From an Innovative Milieu to an Eco-innovative Milieu: Towards Sustainable Territorial Development

Du milieu innovateur au milieu éco-innovateur : vers un développement territorial durable

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ABSTRACT. The aim of this article is to discuss the potential of the eco-innovative milieu for understanding the dynamics of sustainable local innovation. This approach is mainly based on the European theory of innovative milieus but seeks to integrate the sustainability dimension in the analysis of territorial innovation networks. We consider that industrial symbioses, in which a collective of territorial actors are linked by relations of valorization of material and waste flows, can take the form of an eco-innovative milieu. These relationships can be at the origin of the emergence of new dynamics of innovation through the collective learning that results from the common management of territorial resources (adoption of new eco-responsible practices, development of new sustainable technologies, reinforcement of communication and exchange of knowledge around these new practices, etc.). We illustrate our reasoning with an example of application to the industrial territory of Dunkirk, France.

RÉSUMÉ. L'objectif de cet article est de proposer une réflexion autour du concept de milieu éco-innovateur pour analyser la dynamique du développement territorial durable. Il s'agit d'une approche basée sur la théorie européenne des milieux innovateurs mais visant à intégrer la question environnementale dans l'analyse des réseaux territoriaux d'innovation. Nous considérons que les symbioses industrielles, dans lesquelles un collectif d'acteurs territoriaux sont liés par des relations de valorisation des flux de matières et de déchets, peuvent prendre la forme d'un milieu éco-innovateur. Ces relations peuvent être à l'origine de l'émergence de nouvelles dynamiques d'innovation à travers l'apprentissage collectif qui résulte de la gestion commune des ressources du territoire (adoption de nouvelles pratiques éco-responsables, développement de nouvelles technologies durables, renforcement de la communication et de l'échange de connaissances autour de ces nouvelles pratiques...). Nous illustrons notre raisonnement par un exemple d'application au territoire industriel de Dunkerque, France.

KEYWORDS. Innovative milieu, Industrial ecology, Industrial symbiosis, Eco-innovative milieu.

MOTS-CLÉS. Milieu innovateur, Ecologie industrielle, Symbiose industrielle, Milieu éco-innovateur.

1. Introduction

The concept of the innovative milieu provides a set of tools to analyze territories and understand their innovation capacities. All GREMI[1] programs have gradually evolved this concept from a "black box" to a stabilized conceptual framework that makes it possible to explain the success factors of developing territories and the failures of blocked territories [CRE 01]. The approach by innovative milieus thus systematizes the main questions relating to spatial economic dynamics. It makes it possible to qualify, on the one hand, the evolution of technology and interactions between actors coordinating the use of territorial resources [KEB 07], on the other hand, the spatial and temporal forms that these processes take [RAB 17].

Very few of the founding studies on innovative milieus have addressed the environmental challenges of territories in their innovation processes, despite the fact that this dimension occupies an important place in the concerns of companies and public policies. In 1999 Gaussier & Planque have emphasized the necessary link to be developed between the innovative milieu and sustainable development, with the view that the processes underlying them can complement each other [GAU 99].

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In this respect Livi and Crevoiser, have questioned the relevance of the innovative milieu concept in the face of new social and environmental challenges, and raise the necessary consideration of the relationship of local sustainable innovations to the territory [LIV 12].

More recently, Vecchio et al, 2020 have developed the hypothesis that innovative milieu plays a fundamental role in driving sustainable innovation [VEC 20]. They analyzed the role of the innovative milieu in triggering and adopting agricultural innovation in urban and peri-urban environments, focusing on young farmers' attitudes to sustainable innovation based on an understanding of their interaction logics (relational assets and coordination mechanisms activated by farms) and learning logics (innovation profile adopted). Longhurst (2015) also proposed a related concept of alternative milieu, sharing similar characteristics to the innovative milieu [LON 15]. The author highlighted the hitherto unrecognized role of alternative milieus in protecting different forms of sustainability innovation, using this concept to illustrate how a geographically localized concentration of countercultural practices, institutions and networks can create socio-cognitive "niche" protection for sustainability experiments.

This literature is still sparse and needs to be broadened, in particular by tackling industry-related issues (especially heavy industry), which is one of the most polluting sectors requiring more virtuous production models, but also has the most promising potential in terms of sustainable innovation or eco-innovation.

In this context, we propose in this article to discuss the potential of the innovative milieu for understanding the dynamics of sustainable local innovation. To this end, we cross the theoretical framework on innovative milieus with that of industrial ecology. In fact, industrial ecology is presented as a possible way to the mutation of the current production and consumption systems. It is a mode of industrial organization which is characterized by optimized management of stocks and flows of materials, energy, and services. It aims to reduce the negative impact of industrial activity on the environment by drawing inspiration from the functioning of the natural ecosystem, but it can also be at the origin of development and innovation dynamics on a territorial scale which justifies our interest in this concept. We explore the potential of industrial ecology to create an eco-innovative milieu within territories.

