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THE PARADOXES OF ENVIRONMENTAL INNOVATIONS: THE CASE OF GREEN CHEMISTRY

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In the last two decades, the environmental impact of industrial activities has led market actors to propose innovations that are consistent with sustainability issues. The chemical sector has been particularly criticized because of its propensity to increase both depletion of natural resources and the rate of ecological disasters. Since the early 1990s, economists have been particularly interested in the twelve principles of green chemistry which call for new ideas to achieve a sustainable socio-technical regime (Anastas, Warner, 2000). So, it encourages the theory of transition management to propose a multi-level analysis while using prospective tools to design environmental innovations. They are preserved thanks to *technological road maps* and the gathering of players around a common project from niches to maturity (Geels, 2011). However, even though the preservation of these new kinds of innovations is crucial for sustainability purposes, we argue that their identification is a precondition in order to reach a sustainable sociotechnical regime. That is why this paper aims to throw light on the nature of environmental innovations.

For nearly two decades, the theories of environmental innovations have fed economic literature with theoretical and empirical insights. Proposals aim to make for a sustainable socio-technical regime (Kemp, Arundel 1998; Markusson, Olofsdotter, 2001 ; Rennings, 2000). A set of definitions has been given and seems to be accepted regarding the empirical studies. Nowadays, some authors, who are behind this new field of the economy, question the originality of the subject of study. For example, René Kemp argues that sustainable technologies do not exist (Kemp, 2008). This article will follow

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this thesis by showing that environmental innovations need a reconceptualisation. Therefore we focus on the sector of green chemistry because it is seen as a vector of paradigmatic breaks.

We will point to the difficulty of distinguishing a non-environmental "generic" innovation from an environmental innovation. Despite scientific contributions, we argue that the differences between these two typologies are unclear or non-existent. Therefore, we present them in a tabular form in comparing them from a microeconomic, macroeconomic and systemic point of view. Secondly, we apply our results to the sector of green chemistry in order to illustrate the need for reconceptualisation.

ENVIRONMENTAL INNOVATION: A CONTRADICTION IN TERMS?

Here we will deal with the analysis of environmental innovations which are considered as a solution for achieving a sustainable socio-technical regime. We will show that their principles cannot be a new form of viable technologies due to several limitations. We compare them with "generic" innovations from several economic points of view. Firstly, we discuss the difficulties of distinguishing them through their definitions. Secondly, we question whether the environmental innovations have a singular evolution. Finally, we shall show that they are based both on the quest for efficiency and that they are subject to rebound effects.

In search of a definition of environmental innovation

From a stabilized definition…

When we refer to innovations, we consider mainly that the market is a catalyst for creativity. Schumpeter (1939) defines innovations as follow: "*doing things differently in the realm of economic life*". Moreover this author proposes five typologies in order to identify them. First, the introduction of a new good; then, new production methods or new work organizations. It can be a new outlet or raw materials (Schumpeter, 1934). Therefore, innovations are unlimited. Openness has contributed precisely to the development of theories of environmental innovation in order to cope with environmental issues. Therefore, contrary to generic innovations, we note that environmental innovations have a particular identity.

First, the OECD report of 2010 and the European Union define environmental innovations as follows: "*Eco-innovation is the production, assimilation or* *exploitation of a product, production process, service or management or business method that is novel to the organisation (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives*", (Kemp, Pearson, 2008). Secondly, Hemmelskamp argues that "*environmental innovations serve to: avoid or reduce emissions caused by the production, use or consumption and disposal of goods, reduce resource input, environmental cleanup damage done in the past, identify and control pollution*" (Hemmelskamp, 1997). Then, Kemp and Arundel (1998) point out that they are "*new or changed procedures, techniques, systems or products to reduce or avoid environmental damage.*" Meanwhile, Markusson and Olofsdotter thinks that "*environmental innovations can be defined in two ways: first, the effects of innovation on the environment and, secondly, by the intentions of the innovator to reduce the environmental impact of processes and products*" (Markusson, Olofsdotter, 2001). Finally, according to Rennings, they are an "*innovation process towards sustainable development*" Environmental innovations are "*measures taken by sub-players (firms, private households), which (i) develop new ideas, patterns of behaviour, products and processes, introduce or apply them, and (ii) contribute to a reduction of environmental burdens or to ecologically specified sustainability targets*" (Rennings, 2000).

