly blamed on the current economic climate in the Netherlands. It has been suggested that, perhaps, the purpose of the site should be changed. Further, the requirement will propably be used no longer.

5 Comparison of cases

The cases descriptions already refer to levels of success and to possible explanations for success in realising symbiosis and/or utility sharing. This section systematically discusses the potential explanations using the framework of analysis presented in section two. First, however, we look at the differences in the level of ambition in the eight cases and the differences between on the level of ambition and level of performance. Table 1 shows these differences. The cases differ in terms of the level of ambition adopted and in the level of performance (see also Section 3).

Table 1 Difference between the level of ambition and performance in the cases

Ambition / *Performance*	*Individual* (*low*)	*Utility sharing* (*average*)	*Symbiosis and utility sharing* (*high*)
'–'			(1) Ecofactorij Agro Industrial Complex Dinteloord VAM MERA
'+'	(2) The Trompet	(3) The Kleefse Waard Wavin	(4) Business Park South Groningen Emmtec Industry & Business Park

On the basis of Table 1 the cases are arranged in four groups. In group 1. are Ecofactorij, Agro Industrial Complex Dinteloord and VAM MERA. These projects have a very high level of ambition with respect to achieving symbiosis and utility sharing but where in practice none of the proposed measures were carried out. The Trompet falls into group 2; the level of ambition for The Trompet was lower than in the other projects. The majority of the proposed measures were targeted at individual companies. These measures were carried out. A number of sustainability targets were not realised on the basis of realistic arguments. Group 3 includes the cases of The Kleefse Waard and Wavin. The important feature of the projects in this group is the fact that the measures were aimed at achieving utility sharing and they were in fact carried out. Group 4 includes the cases of Business Park South Groningen and Emmtec Industry & Business Park. These two projects have a high level of ambition and of performance with respect to achieving symbiosis and utility sharing.

The question is whether the difference between the level of ambition and the level of performance can be explained by the vision of sustainability, the existing location- and business-specific features, the organisation of the decision-making process and/or the policy instruments adopted. In Tables 2–5 the cases studied are given a score. A score of '0' indicates that the location and/or business-specific features did not exist at the industrial park, the success factor did not exist with respect to the organisation of the decision-making process or the policy instrument was not used. A score of '1' indicates that the location- and/or business-specific features did exist in the industrial parks, that the success factor with respect to the organisation of the decision-making process did exist or that the policy instrument was used. An 'n' shows that the project involves a newly developed industrial park and an 'e' indicates that it involves an existing business park. The numbers 1–4 indicate which group the case falls into (see Table 1 above).

5.1 Vision of sustainability

Interestingly, it is characteristic of the sites where there was no vision of 'sustainability' that the level of ambition was from average to high. From this it can be concluded that it is not by definition necessary to formulate a vision of sustainability. Even without adopting a particular vision or definition of sustainability, symbiosis and/or utility sharing can be achieved.

5.2 Physical location specific and business specific features

Table 2 shows which physical location- and business-specific features existed in the case studies. Our analysis (Table 2) shows that the possibility of achieving symbiosis and/or utility sharing is determined to a significant extent by the existing location- and business-specific features. These features can be physical and social in nature. The most important physical feature for achieving symbiosis and/or utility sharing is complementarity in the needs of the companies in the industrial park for energy, water and/or residual substance flows. If these needs are not complementary there will be no symbiosis and/or utility sharing in practice. In the case of The Kleefse Waard the needs of the companies for residual energy, residual water and residual substances were not complementary. This contrasts with the example of Emmtec Industry & Business Park,

and explains why there is no symbiosis at the The Kleefse Waard industry park but at Emmtec Industry & Business Park there is.

Table 2 Presence of physical location specific and company specific features in the cases studies

Degree of success (*see Table 1*) →	*1*	*1*	*1*	*2*	*3*	*3*	*4*	*4*
Physical location- and business-specific features	*Ecofactorij Apeldoorn (n)*	*AICD Dinteloord (n)*	*VAM Mera (n)*	*The Trompet, Heemskerk (n)*	*Kleefse Waard, Arnhem (e)*	*Wavin, Hardenberg (e)*	*Business Park South Groningen (e)*	*Emmtec Industry & Business park (e)*
Complementary needs for residual energy (symbiosis)	0	0	0	0	0	0	1	1
Complementary needs for residual water (symbiosis)	0	0	0	0	0	0	1	1
Complementary needs for residual substances (symbiosis)	0	0	0	0	0	0	1	1
Complementary needs for energy (utility sharing)	0	0	0	1	1	1	1	1
Complementary needs for water (utility sharing)	0	0	0	0	1	1	1	1
Total score	0	0	0	1	2	2	5	5

5.3 Social location specific and business specific features

Besides the physical features, however, the social cohesion between the partner companies plays at least as great a role in achieving symbiosis and/or utility sharing. As Table 3 shows, the following social location- and business-specific features are very relevant: mutual trust between the partner companies, the presence of an anchor company, the presence of a pioneer and, lastly, a short mental distance between the partner companies. These features also appear to be essential: if the social cohesion is missing, there is no symbiosis and/or utility sharing in practice.

