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What are the origins of eco-innovations? Results from a case based reasoning approach on 300 eco-innovations

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Résumé – Les conséquences environnementales de la consommation de masse obligent à éco-innover, ce qui signifie repenser complètement notre façon de concevoir, fabriquer et consommer en proposant sur le marché des produits et services à forte ambition environnementale. Afin d'aider les entreprises dans les premières phases de conception de l'éco-innovation, cet article explore les origines de l'éco-innovation avec une approche de raisonnement par cas basée sur 300 cas. Grâce à une expérimentation mobilisant 8 experts en écoconception, 5 problèmes de départ et 12 principes d'éco-innovation pour résoudre ces problèmes de départ sont identifiés. Les résultats montrent la contribution des méthodes de conception pour éco-innover dans une vue d'ensemble des origines de l'éco-innovation, en particulier celle d'un ensemble de 7 méso-mécanismes de stimulation de l'éco-idéation, dénommés ESM.

Abstract – The environmental consequences of mass consumption require to eco-innovate, which means completely rethinking our way of designing, manufacturing and consuming by proposing on the market products and services with a high environmental ambition. In order to help companies in early design phases of eco-innovation, this article investigates the origins of eco-innovation with a case based reasoning approach based on 300 cases. Thanks to an experiment mobilizing 8 ecodesign experts, 5 Starting Problems and 12 Eco-innovation principles to solve these starting problems are identified. Results show the contribution of design methods to eco-innovate compared to the eco-innovation origins identified, in particular the potential input of a set of 7 Eco-ideation Stimulation Meso-mechanisms, named ESM.

Mots clés - éco-innovation, raisonnement par cas, phases amont de conception.

Keywords – eco-innovation, case based reasoning, early design phases.

1 INTRODUCTION- CONTEXT

Our society is increasingly concerned with the environmental consequences of mass consumption. Resource use has more than tripled since 1970, and continues to grow. Models based on a propensity to consume and throw away are having devastating effects on our planet. It is established that 90 percent of biodiversity loss and water stress is due to resource extraction and processing. These same activities contribute to nearly half of the world's greenhouse gas emissions. [United Nations, 2019] Further than eco-designing approach, an answer to remedy to this problem is to eco-innovate, which means completely rethinking our way of designing, manufacturing and consuming by proposing on the market products and services with a high environmental ambition.

Despite the increasing interest in eco-innovation noticed in institutions and academia in the past few years [Díaz-García et al., 2015; Hojnik & Ruzzier, 2016], its dissemination in companies remains limited. A recent survey in a small panel of French companies underlined that eco-innovation is still ambiguous for industrial practitioners, and therefore they cannot identify examples of eco-innovative products [Cluzel et al., 2014]. In fact, eco-innovation means to design a new

system integrating the sustainable development dimensions (environment, social, technology, stakeholders). This multi-dimensional aspect makes it more complex to characterize and to design.

To remedy to this, the aim of the ALIENNOR research project is to develop eco-ideation mechanisms [Tyl et al., 2016], which are intended to be a synthesis of recent research works in eco-innovation. This project also includes the creation of a database of 300 eco-innovation cases. This base of concrete cases offers the opportunity to question the real origins of eco-innovations with an analysis operating in a bottom-up way, following the approach of case based reasoning. Then it is possible to compare the tools proposed and the reality, in order to validate or put into perspective the axes pushed by eco-innovation methodologies, in particular the ESMs. This is the purpose of this paper.

This article starts with a state of the arts of eco-innovation definitions, strategies and tools, in particular the Eco-innovation Stimulation Meso-mechanisms (ESM), and with the results of a workshop about eco-innovation operable definition (section 2). In section 3, an experiment based on a case based reasoning approach is presented to investigate Starting

problem to eco-innovate, and eco-innovation principles. Results showing origins of eco-innovation are presented in section 4, and are discussed in section 5 particularly in front of the ESMs set proposed.

2 STATE OF THE ARTS

2.1 State of the art on eco-innovation definition

To select 300 cases of eco-innovations, the question of the attributes defining an eco-innovation arises.

Díaz-García et al. summarized 8 different definitions of eco-innovation appearing in key studies between 1996 and 2013 [Díaz-García et al., 2015]. It concerns a new product or service which significantly reduces the environmental impacts all along its life cycle. Since the first definition was given by Fussler and James [Fussler & James, 1996], the concept has drifted from a product/service to a potentially more organizational focus; from a purely environmental to a mixed environmental, social and even institutional contribution [Mathieu et al., 2015]. Mathieu et al. add that eco-innovation creates positive externalities on one or several dimensions of sustainable development [Mathieu et al., 2015].