In spite of these propositions, the preservation of the environment is a key determinant of environmental innovation identities in terms of objective. Therefore, the environmental innovations exist only because they fit in with the preservation of environment. They both focus on the beneficial nature of technology through market processes. So, what about the structures and characteristics of these two kinds of innovation?

... to confusions in identification

The peculiarities of environmental innovations are classified as goods, services, technologies, processes or organizational systems (Malaman, 1996; Hemmelskamp, 1997; James, 1997; Kemp, Arundel, 1998; Cleff, Rennings, 1999; Jones *et al.* 2001; Markusson, 2001; Oltra, 2008). Yet in comparing them with generic innovations, we note that they are also inspired by Schumpeter's proposals (1934). It seems that the differences between these kinds of innovation do not stand out. This is a problem in terms of achievement of sustainability. Let's illustrate with examples that deal with environmental preservation.

First, every green product has "competitive advantages" and new outlets (Porter, van der Linde, 1995). Second, new production methods can be represented by industrial symbiosis (Erkman, 1998). Third, the ISO 14001 standard is a new form of labour organisation (Patingre, Vigneron, 2001).

Finally, substitution of raw materials is rather significant in using renewable energies (Polimeni *et al.*, 2008). We also note that generic innovations and environmental innovations are difficult to distinguish because they have exactly the same categorization. Could the analysis of patents allow a better distinction?

The lack of patent analysis

Nowadays empirical studies about environmental innovations contribute to an important literature (Kesidou, Demirel, 2011; Faucheux, Nicolaï, 2011). On the one hand, they highlight technological regimes. On the other hand, they analyse the evolutions of technologies thanks to econometrics (Oltra *et al.*, 2009). But, the selection of standards raises two issues. First, should we combine current technologies with closed-loop processes in order to avoid waste and end-of-pipe productions? Secondly, are preventive actions more relevant?

Our first interrogation deals with the relevance of the resources and energy that are used by production processes. Indeed waste and co-products represent the main issue for environmental preservation. They can be dispersed in Nature and generate pollutions. Yet they are treated by using the theories of industrial ecology that propose to optimize production processes upstream – thanks to what is called end-of-pipe technology (Patingre, Vigneron, 2001; Oltra *et al.*, 2009). We argue that it can be applied at two levels within an organization or can be shared by inter-organizational flows such as "industrial symbiosis". The latter represents an ultimate evolution of the conservation of natural resources by imitating ecosystems (Frosch, Gallopoulos 1989; Erkman 1998).

Yet it is difficult to improve closed-loop systems due to evaluation costs and resiliency. Moreover, this aspect of environmental innovation is crucial if we focus on the origins. Despite the popularity of this concept that is presented as a solution for sustainability, we argue that it is based on the principle of circular economy. Indeed before Frosch and Gallopoulos (1989) in the early 1990s, Henry Ford applied it in the 1920s too and the USSR called them *kombinirovanaia produksia* – combined production – in the 1950s (Sathre, Grdzelishvili, 2006). In fact, the productivity of assets is a solution to reduce scarcity. From this perspective, it seems restrictive to develop environmental innovation from this point of view.

The other interrogation about environmental innovations results directly from design methods wherein innovation processes call for preventive action and reflexivity (Porter, van der Linde, 1995). Indeed, co-product life cycles have to integrate waste to be accepted by ecosystems. Therefore, controls and studies underline the interactions between products and environment through the inspiration of industrial ecology and the call for a *cradle to cradle* approach (Braungart, McDonough, 2002). We argue that these analyses start by selecting specific cases, scenarios and various standards for the purpose of finding the best solution and having non-territorial closed-loops (Grisel, Duranthon, 2001). Nowadays this way is the dominant design (Abrassard, Aggeri, 2002; I Fullana Palmer *et al.*, 2011). Therefore, could these preventive practices be the best option to distinguish environmental innovations?