This chapter is divided into three parts: in the first, we explain how industrial ecology can foster the development of an eco-innovative milieu in a territory. We then discuss the barriers that could prevent the development of an eco-innovative milieu. Finally, we illustrate our reasoning with an example of application to the case of the industrial territory of Dunkirk.

2. Innovative milieu and industrial ecology: towards an eco-innovative milieu

2.1. *Innovative milieu*

The innovative milieu approach has been developed in parallel with other concepts such as industrial districts, clusters or regional innovation systems, which are mainly inspired by Marshallian work [MAR 20]. These works share the same hypothesis that knowledge externalities and agglomeration effects produced locally or regionally play an important role in the development and strengthening of innovation capacities.

According to the GREMI, the milieu refers to both the context and the actor environment [TAB 05], and constitutes “a set of relationships occurring in a geographical area that brings together, in a coherent whole, a production system, a technical culture and actors” [MAI 93] (p.7). This definition has become clearer over time with the multiple research programs carried out by GREMI. This work has made it possible – thanks to the strong interaction between empirical analysis and theorization – to explain the characteristics of an innovative milieu and the process that allows innovation to emerge in milieus. A total of six surveys were carried out in different European regions on the basis of a single question: “why are some regions more dynamic than others?” The surveys were based on a common methodology and questionnaire to allow for better comparability between the different regions studied [TAB 05].

GREMI 1 studied the role of the milieu and local factors of innovation in relation to factors outside the region in triggering business innovation [AYD 86].

In GREMI 2, the objective was to understand the relationship between the company and the milieu (internal and external) in order to identify the factors that allow the innovation process to be triggered. Emphasis is also placed on the potentially destructuring effects of opening up to external spaces [MAI 95].

GREMI 3 has made it possible to understand how the milieu as an organized and territorialized whole is transformed through interactions woven by the different networks that participate in the innovation process [MAI 93] [RAT 97].

GREMI 4 focused on the study of the development dynamics of milieus and the trajectories of their evolution over the long term. This survey focused on the impact of history on the evolution of innovative milieus. The decisions and constraints of the past condition the evolutionary trajectory of territories and thus engage them in situations of path dependency [MAI 95].

GREMI 5 and 6 differ from previous surveys in that they study non-industrial urban milieus. GREMI 5 focused on the relationship between the milieu and the city “how and in what way does the innovative milieu differ from the city?” [TAB 05]. In GREMI 6, the study focused on the heritage, natural and cultural resources of the milieu [CAM 04].

All of these surveys have made it possible to identify the characteristics of innovative milieus that constitute criteria that meet the need to measure, identify the innovative capacities of these milieus and understand the dynamics that distinguish them [TAB 2005]. A milieu then becomes conducive to innovation when it is defined by a geographical space integrating a group of actors coordinated by an institutional structure and an organizational logic based on innovation networks allowing the implementation of collective learning dynamics [MAI 92] [CRE 01].

- A geographical space determined by a group of actors and coordinated by an institutional structure: the innovative milieu brings together a set of actors (companies, research and training centers, universities, funding institutes, associations, public administration, etc.) located in a geographical space that presents a certain unity and homogeneity. This group of actors is characterized by behaviors specific to the milieu, notably a shared technical culture [CRE 01]. The relations between actors are marked by economic coherence and cohesion. Multiple exchanges favor the establishment of cooperative and collaborative relationships, while taking into consideration the competitive aspect and autonomy in the formulation of strategic choices [MAI 92]. All of these actors benefit from the existence of geographically close material, human, financial, technological and informational resources offered by the milieu [UZU 10]. The behaviors and relationships they maintain are governed by an institutional structure (set of rules, norms, values, etc.) that makes it possible to organize them and regulate their interactions.

The location of actors close to each other in a defined geographical space has a strong impact on their ability to innovate collectively. This geographical proximity can be at the origin of positive externalities allowing the members of the innovative milieu to benefit from agglomeration effects. Indeed, collaboration and joint learning allow for the exchange and sharing of inputs, specialized services, and infrastructures, a common labor market, and an “industrial atmosphere” conducive to the dissemination of knowledge. The companies that are part of this milieu can thus benefit from external economies of scale that are favorable to their competitiveness. However, geographical proximity cannot generate agglomeration effects without the presence of specific organizational modes that facilitate communication and interaction between the different actors. Other forms of proximity, organizational and cognitive, must then be activated with geographic proximity [Torre 12] [UZU 10].

- An organizational logic based on networks, learning and proximity dynamics: the actors in a milieu cooperate to innovate, and their connection in a network allows the creation of a specific mode of organization, which favors the creation of common projects and the reduction of uncertainties (conflicts, costs related to innovation processes, etc.). The actors inserted in innovation networks develop capacities for the acquisition, production and dissemination of new knowledge. These learning capacities are built up over time and make it possible to modify and adapt the behavior of the actors according to the transformations of their milieu [MAI 92]. They thus guarantee a control of the productive process in the broad sense (technical, commercial, or organizational). The learning capacity of actors presents the milieu as a context favorable to innovation. These processes of interaction and learning enable the creation of specific resources that nourish the innovation process [KEB, 08].