With O'Hare and Mc Aloone [O'Hare & McAlloone, 2014], the concept of eco-innovation is discussed with regard to three anchoring domains: engineering design; strategy and management; environmental science. The recent contribution of the UNEP guide emphasizes the importance of the business model issue associated with eco-innovation [O'Hare et al., 2014]. In a practical way, Bocken et al. [Bocken et al., 2014] unify bodies of knowledge into eight sustainable business model archetypes. Rennings shows that eco-innovation can be technological, organizational, social or institutional, and developed by a wide range of stakeholders, from companies to NGOs [Rennings, 2000].

Díaz-García et al. [Díaz-García et al., 2015] stress that the focus of eco-innovation is either on the effect (i.e. the contribution to environmental improvement), on the motivation (the goal of sustainable development) or both. For Mathieu et al. [Mathieu et al., 2015], eco-innovation may be intentional or not, as it is the contribution (and not the objective) that has to be relevant to sustainable development. This means that eco-innovation may be appreciated ex post, after launch to market.

These elements describe the evolutions of eco-innovation definition taking into account different dimensions, but don't give really actionable criteria to characterize what an eco-innovative system is.

Concerning the criteria of eco-innovation, in addition to the originality or feasibility of ideas, an environmental criterion is necessarily required. This characterization is often associated with a quantitative evaluation, such as life cycle analysis (LCA) or simplified LCA [Hunt et al., 1998]. Bocken et al. [Bocken et al., 2012] emphasize that most environmental assessment tools are intended for the downstream design phases. So the characterization of eco-innovative ideas becomes more critical, subjective and uncertain [Vallet et al., 2013]. In other words, at the end of the eco-ideation process in the early design phases, there is a difficulty to assess the environmental potential. The system is not well-defined yet and it is not possible to do an LCA analysis due to the lack of information. When it is necessary to characterize an eco-innovative project, there is the same problem: the available information about these eco-innovation cases are often just described with outlines, performance claims, interests and functionalities in use, a new technology, etc.

Specific research on the evaluation of ideas in eco-innovation is rare. From a qualitative experiment based on focus groups and on a case based reasoning approach emerged the double intent of "environmental gain" and "mass effect" to characterize an eco-innovation [Pialot & Millet, 2018]. The authors propose to transform these characterization elements of eco-innovation used a posteriori into two criteria that can be used from the early design phases of design:

Criterion Environmental Potential: To achieve large-scale environmental gain, two pathways seem possible (Table 1). What can be considered:

- "direct" environmental gains generated by a change of conceptual models in the design of the existing system (disruptive elements bringing a gain on one or more phases of the lifecycle without changing the functional set of system)
- "indirect" environmental gains by a transition towards a new system/mode of consumption with softer environmental impact considering a new functional set as reference (democratization of a new system that challenge a more impacting consumption pattern, pooling of objects etc.) or with a change of consumers behaviour (more parsimonious usages, local consumption, increasing of the product lifetime due to a better maintenance etc.). For example, an electric bicycle with protection against rain and accidents provides an alternative to private car use, especially in the city. There is no direct environmental gain due to the added modules integrated but it is obtained a potential strong indirect environmental gain.

Table 1. Environmental Potential Criterion illustrated on the bicycle system

Type of gain	"direct" environmental gains	"indirect" environmental gains
Case		
Bicycle in bio-materials	Use of « green » Materials	NO
Electric bicycle with protection against rain and accidents	NO	Democratization of biking (soft mobility strategy in the city compared to a private car use)
Upgradable bicycle with system to rent it if not used	Rationalization of the materials use over time (due to upgradability)	Change of consumption behaviour with pooling of objects

If there is no environmental gain (neither direct nor indirect) easy to identify, the idea of eco-innovation is stopped. This aspect can be characterized very early.

Then, the "mass effect" underlies in fine a commercial success of the future eco-innovative product and no environmental drift. To achieve this status, it is proposed to check during the early design phases if the new eco-innovative concept satisfies certain requirements grouped under the name "viability of diffusion".

Criterion Viability of diffusion: it is proposed to check if the new eco-innovative concept with all the changes it generates can reach a satisfactory level of viability, in terms of technical feasibility (technical viability), attractiveness of the value proposition -i.e. value for the client / price- (attractiveness viability), stakeholder satisfaction (stakeholders viability), and potential negative rebound effects (environmental viability). The authors consider that if these four viabilities are satisfied, it is then possible to speak of eco-innovation. If not, it can be a project / concept of eco-innovation.