An answer cannot be found because life cycle analyses were made by several economic groups to reduce commodity prices and to lighten competitive pressure in the 1970s (Tan *et al.*, 2002). Such an approach is built on economic interests, that is to say that life cycle cost analysis could not exist without it. Moreover environmental qualities are not taken into account because there are no territorial specificities and environmental innovations cannot evaluate consumer behaviour in an economic model which stretches all over the world. Finally, we shall argue that environmental and generic innovations upstream and downstream are similar. In this case, it is necessary to study each of them from an evolutionary point of view.

Environmental innovation: a singular evolution?

Degrees of change and uses

The contributions of evolutionary economists go into greater detail concerning innovation peculiarities by analyzing three degrees of change. They can be incremental, radical or systemic (Freeman, Soete 1982; Oltra, Saint Jean, 2005). The first one deals with a low degree of change consisting in adding options to an existing technology. We note that it does not fundamentally change behaviour and current production (Nuij, 2001; Brunnermeier, Cohen, 2003). The second generates more results by influencing the evolution of production processes, uses and organization (Freeman, Soete, 1982; Cleff, Rennings, 1999). The last is a systemic innovation where both radical and incremental innovations are combined - such as clusters - thanks to complex and stochastic phenomena (Falk, Ryan 2006; Jones, Stanton *et al.* 2001). As a matter of fact, we note that this cluster principle was also proposed by Schumpeter. This degree of evolution goes beyond organization boundaries and directly affects economic issues, institutions, technologies, territoriality as well as our perception of the environment (Nelson, Winter, 1982; Forest, 2009; Oltra, Saint Jean, 2009). Thus, is it any easier to distinguish generic innovation from environmental innovations?

Actually, a slight difference can be observed between them. Indeed, changing behaviour is often considered as a solution for preserving natural assets (Oltra, Saint Jean, 2009; Ehrlich, Holdren, 1971). So, radical innovation seems to be the best solution. But we will argue that it might be through the observation of environmental innovation principles. They have to integrate both environmental and economic challenges. That is to say, they are designed in order to include both long-term and short-term effects. First, long-term dimension focuses on the functionality of an artefact which is identified in term of meanings and purposes (what / why). In our case, we need other functions in order to decelerate scarce natural resources. Second, we can focus on its structure that needs means to achieve satisfactory results (how / what) in the short term (Koestler, 1967; Polimeni *et al.*, 2008). In fact, it could be an incremental solution which follows a classical problem that engineers need to resolve immediately due to uncertainty (Hatchuel *et al.*, 2006). Besides, these two dimensions are both conflicting and complementary, because decision makers cannot simultaneously think about means and functions. Thus according to Funtowicz and Ravetz, they face a *tragedy of change*. Choices are oriented towards innovation which can give an immediate action and viability thanks to the market (Funtowicz, Ravetz, 1990). On the one hand, we shall argue that short-term preferences do not fit in with the evaluation of environmental impacts, because of unexpected effects. On the other hand, if the long term dimension is selected, it means that the nature of environmental innovation will be anticipated. It is inferred that environmental innovation principles are closed to generic innovation. This confusion will be more obvious if we analyze the supply chain.