The functioning of an innovative milieu is based on a logic of interaction that translates into cooperation and collaboration between actors and a logic of collective learning based on the mobilization of resources specific to the milieu by the actors. These logics allow the creation of innovation, only when activated by the cross-fertilization of the geographical, Organizational and cognitive proximities.

The organizational proximity can be defined as the extent to which relationships are shared within an organizational arrangement (within an organization or between organizations). It implies both the intensity of relationships and the degree of autonomy within these organizational arrangements [BOS 05]. It enables the formation and modification of the relationships and synergies that bind them, thus promoting interaction and collective action. It also integrates an institutional dimension that plays an important role in providing a favorable framework for the behavior of economic actors through rules, laws, norms, values and so on. The logic of interaction is activated when organizational proximity is strong.

Cognitive proximity enables collective learning, it is based on the sharing of the same knowledge base, experiences, know-how, routines, and more, allowing actors to engage in common projects [UZU 10]. The learning logic is activated when the cognitive proximity between actors is strong.

The articulation of the three forms of proximity (geographical, organizational and cognitive) in the milieu contributes to the implementation and reinforcement of two logics [UZU 10] [TAN 16] thus giving the milieu its systemic character.

In sum, the theory of innovative milieu provides a rich analytical framework that has contributed to understanding the mechanisms behind the genesis of an innovation rooted in its territory. However, the founding works of the concept have not sufficiently addressed the issues of sustainable development and the innovations it requires, with the exception of a few more recent works [LIV 12] [LON 15] [VEC 20]. This tendency can be explained by the absence of pressure on the use of resources at the time, considered as infinite [LIV 12] and whose use was considered as substitutable by technical progress and technology.

In order to contribute to the debate on the evolution of the concept of the innovative milieu, in this article we seek to explore its potential for understanding the modalities of emergence of a sustainable innovation dynamic that considers the environmental issues facing territories today (climate change, pollution, scarcity of natural resources....).

To this end, we mobilize industrial ecology, in particular through its operational mode of application in stakeholder networks known as industrial symbiosis, which we believe can provide an illustration of possible territorial configurations of sustainable innovation or eco-innovation to accompany transformations towards a more sustainable local economy.

2.2. *Industrial ecology and industrial symbiosis*

Industrial ecology is an approach that brings together a set of practices aiming to reduce polluting industrial discharges. It promotes the transition of an industrial system to a sustainable system, inspired by the functioning of natural ecosystems [FRO 89] [ALL 92]. The term industrial ecology was popularized in the 1990s following the publication of the article by Robert Frosch and Nicholas Gallopoulos (two engineers at General Motors). According to these authors, the pollution and the depletion of natural resources caused by industrial activities should lead to reconsideration of the development model of industrial economies. These authors consider that it is necessary to move from a traditional industrial system to an industrial ecosystem (1989, p. 106). The implementation of industrial ecology is based on four levers of action [ERK 2004]: The systematic recovery of waste and by-products, the minimization of losses through dissipation (energy, polluting emissions...), the dematerialization of the economy (which translates into the substitution of products with services), and the decarbonization of energy. In opposition to the end-of-pipe and clean technologies approaches, industrial ecology proposes concrete actions and solutions allowing the implementation of sustainable development.

Industrial ecology has been historically applied to industrial territories, its implementation implies an analysis of the industrial metabolism [AYR 89] allowing to study quantitatively and qualitatively the physical characteristics of the industrial system, namely the flows and the stocks of materials necessary to the functioning of the industrial activities [ERK 04]. This analysis is an essential prerequisite for industrial ecology since it allows the identification and creation of industrial symbioses.

Industrial symbiosis is the establishment of eco-industrial synergies between actors in a defined geographical area [CHE 00]. It is constituted by a set of relationships based on the exchange of waste flows from a production process, which may be material, water or energy, to another production process, so that the waste or by-products of one company become resources for others. There are two forms of eco-industrial synergies: substitution synergies (substituting a new incoming flow with an outgoing flow from another company) and mutualization synergies (mutualization of flows between companies: collective collection and treatment of waste, etc.).

2.3. *Industrial symbiosis as an eco-innovative milieu*

The implementation of industrial ecology within a territory can appear as a tool for the development of an "eco-innovative milieu" [KAS 18]. The symbiotic relations resulting from industrial ecology can be brought closer to the concept of the innovative milieu, which shows how innovation can emerge from proximity relations between actors also located on a given territory [MAI 93].

As discussed above, an environment that generates innovation dynamics is characterized by: a physical space shaped by a group of actors and coordinated by an institutional framework and an organizational logic based on innovation networks that allow for the implementation of a learning dynamic [MAI 92a] [MAI 92b] [CRE 01]. It also generates agglomeration effects reinforced by the articulation of forms of proximity (geographical, organizational, and cognitive) and is based on effective territorial governance.