2.2 State of the art on eco-innovation tools

In the literature, creativity in eco-innovation is widely considered as critical. Consequently, some researchers have analysed how to support eco-ideation courses, through the development of the specific eco-ideation tools.

Eco-ideation sessions were first supported by diagrams or radars, such as the LiDS Wheel [Brezet & Van Hemel, 1997] or the Eco-Compass [Fussler & James, 1996]. Cluzel et al. [Cluzel et al., 2016] presents the eco-design strategy wheel from [Brezet and Van Hemel, 1997] to generate eco-innovative ideas. The creative operation roughly consists in performing a brainstorming session on each axis of the diagram or the wheel (Table 2). These tools use macro level mechanisms of eco-ideation, that is to say innovative axes to explore are proposed but without developed methodological guidelines.

Table 2. Presentation of the strategies of the LiDS wheel [Brezet & Van Hemel, 1997]

Lifecycle Design Strategies (LiDS)
LiDS 0: New concept development
LiDS 1: Selection of low-impact materials
LiDS 2: Reduction of materials usages
LiDS 3: Optimisation of production techniques
LiDS 4: Optimisation of distribution system
LiDS 5: Reduction of impact during use
LiDS 6: Optimisation of initial lifetime
LiDS 7: Optimisation of end-of-life system

A wide part of the literature on eco-ideation methods and tools is based on TRIZ methodology. TRIZ is a systematic creative method to solve design contradictions [Altshuller, 1998; Kobayashi, 2006], but also mixed with biological patterns [Bogatyrev & Bogatyreva, 2014]. These tools use micro level mechanisms of eco-ideation because they need precise data to be used.

Tyl proposes to use "meso" mechanisms to support eco-ideation sessions, to efficiently stimulate the design team during the whole eco-innovative process with tools at the same time generic, that require no precise data, but didactic with a methodological guide [Tyl et al., 2016]. Tyl [Tyl et al., 2014] developed the EcoASIT tool, adaptation of the ASIT tool for eco-innovation. In line with recent developments in eco-innovation to consider business model innovation as a way to generate sustainable ideas, the Value Mapping Tool proposes to cover the different values for key stakeholders and to transform them from missing or destroyed values into opportunities [Bocken et al., 2013].

In order to eco-innovate, the exploration field of the designer goes beyond the scope of the product, by integrating in system design the sustainable development dimensions (environment, social, technology, stakeholders). Building on the research work of UNEP approach [O'Hare et al., 2014], the 8 archetypes of sustainable business models [Bocken et al., 2014], the adaptation of the Business Model Canvas [Osterwalder & Pigneur, 2010] for sustainability by Joyce [Joyce et al., 2015], etc., Tyl proposes an original set of Eco-ideation Stimulation Meso-mechanisms, named ESM. This set of ESMs leads to an exploration of systemic dimensions related to the sustainable development, still under-exploited, but very promising (locality, stakeholders, etc.) [Tyl et al., 2016]. After trials and in order to have a homogeneous content, the original 8 ESMs set has been reviewed and restricted to 7 (the concept of rebound effects will be ultimately used in evaluation of ideas). Table 3 describes each of these ESMs.

These ESMs seem to deliver ideas that are sufficiently well defined and cover the sustainable development dimensions as they appear in the literature.

In order to validate the completeness of the ESMs set or to position it on a wider field, it is necessary to explore the

different possible origins of eco-innovations in another way. The approach proposed by this article is to analyse 300 cases of eco-innovation.

Table 3. Presentation of the set of 7 ESMs [Tyl et al., 2016]

ESM	Justification
ESM1: Innovate through value creation considering all stakeholders	This ESM explores the value creation for all stakeholders (customers, business, environment and society).
ESM2: Innovate through biomimicry	This ESM explores natural strategies of development at several system levels (organ, organism, ecosystem).
ESM3: Innovate through end-user and sustainable uses	This ESM explores the issues of frugality, eco-usage and energy efficiency.
ESM4: Innovate through services and functional economy	This ESM explores the possibility to add services in the offer to avoid the ownership transfer.
ESM5: Innovate through local and collaborative networks	This ESM explores the possibilities of territorial and local resources, and collaborative networks (crowdfunding, fab-lab concept, etc.).
ESM6: Innovate through lifetime lengthening and closed loop thinking	This ESM explores the different possibilities to optimize use of materials remanufacturing, upgradability, or recycling.
ESM7: Innovate through new trends "materials-technologies-models-process"	This ESM explores the new technical advances (new material, new process, new technological model, etc.).