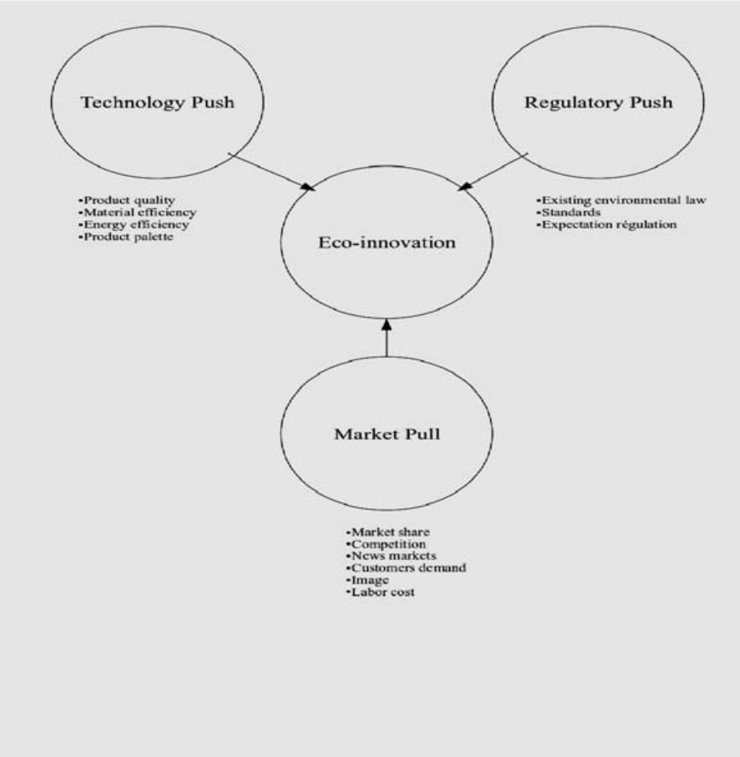
Incrementality or radicality of environmental/generic innovations can be interpreted at all levels of the value chain. We will argue that finding whether structures and functions are consistent depends on the user's position. For instance, a radical innovation can be an incremental one for industries using them as technologies which are ready-to-use (Hemmelskamp, 1997). Thus, how can we make a clear distinction?

What technological paths for environmental innovations?

Technological paths help us by understanding generic innovation from a dynamic point of view. According to economic literature, evolution depends on a triad: *demand pull, technology push* and *science push*. This matrix opens endless possibilities (Dosi 1982, 1988) which are slowed down by various institutional fetters: path dependency, representations, social acceptability and network externalities (David, 1985, Kline, Rosenberg, 1986; Malerba, 2002). Thus, technological paths of generic innovations show the importance of complex and stochastic phenomena. What about environmental innovations?

Technological paths of environmental innovation are also based on Dosi's proposals. However, regarding Rennings' work, several specific characters confirm oriented pathways (Rennings, 2000, p. 8). They are recognizable by their quest of efficiency through optimization of raw materials and of energy consumption. Moreover, they are driven by environmental policy with taxes, standards or regulation (See figure 1). By comparing technological paths, we note that generic innovations can be identified *ex post*, while environmental innovations are oriented *ex ante*. Then it shows that its definition is clearly stabilized *ex ante*, but, as we have shown, they cannot be identified *ex post*.

Figure 1 – The determinant of environmental innovations (Rennings, 2000)



Therefore, we cannot distinguish environmental innovation from generic innovation by choosing between static and dynamic analysis. Their peculiarity deals with technological expectations which are based on closed-loops, quest of efficiency and expectations. As a matter of fact, we would consider that these confusions come from the definition of "environment".

Environmental innovation and generic innovation *vs.* environmental impacts

Eco-efficiency: a singular interpretation of the environment?

First of all, we note that the definition of "environment" is paradoxically absent from the literature of environmental innovations. We argue that this notion is essential to embed the technosphere with the biosphere, even if natural dimension is a debatable concept (Theys, 1993). As a matter of fact, several definitions can be proposed and used by multidisciplinary studies. On the one hand, designers need to consider originality and users' behaviour (Abrassart, Aggeri, 2002). On the other hand, engineers apply knowledge in the resolution of industrial problems. Finally, biologists, chemists, ecologists, biochemists are also concerned with the environment. Besides, how can we reconcile these various points of view (designer, engineer and scientist) for the same project?

We argue that "environment" can be interpreted because it is complex to define. But a technocentric approach is a popular solution in proposing to resolve environmental impact: life cycle assessments and ecosystem models are good examples (Theys, 1993; Grisel, Osset 2004; Odum, 1969; Erkman, 1998). This point of view considers environment defined as materials and energy flows to be optimized. Eco-efficiency meets this request by proposing to optimize input and output ratios. It has two main advantages. On the one hand, higher economic rents; on the other hand, a lower consumption of natural resources saves natural assets while improving product quality on the market (Polimeni *et al.*, 2008; Blake, 2005). Thus, if environmental innovations aim to create an alliance between the market and natural resources, it will be necessary to intensify eco-efficient practices.