Table 3 Presence of social location specific and business specific features in the cases studied

Degree of success (*see Table 1*) →	*1*	*1*	*1*	*2*	*3*	*3*	*4*	*4*
Social location- and business-specific features	*Ecofactorij Apeldoorn (n)*	*AICD Dinteloord (n)*	*VAM Mera (n)*	*The Trompet, Heemskerk (n)*	*Kleefse Waard, Arnhem (e)*	*Wavin, Hardenberg (e)*	*Business Park South Groningen (e)*	*Emmtec Industry & Business park (e)*
Mutual trust	0	1	0	0	1	1	1	1
Anchor company	0	1	1	0	1	1	1	1
Pioneer	0	1	1	1	1	1	1	1
Small mental distance	0	1	0	0	1	1	1	1
Environmental profile	1	1	0	0	1	1	0	1
Degree of organisation	0	1	0	0	1	1	0	1
Link to place of establishment	0	1	1	0	1	1	0	1
Total score	1	7	3	1	7	7	4	7

The conclusion is that both the physical features and the social features play an important role in achieving symbiosis and/or utility sharing. In practice, there will be no symbiosis and/or utility sharing if the social features are present and the physical features are missing. Correspondingly, the case studies show that there is no symbiosis and/or utility sharing if the physical features are present but the social features are missing. An important finding is that in the cases studied the co-existence of both physical and social requirements occurred primarily in those industrial parks where the companies shared a common past (Wavin, Emmtec Industry and Business Park and Kleefse Waard) or industrial parks where the companies were already partners in a chain (Business Park South Groningen). The two most successful examples are Business Park South Groningen and Emmtec Industry & Business Park.

5.4 Organisation of the decision-making process

The analysis also looked at the organisation of the decision-making process (Table 4). This is also an important factor with respect to the ambitions and performance of eco-industrial parks. There are various success and failure factors that can play a role in the process. As noted earlier, success and failure factors are very closely related: the absence of a success factor may be a failure factor. Naturally, the opposite also applies, the absence of a failure factor may be a success factor.

Table 4 Presence of success and failure factors with respect to the organisation of the decision-making process in the cases studied

Degree of success (*see Table 1*) →	*1*	*1*	*1*	*2*	*3*	*3*	*4*	*4*
Success and failure factors in the organisation of the decision-making process	*Ecofactorij Apeldoom (n)*	*AICD Dinteloord (n)*	*VAM Mera (n)*	*The Trompet, Heemskerk (n)*	*Kleefse Waard, Arnhem (e)*	*Wavin, Hardenberg (e)*	*Business Park South Groningen (e)*	*Emmtec Industry & Business park (e)*
Joint defining of process	0↓	1↔	1↔	0↓	0↑	0↑	0↑	0↑
Connections with community	0	1	0	1	0	0	0	0
Communication of proposed initiatives/results	0	1	1	1	1	1	1	1
No financial obstacles	0	1	1	1	1	1	1	1
No legal obstacles	0	1	1	1	1	1	1	1
No lack of political/administrative support	1	0	1	1	1	1	1	1
No lack of expertise	1	1	1	1	1	1	1	1
No change in context	0	0	0	0	1	1	1	1
Total score	2	6	6	6	6	6	6	6

The arrows in the table indicate the nature of the decision-making process. A top-down process is represented by '↓', a bottom-up process by '↑' and a joint process by '↔'.

An important failure factor in the organisation of the decision-making process is that it is a top-down process. In a top-down process there is no consultation with the companies in the (future) industrial park. The measures to achieve sustainability are chosen by the government. The result of a top-down process is that there is insufficient support among companies for the sustainable development of the industrial park. The case of The Ecofactorij shows that the top-down process employed by the municipality of Apeldoorn had a negative effect on support among local NGOs for the decisions made by the local authority. As a result of this lack of support a number of parties commenced legal proceedings against the local authority. These legal obstacles probably could have been prevented if these parties had been involved in the decision-making process. A bottom-up or joint process can avoid this lack of support. It is important that other parties besides the business community and the government are given the opportunity to become involved in the process so that such problems and disagreements can be avoided in the future.

The decision-making process can be seriously delayed or it can even break down entirely due to the absence of political and administrative support or because of legal or financial obstacles. This can have the result that the issuing of sites in the industrial park stagnates and hence the ambitions are not translated into performance. In the case of the Agro Industrial Complex Dinteloord there was a lack of political and administrative support. A change in the context during the decision-making process, specifically a redrawing of local authority boundaries, complicated the decision-making process. This change of context led to a lack of political and administrative support for the development of the AICD.