3 RESEARCH METHODOLOGY

Faced with this issue, an experiment was conceived, based on a panel of concrete cases of eco-innovation, operating in a bottom-up way, following the approach of case based reasoning. Starting from eco-innovative examples and "best practices" is relevant to better understand eco-innovation. Some academic works have already been proposed accordingly [Bocken et al., 2014; Hellström, 2013 ; Carrillo-Hermosilla et al., 2010].

This experiment was built on 300 eco-innovative cases. Any eco-innovation project / concept are eligible. In other words, only the Criterion Environmental Potential is required to select a case because it is not question in this paper to assess the viability or the dissemination of a eco-innovative project for the future but to identify in a broad way the possible origins (stimuli, problems, motivations, technological discoveries, etc.) to eco-innovate. A second criteria mobilized is the originality. In third criteria, the cases retained must cover different human needs (food, transport, energy, etc.) and different industrial / economic sectors (ICT, transport, household appliances, web-platform, etc.). The cases originated in particular from the French database Efficycle scanning online social and environmental oriented- projects (see Table 4).

Table 4. Presentation of 5 eco-innovation cases

Case study	Short description
Glowee Lighting	Bioluminescent system without electricity consumption, thanks to natural properties of bioluminescent cells.
Obiflam log	Heat logs manufactured from sawdust (80%) and coffee grounds (20%).
Fairphone	Smartphone integrating ethical, social and environmental criteria (no conflict minerals, fair supply chain, modular and repairable)
Bike sharing	Large-scale public bicycle sharing system in Paris
Eco-cup	Sharing system of reusable and customizable cups for festivals and others events

The experiment take the form of the analysis of the 300 eco-innovations retained, dealing with the potential origins of case in imagining the starting problem to resolve to eco-innovate and the potential eco-innovation principles mobilized to solve the starting problem. The selection of the 300 cases is not intended to accurately reflect reality. Rather, the goal is to have a broad spectrum of potential type of eco-innovation. The experimental approach was conducted with 8 eco-design experts split in three groups of 2-3 participants corresponding to the 3 partners of ALIENNOR project.

The experiment was structured in three parts:

- During Part 1, the analysis concerns only 50 cases and aims at identifying the list of “starting problem” and the list of “eco-innovation principles mobilized to solve the starting problem”. To do this, participants analysed individually and with their expertise the different cases and modelled the categories of starting problem and eco-innovation principles. Then, a collective discussion began with the pooling of individual results and was conducted in order to develop a common view within each group and between each group. The lack of information does not always make it easy to say what the original problem is or the real principles that have been mobilized. In some cases, there are several potential eco-innovation origins. The lists of “starting problem” and “eco-innovation principles mobilized to solve the starting problem” are considered valid if each item can be associated at least to one case and if each eco-innovation project / concept can be associated at least one origin.
- During Part 2, participants associated “starting problem” and “eco-innovation principles mobilized to solve the starting problem” with the 250 remaining cases of eco-innovation project / concept
- During Part 3, participants compared the lists of “starting problem” and “eco-innovation principles” with the set of ESMs to determine if these tools are sufficient to eco-innovate on each identified dimension or if they need to be completed.

4 EXPERIMENT AND RESULTS

4.1 List of “Starting problem” (SP)

From the analysis of Part 1 focused on 50 cases of eco-innovation emerge 5 different “starting problem” (SP). These problems invite to imagine a new system or to improve the existing system. They are the followings:

- The first SP is the observation of waste out of the scope of the system that is designed.
- The second SP is a lack in a group of systems at macro level
- The third SP is a lack of green intention of the existing system
- The fourth SP is a functional mismatch of the system in considering a frugal need or an augmented need (Figure 1).
- The fifth SP is a new principle of invention, that means a new intention concerning the existing system, a new invention at micro level or a new need or new problem that requires a new system (Figure 1).