Yet, this is not a singular solution for sustainability, because efficiency principles were proposed at the very beginning of capitalism. In fact, we would argue that efficiency and eco-efficiency are the same but eco-efficiency is considered as a solution for sustainability. According to Ricardo (1817), two dimensions of efficiency are taken into account. The first one increases productivity thanks to technologies that are used in agriculture. The second one deals with regenerative capacity of fields and grounds. Which is better? We might think that extending the life cycle of products is a reasonable thing for sustainability in using the economics of functionality (du Tertre, 2007). Besides, this scenario seems to be connected directly to the second kind of eco-efficiency, because it proposes to decelerate natural resource scarcity. However, there are conflicts between technical and economic obsolescence. At first sight, technical obsolescence can have a longer life span, so it could be better from an environmental point of view. But its economic obsolescence can mean a shorter life span and can mean a stronger product diversity (Vernon, 1966; Hatchuel *et al.*, 2006). Therefore users can replace environmental innovations faster and faster because of a portfolio of solutions that are proposed by innovators. Then I would say that distinctions depend on the dynamics of transformation in which closed-loops strategies can legitimate the quest for recycling and diversity. What then is the impact of acceleration together with eco-efficiency from a global point of view?

The rebound effects: the paradox of environmental innovation

Actually, a global scale is the appropriate level on which we should be careful with environmental/generic innovations: eco-efficiency and efficiency encourage the productivity and the reduction of costs. Moreover, eco-efficiency calls for more productivity of natural assets. As a founding father of neoclassical economics, Jevons argued that they have paradoxical effects on the environment because competition race directly contributes to increase resource depletion in the long term. His book *The Coal Question* has been largely taken over by the Ecological Economics group in order to analyze this rebound effect (Jevons, 1865). Then, six effects are identified (Giempietro, 2008).

Actually, direct and indirect effects have been identified. First, since economic players have limited budgets, they are encouraged to buy more thanks to savings. Secondly, lower costs open the way for technological access to some population who did not benefit previously. Then there will be a larger number of users. Third, it can lead organizations to accelerate their competition and their transformation of matter in a sector or in a branch. Then, there are indirect effects. Fourth, the substitution of human labour with machines may require the same amount of energy for the same amount of inputs, economic players have more "free time" to produce and consume more. Fifth, an inelastic price demand cannot influence the behaviour of the consumer. Sixth, if prices of the commodity decrease, economic players will rely on this new economic value rather than on the energetic value of resources which are scarce. We can conclude that the identity of environmental innovations is based on the quest of eco-efficient improvements: their effect can be more risky than generic innovations (Polimeni *et al.*, 2008).

Table 1 – Six rebound effects and limit the scope of eco-efficiency (Polimeni *et al.*, 2008)

Impacts	Principles
Direct	Technologies are more efficient, but increase use (1)
	Population needs and income (2)
	The dynamics of sectors and branches (3)
Indirect	Substitution of human labour with machines with the same amount of energy needed (4)
	Elasticity of demand equal to 0 (5)
	Fall of commodity prices falls (6)

In the next part, we will apply our conclusions that are summarized in table 2 and table 3 (see appendix). They will be helpful for us to confirm our thesis by applying it to the sector of green chemistry. It is one of the few sectors that are able to change the structure and functionality of material for other products. That is why chemistry has been seized on by the scientific communities in order to restore a balance between the technosphere and the biosphere since the 1990s.

TOWARD A GREEN CHEMISTRY BASED ON NATURAL PRINCIPLES

This section aims to emphasize principles of green chemistry and its difficulties to break with the paradigm. First, we present how green chemistry argues that it is an real application for sustainability. Then, we moderate it by presenting its applications and limitations.