Industrial symbiosis integrates a group of diversified actors within a given territory, most often of an industrial nature. It involves industries that are usually separated in exchanges of material and energy flows [CHE 00] [ERH 04]. A waste or by-product from one company's production process becomes a resource for another, thus guaranteeing the optimization of costs (of supply, transport, etc.) and the creation of a competitive advantage [CHE 04].

In industrial symbiosis, cooperation is an essential ingredient and the actors are linked by eco-industrial synergies. In practice, industrial ecology involves two main types of synergies: substitution synergies, which consist in substituting a new incoming flow with an outgoing flow from another company, and mutualization synergies, which are based on the mutualization of flows or production between companies. All these elements lead us to consider that industrial symbiosis is characterized by the presence of a collective of interacting actors as defined in the literature on the innovative milieu.

The institutional framework, particularly through environmental regulations, plays an important role in the organization and coordination of industrial symbiosis. Taking the case of Kalundborg as an example, it can be seen that environmental rules and laws, as well as government intervention, have contributed to the profitability of synergies. For example, the municipality of Kalundborg has required residents to connect to the heat network in which it has invested [BUC 11]. In this context, work on industrial ecology emphasizes the importance of territorial governance, not only public (regulations, rules, etc.) but also private, in generating and sustaining interactions between actors [SCH 11] [BRU 14] [DEC 13].

The eco-industrial synergies specific to industrial symbiosis allow the constitution of networks based on the collective management of specific resources by local actors (companies, institutions, research centers, associations, etc.). In this context, the implementation of industrial ecology is a collective action that requires clear communication, collaboration, and good coordination of local actors [BAS 97]. It brings the actors into symbiotic relationships, forming networks based on cooperation and trust. These networks can be very limited relationships (e.g., when hot water from an industry is used to heat adjacent homes), or they can take the form of complex industrial ecosystems in which infrastructure, homes, and products are designed to operate in a cyclical fashion [CHE 00] [ALL 06]. One example is "eco-industrial parks" which are defined as "any grouping of industries seeking to improve their environmental and economic performance through collaboration in the management of resources including energy, water and materials. By working together, the community seeks a common benefit greater than the sum of the individual benefits that each industry would have gained if it operated alone" [LOW 96] (p. 12). The networking of actors in an eco-industrial park could lead to the reduction of uncertainties (conflicts, costs...). Actors will benefit from a shared infrastructure, fluid information flows, common benefits, and regulations that favorably frame their behaviors, thus reducing conflicts between them [CHE 00].

The network organization of actors in industrial symbiosis is based on the presence of pivotal firms (hub firms), as shown by examples of industrial symbioses, including the industrial symbioses of Kalundborg (Denmark), Jorf Lasfar (Morocco) and Jyväskylä (Finland), in which pivotal firms have contributed to the sustainability and development of eco-industrial networks. The functioning of the industrial symbiosis based on eco-industrial networks and the presence of a driving unit is thus close to the organizational logic of the innovative milieu. These networks, combined with the other characteristics analyzed here, are at the origin of innovations.

The grouping of actors in the industrial symbiosis allows the creation of a dynamic related to the rational use of natural resources resulting in the development of new knowledge. Indeed, the implementation of industrial ecology approaches requires significant organizational and technological transformations to cope with the complexity of flow reuse processes [DIE 12]. Actors modify and adapt their behaviors through the acquisition and production of new knowledge. To exchange material or energy flows, actors build relationships based mainly on the sharing of information (e.g., types, characteristics, volumes of waste...), know-how, practices, skills, experiences, etc., which results in collective learning. The learning capacities acquired in the context of eco-industrial synergies between actors give rise to specific resources [CHE 04] [DIE 12]. These may be material, financial, technological or human in nature. The integration of material (water, waste, steam...) and energy flows in the production process allows the optimization of natural resources, but also favors the creation of new eco-designed products or services. This process is at the origin of the emergence of new financial resources, resulting from the reduction of raw material purchase costs, transport costs, the search for suppliers, etc., or by the realization of gains thanks to the sale of waste. The reuse of material or energy flows allows the development of new technologies, in particular, technologies for recycling and recovery of waste/water. These technologies are developed through the acquisition of new knowledge, practices or experiences. New human resources can emerge within the framework of an industrial symbiosis. This can result in the development of new skills and qualifications or in the creation of new jobs. Thus, an industrial symbiosis is characterized by a learning dynamic allowing the creation of specific resources on the territory.

Finally, industrial symbiosis shares a number of characteristics that make it similar to an innovative milieu. The eco-industrial synergies established between the actors in the industrial symbiosis form a collective of actors. The multiple interactions of these actors within the framework of the exchanges and the common management of the flows of materials leads to the constitution of networks. In these eco-industrial networks, the acquisition and sharing of new knowledge (especially on the characteristics, processes of valorization) are necessary for the functioning of synergies. We can thus consider that industrial symbiosis can take the form of an innovative milieu.