5.5 Policy instruments

The last aspect in the analysis concerns the use of policy instruments (Table 5). In practice, both voluntary and binding policy instruments are used. The analysis does not give a clear impression of the relationship between policy instruments and success in achieving symbiosis and/or utility sharing. In the most successful cases, Business Park South Groningen and Emmtec Industry & Business Park, relatively fewer policy instruments were used than in the cases that were less successful. It could be concluded that the use of policy instruments is a less decisive factor than the existence of location- and business-specific features or the organisation of the decision- making process.

Table 5 Policy instruments adopted

Degree of success (*see Table 1*) →	*1*	*1*	*1*	*2*	*3*	*3*	*4*	*4*
Policy instruments	*Ecofactorij Apeldoorn (n)*	*AICD Dinteloord (n)*	*VAM Mera (n)*	*The Trompet, Heemskerk (n)*	*Kleefse Waard, Arnhem (e)*	*Wavin, Hardenberg (e)*	*Business Park South Groningen (e)*	*Emmtec Industry & Business park (e)*
Promotion and acquisition(voluntary)	1	1	1	1	1	0	0	1
Facilitation	1	1	1	1	0	0	0	0
Park management	1	1	1	1	1	1	0	1
Financial incentives	1	1	1	1	0	1	1	0
Establishment requirements and private law agreements	1	1	1	1	1	1	1	1
Legislation (binding)	0	1	0	0	0	1	0	0

6 Conclusions and discussion

The concept of Industrial Ecology, introduced by Frosch and Gallopoulos, seems to be a promising approach with which policy makers can stimulate sustainable development in industrial parks. The concept uses an integrated approach to the environmental impacts of industrial activities rather than addressing individual business processes. The vision of industrial ecology is to achieve material cycles and energy cascades that would contribute to sustainable development. The Dutch government has been promoting the establishment of eco-industrial parks for some years now, focusing partly on the design of industrial parks (infrastructure and management of green space) and partly on industrial processes and symbiosis. The most important lessons that have emerged from the study concerning the practical implementation of the concept of industrial ecology are summarised below.

Industrial ecologists suggest that if industrial parks are designed on the basis of this concept it can be possible to significantly reduce the environmental burden caused by the industrial park, because those involved are more aware of the possibilities of recycling and exchanges of energy, water and residual substance flows. This theoretical claim is based on the often-cited example of industrial symbiosis, the Kalundborg project in Denmark. In only four of the eight cases we investigated in this study was symbiosis and/or utility sharing actually achieved. This is all the more remarkable because the cases we selected were the most practical from the larger group of subsidised projects in recent years. Apparently, what has evolved 'organically' or self-organised elsewhere is very difficult to create in a planned fashion. Previously existing social networks, as sources of mutual trust, seem to be essential resources.

Taking this observation further, we were able to discover little information about the actual environmental gains from this eco-industrial cooperation. On the one hand this is because the environmental benefits are not known, on the other, this is due to a reluctance to provide information. It was not our goal to assess such claims of combined economic and ecological benefits. However, this observed lack of information may pose a problem for further dissemination of eco-industrial park practices. Quantitative data about the economic benefits and environmental gains generated by the measures could be an important stimulus for other companies in industrial parks to try and work toward symbiosis and/or utility sharing in practice, since greater familiarity with these benefits of symbiosis and/or utility sharing could challenge other companies and industrial parks to study their possibilities. This form of information exchange could be stimulated, in any case with projects where government subsidies are provided, by requiring the companies involved to provide quantitative data about the environmental gains and economic benefits achieved.

The concept of industrial ecology suggests that environmental gains can be achieved through cooperation between independent companies. In light of this study, the question might be asked to what extent independent companies are willing to work together. Physical business specific and location specific features are important. Moreover, the study showed that the social cohesion between companies is very important. In all the successful cases that were studied the companies knew each other. In successful cases the companies had a shared history or the companies had been partners in the same chain for a long time. Other successful cases in the Netherlands that were not covered in this

study show that besides existing chain partners or companies that shared a common history, the production of goods in a joint venture can be a successful form of cooperation in an industrial park [47]. Our findings very much echo Cohen-Rosenthal's 'walk on the human side of industrial ecology' [21] where he challenges the reductionist and engineering approaches in industrial ecology, by stressing the importance of a solid understanding of the functioning of industrial networks and the role of human resources.

The study has shown that it can be possible for the companies to be able to form the necessary partnerships in industrial parks on their own. The government can stimulate cooperation and provide initiatives. A serious potential pitfall with respect to initiating cooperation among companies in industrial parks arises when the government plans this cooperation without involving the companies and other stakeholders. With top-down management there is the risk that there will be no support among the companies for sustainable development of the industrial park.

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