The green chemistry principles and applications of environmental innovations

What is green chemistry?

Since the 19th century, the chemical industry has been criticized for its development on an industrial scale. Economic theory informs us about transformation, complexity and recycling of materials. Indeed, the intensive aspect of the chemical sector has been highlighted since the 19th century: "*The most striking example of utilising waste is furnished by the chemical industry. It utilises not only its own waste, for which it finds new uses, but also that of many other industries. For instance, it converts the formerly almost useless gas-tar into* *aniline dyes, alizarin, and, more recently, even into drugs*" (Marx 1894, volume III, part 1). Nowadays, economic opportunities are more questioned. Indeed the scarcity of raw materials, including peak oil and ecological disasters such as Bhopal, forces stakeholders to gather around the chemical sector in encouraging new practices for a sustainable socio-technical regime (Macquarrie, Clark, 2002). In the 1990s, the sector of green chemistry has emerged thanks to the Pollution Prevention Act and the Environmental Protection Agency in the USA (Nieddu *et al.*, 2010). Then twelve principles of green chemistry have been proposed. Yet it seems that they cannot be used at the same time and choosing several of them is enough to be called green chemistry (Anastas, Warner, 2000).

We argue that these principles are rooted in the industrial ecology proposed by Frosch and Gallopoulos (1989). This approach is followed by Lankey and Anastas (2002). "*As a concept, green chemistry is one of a set of tools that can be used to implement the ideas embodied in industrial ecology. The concept of green chemistry has been a set of twelve principles, given in Table 1, whose goal is to prevent pollution and, like industrial ecology, to help achieve more sustainable activities*". These twelve principles can be summarized as follows: designing green products needs to optimize material and energy flows (1,2,4,6) and promoting materials substitution (2,3,4,7,8,9) in order to get a type II or III ecosystem (10) thanks to information tools (3,11,12) and control devices (3,4,11,12). So, are they compatible with the principle of environmental innovation?

Green chemistry and inspiration of ecosystems on an industrial scale

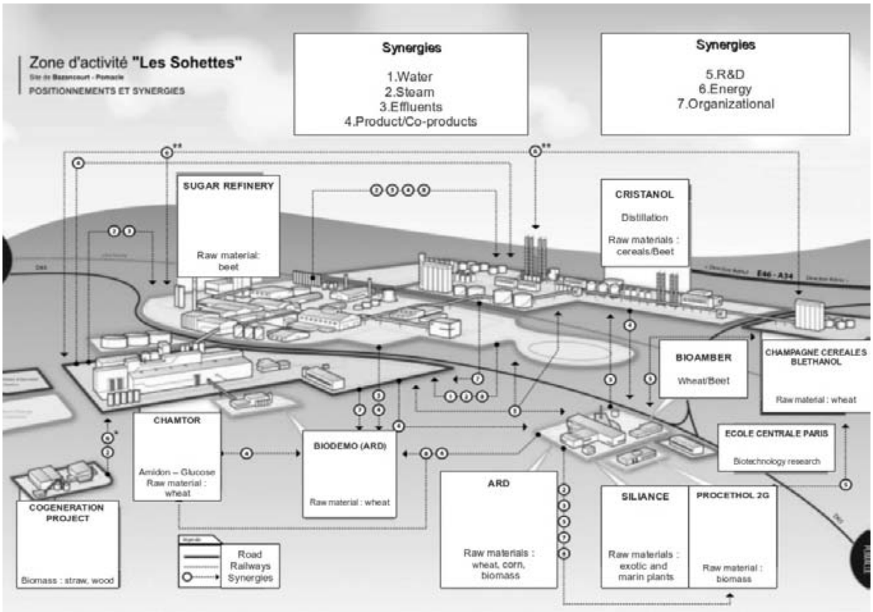
In integrating type III ecosystem in innovations into green chemistry, we argue that this proposal calls for self-sufficiency of energy and material flow (Allenby, Cooper, 1994; Erkman, 1998, p. 36). Even if eco-efficiency is improved by closed-loops, there are grounds for optimism: "*Today's industrial operations do not form an ideal industrial eco-system, and many subsystems and processes are less than perfect. Yet there are developments that could be cause for optimism. […] Nonetheless, we are optimistic. The incentive for industry is clear: companies will be able to minimize costs and stay competitive while adhering to a rational economic approach that accounts for global costs and benefits*" (Frosch, Gallopoulos, 1989). Thus, according to these authors, if green chemistry is based on industrial ecology, then the quest for eco-efficiency seems to be the way to sustainability. Yet we need to see if applications of these principles can be considered as environmental innovation.