Like the innovative milieu, industrial symbiosis can also be described by the innovations generated, which take the form of environmental innovations or eco-innovations [KAS 17]. The eco-innovations generated by industrial symbioses can be defined as "the assimilation or exploitation of a product, production process, service, management, or business method, new to the company or user and which result, throughout its life cycle, in the reduction of environmental risks, pollution and other negative effects of resource use (including energy use)" [KEM 07] 5p. 3). They can be of different natures [GAL 12]: of an incremental nature, which consists of improving an existing technology, without changing uses and practices, or techno-fixed, which allows for radical technical changes that preserve existing practices, or transformative, which correspond to the implementation of new technological systems, and which require a complete reconfiguration of production processes and lifestyles.

Eco-industrial synergies generate eco-innovations of various kinds: processes innovation that reduce the negative impacts of production processes on the environment; product innovation that prevent or reduce the production of pollutants and / or the consumption of resources, energy, etc. of the production process ("eco-products"); organizational innovation, allowing to ensure a good organization of the exchanges of material/energy flows; institutional innovation, including the changes brought to the whole of the values, standards and regulations that the actors share in a collective project of industrial ecology; and finally commercial innovation, which are translated by the implementation of new methods of promotion or pricing allowing to ensure the profitability of the eco-innovative products/technologies or services.

In sum, we consider that industrial symbiosis shares the main characteristics and features of the innovative milieu concept. Moreover, through the environmental innovations or eco-innovations that it generates, it brings the "sustainable" dimension to the innovative milieu (table 1).

Common characteristics	Innovative milieu	Industrial symbiosis
Localized collective of actors	Coordinated set of players in dynamic territorial networks	Association of normally separate industries in a collective process of exchanging material and energy flows and creation of eco-industrial networks
Institutional structure	Monitoring the behavior and decisions of economic actors	Organization of industrial ecology practices based on environmental laws, rules and regulations
Presence of a pivotal stakeholder	Driving firm (pivotal firm)	Initiator of industrial ecology projects
Learning capabilities	Adaptation of stakeholders to changes and transformation of their environment	Technological and organizational transformation for the implementation of industrial ecology approaches
Specific resources	Mobilization and creation of specific resources: material, human, financial, technological, informational... etc.	Recovery, reuse/recycling of material or energy flows (co-products, waste, wastewater, steam, etc.) Creation of new specific resources (financial (reduced costs and sales of waste and material flows, new specific skills, etc.)
Innovation dynamics	Creating traditional innovations: products, processes, new markets...	Generation of eco-innovations (eco-designed products, new business models, new clean technologies, new work methods, new modes of governance and collaborative management of local resrouces , etc.).

Table 1. *Innovative milieu and industrial symbiosis: homothetic characteristics*

2.4. *Eco-innovative milieu and territorial development*

The eco-innovative milieu is characterized by the articulation of forms of proximity (geographical, organizational, and cognitive). Indeed, the forms of proximity play an important role in the maintenance and development of eco-industrial synergies. The reduction of the geographical distance between the actors allows the reduction and the control of the costs of transport and facilitates the collection and the mutualization of waste (circulation of the flows of materials, vapor, and water...). Organizational proximity allows for better coordination of the relationships that bind the actors around the exchange of flows. It facilitates collective action and reduces transaction costs, particularly those related to the search for a partner. In its institutional dimension, proximity makes it possible to deal with regulatory constraints and establishes a climate of trust between the players. Cognitive proximity also plays an important role, insofar as the sharing and dissemination of information, knowledge and good practices are essential to the implementation of industrial ecology approaches. The articulation of these forms of proximity in the industrial symbiosis makes it possible to generate agglomeration effects at the origin of positive externalities [GAL 16]. Externalities in the eco-innovative milieu are both static, resulting in particular from the specialization of skills, jointly developed infrastructures, etc.; but they are also dynamic due to the diversification of activities [KAS 20].

Within the eco-innovative milieu, firms can benefit from external economies of scale - savings in terms of labor costs, material/energy flows, by-products, a diversified common knowledge base: sharing of similar or complementary knowledge and skills, collective learning, eco-technological externalities, communication networks, etc. - which can indeed reinforce their flexibility, reactivity and capacity to adapt and justify their maintenance or development on site. These positive externalities strengthen the routines of all the involved actors (not only companies but also institutions, associations, research centers, etc.). Consequently, it is the whole attractiveness of the territory that can be reinforced by the implementation of industrial ecology strategies. A better attractiveness can allow economic diversification by the creation of new sectors (such as waste treatment and transformation of waste into raw materials that can be used by others) or by the creation of new service activities linked to the implementation of industrial ecology (service providers: waste transport, logistics; decision support services: advice, lawyers, engineers; broad training services, etc.) [BOU 15]. New companies are created or established in the territory to take advantage of these externalities and specific assets (material flows, infrastructures, knowledge and skill base, etc.). Thus, in our opinion, through its effects on attractiveness, the externalities resulting from the eco-innovative milieu can be at the origin of a linked variety of the territory. The eco-industrial synergies link new companies to existing ones.