Limits of the application of environmental innovations for green chemistry

The biorefinery, an environmental innovation that is limited to a local scale

Improving closed-loop systems calls for an ecosystem paradigm for sustainability (Erkman, 1998). In the case of green chemistry, bio-refineries are inspired by this proposal and move from organization to "industrial symbiosis" on territories. Pomacle Bazancourt's biorefinery in Champagne-Ardenne in France is a good example thanks to its 'technological road map' (Delphine *et al.*, 2007). We note that it needs renewable inputs and outputs from the food industry (Nieddu, Garnier, 2010). Then, a new generation of processes calls for more and more efficient methods in using non-food products, such as straw, in order to transform cellulose for many other carbon functionalities. From this point of view, substitution of raw materials can be mixed with current plastics. At first sight, the green chemistry paradigm is peculiar in that it uses renewable resources. Thus, are green chemistry principles ready to make for environmental innovation?

Figure 2 – Biorefinery and industrial symbiosis in Pomacle-Bazancourt (France) (Nieddu, Garnier, 2010)



We argue that this mechanism is not perfect, because symbiosis means interdependence of economic players. Indeed, if one of them disappears or slows down his activity, then the overall balance will be affected. From an historical point of view, Henry Ford was an example in terms of industrial symbiosis by using natural assets for his refinery and energy power plant between the 1920s and 1930s at Ford River Rouge complex (McCarthy, 2006). Responsiveness and adaptations of raw materials need to get simplified structures for easier storage and a higher level of consistency with other products. In our case, biorefining intensifies the uses of biomass for building platform molecules (Nieddu, Garnier, 2010). Product structures are built for ensuring a high adaptability in order to enjoy new economic opportunities from inside and outside the system. From this point of view, we cannot know exactly what is a 'green product' if one small part of material is renewable and included in a 'generic' product. Moreover, deconstruction of matter also faces entropy as shown by Georgescu-Roegen (1979). It requires an abundant source of energy that the quality of soil and climatic conditions cannot manage to provide by them. Moreover, from a local point of view, a biorefinery cannot control co-product growth. Then the increasing complexity of products and processes cannot control consumer behaviour because a single substitution does not modify the structure, functionality and services that are offered. Therefore, it could be faced with rebound effects as much as non-generic products. As a matter of fact, nothing changes.

Ecodesign: a source of value of the material to test the market

If a territorial approach has lacks, reflexivity of design may be an opportunity to make environmental innovations. Indeed, I would say that it is important to integrate environmental issues into design methods. From this point of view, we could consider it as a green process and service. But eco-design methods are based on principles of the quest for eco-efficiency too: "*When designed correctly, green chemistry and engineering can affect multiple stages of the life cycle of a product or process. Successful implementations of green chemistry and engineering research are improving the environmental impacts of chemical products and processes in every stage of the life cycle while also offering economic incentives*" (Lankey, Anastas, 2002). That is why life cycle analysis follows a *cradle to cradle* strategy that seems to be the main interest for sustainability (Patingre, Vigneron, 2001; Braungart, McDonough, 2002). Paradoxically, this dimension allows long distance between the processes of production, including beyond borders! To be more precise a lifecycle analysis is built on indicators which legitimate not space anymore but rather the supply chain itself. That means that no peculiarities of land and resilience capacities of the population are analysed: only potential 'generic' consumers are accounted for in the interests of eco-efficiency. This point of view can be legitimated by supply chain eco-systems that legitimate the institutionalisation of smart logistic organisations. What does it mean in substance? Since recycling raw materials or renewable materials could be better than fossil assets, we could develop various strategies that can accelerate flows and transformation of matter all over the world. We should take into account entropy and rebound effects due to economic purposes of ecodesign methods (Tan *et al.*, 2002). Yet what kind of energy should we use to allow this scenario regarding population needs? Certainly not biofuel from biorefineries.