The potential of industrial ecology in the development of eco-innovative milieus presented in this article remains a theoretical ideal built on observations from the literature and practical experiences. However, studies on industrial ecology highlight the existence of a gap between theory and the reality of the ground [KOR 04] [BOU 15]. The metaphor of the eco-industrial system is difficult to implement as certain constraints may prevent the feasibility and durability of synergies in the eco-innovative milieu. These challenges are discussed in the next section.

3. The barriers to the development of an eco-innovative milieu

Difficulties in setting up industrial ecology and industrial symbiosis can be divided into two categories: the first category concerns the boundaries related to the functioning of eco-industrial synergies (the operational aspect of material and energy flows, notably economic and technical) and the second category includes difficulties related to the organization and regulation of synergies (notably regulatory, informational, relational, etc.).

3.1. *Barriers to the operationalization of eco-industrial synergies*

The realization of a synergy for companies depends essentially on its economic interest since the decision to its implementation is based on the calculation of costs, prices and also the consideration of risks. The transformation of waste into raw material requires important investments since it often implies the purchase of new equipment, the operation and maintenance of this equipment. As a result, the need for qualified human resources increases and their training is necessary in order to master the implementation of an industrial ecology approach [ADO 07]. These company managers may be reticent to invest in industrial ecology. The profitability of this type of approach is achieved in the long term and does not necessarily respond to the logic and strategies of short-term profitability: "the priority of companies is given to the time of return on investment and short-term economic profitability [COR 14]. Industrial ecology projects must provide interesting results for the company within a short timeframe" [DUR 07]. In addition, there can be a lack of experience with the financial and legal framework for industrial ecology, which can lead to additional costs to the companies.

The economic profitability of industrial ecology practices may also be limited by quantitative barriers arising from insufficient quantities of flows to be recovered [GIB 07] [GAL 16]. Considering waste treatment as a production chain in its own right, the inverse correlation of quantities treated and costs remain the same as for any other production chain, where cost control depends essentially on achieving economies of scale. When waste quantities are low, the break-even point is also low. This can slow down the establishment of synergy.

The implementation of synergies can be hindered by technical constraints [RAV 15]. Companies face the complexity of the product streams to be recycled, the degradation of the material, and the impurity of the by-products used in the recycling process [GEL 12]. Indeed, the physical characteristics of the recoverable streams may make it impossible to establish certain synergies. The physical state and dimensions of the material or energy stream components are sometimes incompatible with the product manufacturing process. In addition, there is the problem of material degradation. Industrial recycling degrades the materials; for example, the extracts from deposits lose their purity at the very first stages of the manufacturing process. They are mixed and treated with various additives so that they have the desired properties. The recovery process is not limited to the recovery of the waste, but an effort is made to conserve its properties during recycling [ADO 07].

Waste sorting and separation are also technical challenges in recycling [ERK 04]. Sorting plastics, mixed scrap, and all types of waste incurs significant costs associated with collection and transportation of materials. In addition, there are materials that were not designed to be recycled and are virtually impossible to recover, since separating their components poses several difficulties and significant costs to the company.

In addition to sorting problems, there is another major obstacle for companies, especially small and medium-sized ones. This is the lack of physical space to store outgoing and incoming waste. A survey of 12% of SMEs in the city of Hobart, (Australia) conducted by Parsons and Kriwoken (2010), found that "inadequate storage space" was a major barrier to waste recovery or recycling [PAR 10].

3.2. *Barriers to the organization of eco-industrial synergies*

The emergence and development of an eco-innovative milieu can be slowed by factors that weaken the establishment of eco-industrial synergies. These problems can be related to the regulatory, human, informational, (etc...) context. Synergies are built in an organizational structure based on the interaction of actors. These relationships can be complex due to the regression of trust and cooperation, the divergence of interests, or the presence of a rigid institutional (regulatory) framework. In studying several cases of industrial symbiosis around the world, [DUR 07] points out that some industrial ecology initiatives" have been severely undermined by the end of initial funding, by changes in the management of companies or local elected officials, by the departure of the project leader (as an institution or as a person), or by a profound disagreement between the various stakeholders on the organization of the project (relational quarrels linked to power issues)" (p.29). This shows the fragility of the collaborative aspect that characterizes industrial ecology projects.

The information needed to implement industrial ecology is not always accessible and the culture of industrial secrecy can slow down the flow of information between companies. On the one hand, the dissemination of information on the processes (characteristics of the materials used, components, quantities...) is sometimes difficult for the companies. On the other hand, industrialists do not reach an agreement and do not trust each other [ADO 07] [COR 14]. They prefer to keep confidential the data of the balance of incoming/outgoing flows necessary for the establishment of eco-industrial relations. This makes it more difficult to establish synergies between them. Confidentiality issues can also be a hindrance to collective learning and knowledge diffusion from skilled labor mobility between firms [VAN 07].