Despite these failings, there is a market for ecodesign methods proposed by the biggest petrochemical firms – such as BASF that proposes to sell ecodesign methods for its own sector. They are directly inspired by ISO 14040 standards (Saling *et al.*, 2002, p. 3). However, even if chemical products are selected with improvement of eco-efficiency in mind and are characterized by substitution of raw materials, we argue that standards are the main objective for new competitive advantages. It means that, if environmental innovations are made with eco-design standards, then the market is essential to spread them, because there is a market for eco-design standards. That is why we will argue that this kind of environmental innovation applied to eco-design methods cannot point to a balance between the technosphere and the biosphere.

Figure 3 – Eco-efficiency, eco-design methods by BASF (BASF, 2010)

CONCLUSION

We analysed the principles and limitations of environmental innovations which are considered as indispensable for a sustainable socio-technical regime. For this, we criticized the dominant design in comparing generic and environmental innovations in order to find out if the latter is better for the environment. Our analytical framework compared these innovations with others in order to identify their specificities from a microeconomic, dynamic and macroeconomic point of view. Finally, we applied our conclusions in the analysis of the sector of green chemistry which thus becomes a leading player in terms of sustainability.

Our study produced four results. First, there are no fundamental distinctions between environmental and generic innovations, because they are based both on the same principles. On the one hand, this is due to the role of the market that contributes to the acceleration of trade while depending on population needs. On the other hand, resolving environmental issues is based on the quest for eco-efficiency which is limited by monetary valuations. Our second result shows that environmental innovations are made to improve acceleration of flows but they face rebound effects. Third, the principle of green chemistry and their applications favour energy transformation acceleration too. Finally, the philosophy of environmental innovation cannot provide sufficient resources to propose a “revolutionary solution” and can have a worse environmental effect than generic innovation. That is why we would call for the re-conceptualization of environmental innovations.

Finally, this work calls for deeper studies on technological aspirations and an innovative project for green chemistry. We argue that institutions, space and collective actions have a major role in the coordination of actions. That is why we invite further work to be informed by the Promethean technologies proposed by Nicholas Georgescu Roegen (1979). Since “matter matters too”, this author shows three particular Promethean technologies that we need to apply to green chemistry in order to achieve a sustainable socio-technical regime.

Table 2 – Comparison between generic innovations and environmental innovations – part 1

			Generic innovations	**Environmental innovation**
Socio-technical regime			**Dominant design**	**Emergent design**
Static point of view				
	Microeconomic scale			
	Definition of innovation	*Field*	Market	
			New goods	
			New production methods	
			New work organizations	
			New outlets	
			New raw materials	
		Characteristics	Any types of technology that exist thanks to markets	Oriented approaches by using "end of pipe" and "clean technologies"
	Definition of environment	*Definition of "environment"*	Technocentric approach (Theys, 1993)	
		Value	Marginal utility	
		Logic	Eco-system and circular economy	
		Means	Resolving economic issues thanks to the quest for efficiency	Resolving economic and environmental issues thanks to the quest for efficiency/eco-efficiency
	Macroeconomic scale			
		Rebounds effects	Six rebound effects	

Table 3 – Comparison between generic innovations and environmental innovations - part 2

Generic innovations				**Environmental innovations**
Dynamic	**Socio-technical regime**		**Dominant design**	**Emergent design**
	Degrees of change for innovations			
		Incremental	Yes	
		Radical	Yes	
		Systemic	Yes	
	Users	Population growth		
	Technological trajectory			
		Demand pull	Yes	
		Technology push	Yes	
		Science push	Yes	
		Regulatory pull	Yes	The quest for eco-efficiency
	Speediness	+		++
	Time	Short-term		

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