The human factor (related to human resources) thus plays a key role in the success or failure of this environmental strategy. Even if the realization of synergies proves to be economically possible, the resistance of managers to cooperate with other companies, the lack of involvement in such an approach, and even the reluctance to share data are elements that are part of the culture of competition and industrial secrecy. Not only do these elements slow down the implementation of industrial ecology, but they also prevent them from creating synergies that can be profitable in the medium term (by allowing the costs resulting from the former to be covered) [LI 18] [DOS 19].

Operations involving a waste or energy exchange can sometimes be unrelated to the company's core business. This means that many companies have very little information about the quantity and composition of the waste they produce, the costs of disposal, and the costs of materials, energy, and labor required to recover their waste [GIB 07]. This can be a constraint to establishing synergies. Firms may have little incentive to explore waste recovery.

In sum, the lack of a culture of partnership and change and the confidentiality of data directly affect the interest in implementing synergies. However, in some cases, despite the presence of information, the constraint may be related to the inexploitation of the information by the companies. Several tools for managing industrial ecology flows exist, such as: intranet/extranet platforms, databases on material, water and energy flows, exchanges, geographic information systems (GIS), etc. This type of tool makes it possible to gather and disseminate information on incoming and outgoing flows and to facilitate the identification of partnerships or synergy opportunities. A lot of information can be made available to companies through a GIS or a waste exchange, for example. However, the results of the surveys conducted by [DUR 07] have shown that, for example, material exchanges via Internet sites are numerous, but remain largely under-exploited by users. The number of visits to these sites is insufficient to generate significant results.

In addition to these organizational limits, there are internal limits to the organization of the company, in particular, the unavailability of productive devices and technologies adapted to waste treatment. Other external limits are linked to the lack of necessary infrastructures, such as transport and logistics services, waste treatment services, water services, and energy and gas flow transformation services [LAP 16].

The motivation of companies to implement industrial ecology actions can be impacted when the institutional framework organizing these actions is rigid [LI 18]. In practice, regulation is an essential factor for the development of eco-industrial synergies. We have already mentioned the example of Kalundborg and the role played by regulation in the sustainability of synergies. However, regulation can sometimes be a barrier. It has an impact on the interest in exchanging flows between industrialists as well as on their motivation. The absence of a regulatory framework and fiscal tools that can facilitate recovery operations, as well as insufficient incentives from public authorities, effectively influence the decision to establish synergies between companies. The absence of environmental regulation or too flexible environmental regulation can reduce incentives for value addition.

The example of the Kwinana industrial symbiosis, in which environmental regulations have been an impediment to the establishment of certain synergies, is interesting to discuss. According to [VAN 07] some companies in Kwinana have difficulty obtaining government approvals for the use of alternative fuels and feedstocks. Although some by-product synergies seem technically and economically feasible and have a positive environmental impact (e.g., alternative fuels in cement kilns and use of bauxite residues for soil conditioning), their implementation has been halted by uncertainties in the legislative framework. In addition, when a by-product is classified as a controlled waste (e.g., fly ash), strict procedures and transportation requirements apply. This shows the complexity of environmental regulation.

The valorization of symbiotic relationships between the actors of the eco-innovative milieu enables the emergence of an industrial atmosphere based on relationships of trust. These relationships are at the origin of the attitudes likely to favor the implementation of eco-innovations. However, the nature of economic relationships raises certain limitations, as we have seen above, related to their organization that can prevent the development of technological and non-technological eco-innovations. The highly uncertain nature of environmental innovation activity is an important barrier [LOR 12]. The uncertainty is firstly technological, and is based on technical and economic choices. Secondly, it is linked to economic, social, cultural and stakeholder behaviors that are difficult to predict. Uncertainty can also be organizational in nature: the need to adopt changes in internal (and/or external) organization, production or distribution methods, routines, or even strategy.

4. The example of the industrial symbiosis of Dunkirk

The eco-innovative milieu analytical model can be illustrated by the case of the industrial-port complex of Dunkirk (Hauts de France), a territory with a high degree of industrial specialization in search of new sustainable production models [KAS 17] [KAS 20]. The territory of Dunkirk has a number of assets to make industrial ecology a major activity in the construction of an eco-innovative milieu. First of all, the practices of industrial ecology are old in Dunkirk (they go back to the early 1960s) which should allow the territory to capitalize on the experiences already conducted. On the institutional level, local authorities have very early integrated environmental concerns in their actions; this should be a key element to encourage the implementation of effective practices.

The results of our study show that industrial ecology approaches were implemented in Dunkirk as early as the mid-1980s with the installation of the urban heating network. Exchanges of material and energy flows have gradually multiplied to form an industrial symbiosis, consisting of synergies between different actors in the territory, around a pivotal actor (the steel manufacturer).

In this industrial symbiosis, the synergies are carried by private actors but also public (local institutions) and semi-public (Ecopal association, business clubs...). The latter intervene mainly by accompanying the industrialists in the implementation and, especially, in the promotion of industrial ecology practices. The presence of these synergistic relationships shows the existence of a diversified group of actors and an institutional structure that guides their activities.

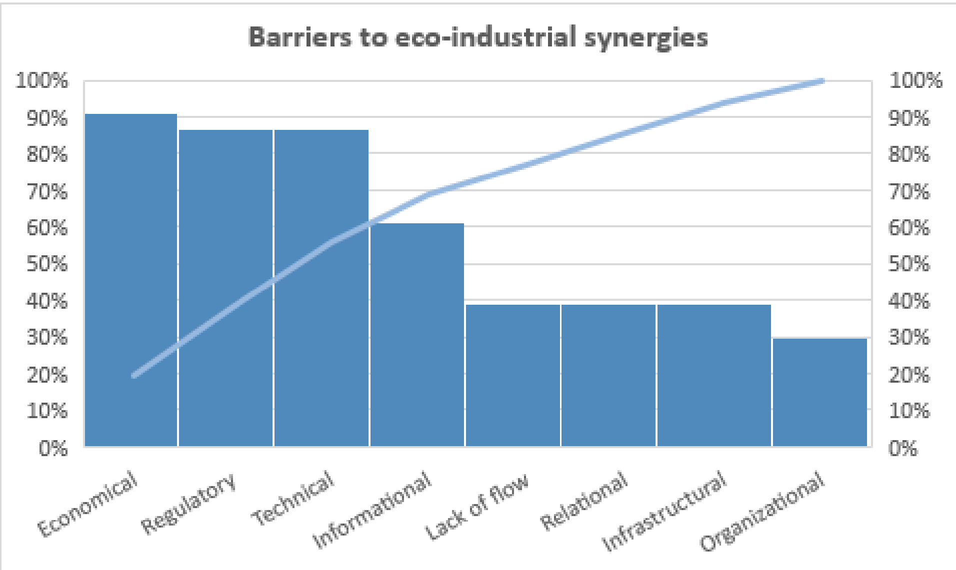

Figure 1. *Main barriers to industrial ecology in Dunkirk*

The companies that have implemented industrial ecology practices have, in some cases, developed new knowledge and skills that have been transformed into eco-innovations (notably of products, processes or new practices). These dynamics of industrial ecology have also generated the creation of new activities on the territory. Some new companies have settled in the symbiosis and are connected by synergies to the existing companies. In addition to the cyclical and structural attractiveness factors of the Dunkirk territory (in particular, the adapted and specialized infrastructure, the specialized workforce, the support of local actors, etc.), the presence of material flows and synergy opportunities have been essential elements in the location of these new companies. Eco-industrial synergies offer these companies opportunities to create new markets and develop new technologies. This observation confirms the potential of industrial ecology in strengthening territorial attractiveness and therefore the diversification of activities.

However, as discussed above, the implementation of industrial ecology in Dunkirk is facing many obstacles that hinder the creation of synergies, their organization, but also the installation of new companies in the industrial symbiosis. These difficulties are linked to the operational aspect of synergies (economic and technical) and to the organization of synergies (informational, relational, regulatory, etc.). They are also reinforced by the fragility of the Dunkirk territory; whose installed production units are subject to the location/relocation decisions taken by the decision-making centers of multinational groups (Figure 1). The contribution of industrial ecology to the diversification of industrial territories depends, in fact, on the resolution of these difficulties linked to the instability of investment and material flows. The development of commercial and non-commercial service activities and governance actions can contribute to improving the eco-industrial business climate [KAS 17].

Conclusion

In this paper, the concept of the eco-innovative milieu is introduced to explain the mechanisms for the emergence of new innovation dynamics integrating the inclusive and sustainable dimensions of economic growth [KAS 18]. This new approach aims to build an analytical framework to guide innovation policies towards the development of new economic models combining competitiveness, innovation and sustainable development, based on industrial ecology practices. These practices make it possible to move from a linear economy, in which resources are considered to be unlimited, to new ways of organizing economic activities inspired by the functioning of the natural ecosystem. The implementation of the industrial ecology on a territorial scale results in the constitution of networks of actors sharing common territorial projects around the valorization of material and energy flows. This functioning in networks specific to innovative milieus can be at the origin of new eco-innovation or environmental innovation dynamics that participate in the bifurcation of territorial trajectories.

The eco-innovative milieu is in fact an ideal framework that is formed on the basis of eco-industrial synergies. In reality, the creation of these synergies is the source of many difficulties that can hinder the reasoning described. These difficulties can be summarized in two categories: the limits linked to the operational functioning of eco-industrial synergies (operational aspect of material and energy flows) and the difficulties linked to the organization of synergies (informational, organizational, human and regulatory). In order that industrial ecology can be used as a tool for the construction of an innovative milieus, it is then necessary to reduce its limitations. The service activities (public and private) can actively participate in the good functioning of the industrial ecology processes. These activities may provide a number of functions related to the organization and coordination of market relations (coordination functions of industrial ecology approaches), the acquisition or maintenance of capacities by agents (training functions), or to the development of new practices such as new business models [LAP 16] [KAS 17].

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