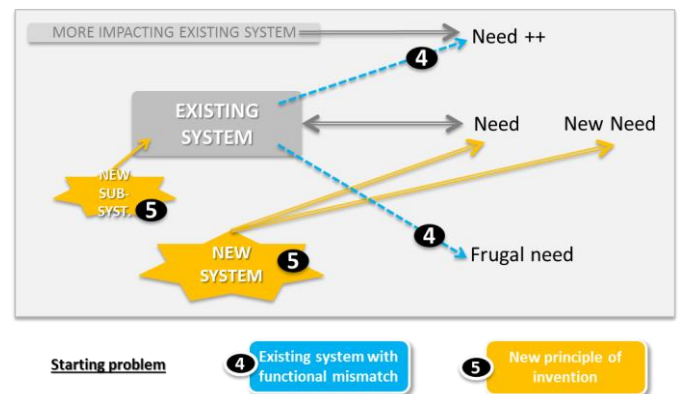


Figure 1. Presentation of Starting problem to eco-innovate

Starting problem	Eco-innovative principles	Links with ESM (Tyl et al. 2016)	Links with LiDS (Brezet & Van Hemel, 1997)
1 Observed waste 36	1a Transform waste into raw material or as resources 23	ESM 1	✗
	1b Avoid waste (design of new system, better collection ...) 13	ESM 1	✗
2 Lack at the Macro-system level 107	2a New system to generate a Macro-system that is of “sharing and pooling economy” type 38	ESM 1	LiDS 0
	2b New system to improve environmental performance at the Macro-system level 36	ESM 3	✗
	2c New system to generate a Macro-system that is of “new consumption behaviour” type 33	ESM 4	LiDS 0
3 Existing system with a lack of green intention 56	3a System with green intention: Environmental quality of production and distribution modes 19	ESM 5	LiDS 3, 4
	3b Efficient Design and Use 32	ESM 2, 3, 7	LiDS 1, 2, 5
	3c Extended LifeTime & closed loop at the end-of-life 5	ESM 6	LiDS 6, 7
4 Existing system with functional mismatch 23	4a System considering a change of target: Added features to compete with a more impacting system 4	✗	LiDS 0
	4b Frugality for democratization of Good systems & products 19	ESM 3	LiDS 0
5 New principle of invention 78	5a New Techno Brick / New concept of System: New discovery / techno development for new raw material or new technical module 34	ESM 2	✗
	5b New concept of system meeting a new intention (willingness to have much better performance, to solve a new problem, to change environmental consciousness of consumer ...) 44	ESM 2, 7	LiDS 0

Figure 2. Full results on the origins of eco-innovations.

4.1 List of “eco-innovation principles mobilized to solve the starting problem” (EP)

In front of these “starting problem”, participants identify “Eco-innovative principles” (EP). For each SP correspond(s) one or several EP. The results are presented in Figure 2 (Figure 2).

All eco-innovation cases are related to at least one starting problem and one eco-innovative principle. The quantitative results in terms of number of cases concerned by each item (SP, EP) are presented in (Figure 2) next to the item title. The eco-innovation cases related to a lack at the macro-system level are the most numerous (107). At the other side, those related to the starting problem “existing system with functional mismatch” represent a part of 8%.

4.2 Comparison between the lists of “starting problem” and “eco-innovation principles” and the set of ESMs

At the right of Figure 2 are presented the links with the ESMs proposed by Tyl et al. 2016] and with the Lifecycle Design Strategies (LiDS) of Brezet [Brezet & Van Hemel, 1997]. The link is strong when the meso-mechanism or the Lifecycle Design strategy covers the considered eco-innovation principle. This strong link is evidenced by a dark grey background. The link is partial, that is to say not complete, or “possible / rare” when the ESM or LiDS can contribute to the emergence of the type eco-innovation considered but when there is also more or less others paths to do this. These weak links are evidenced by a light grey background.

From the set of ESMs emerge for the most part eco-innovations related to the SP 2 and 3. Each of 7 ESMs except one is concerned in the form of strong link. The eco-innovations corresponding to the SP 2 and 3 represent more than 50% of cases. But for the others eco-innovations, the contribution of the set of ESMs is possible or rare because these tools are one potential path but not the most natural.

With regard to the Lifecycle Design Strategies (LiDS), the 7 LiDS are focused on the SP 2. Only the LiDS 0 related to “new concept development” deals with the others types of eco-innovation (SP 1, 2, 4, 5), with a limited contribution, except for “shared use of the product” that brings naturally Eco-innovative principle 2a. More generally, the LiDS wheel is a “macro” type tool that is to say eco-innovation axes to explore are given but without real methodological guidelines. So the contribution of ESMs to eco-innovate is stronger than that of LiDS approach.

More broadly, starting point to use a meso-mechanism or a LiDS is an existing system that it is subsequently “deformed” from different eco-innovative angles proposed. That's why certain eco-innovations are hard to generate for these methods. The watching of a plastic discharge into the sea or the discovery of a new material in the laboratory or the idea to build a vegetable garden floating above a river are examples of new opportunities to imagine new system whose starting point is not “an existing system” to improve. More generally, when the starting problem is out of the scope of an existing system, it is very hard to find tools in the literature to support these opportunities.

In the light of those, the real weakness of the set of ESMs and of LiDS is to not propose eco-innovation axes faced to the SP “existing system with functional mismatch” because the starting point concerns an existing system.

5 CONCLUSION AND DISCUSSION

In conclusion, this article focuses on a practical case-based approach to eco-innovation. 300 cases have been selected to be analysed by eco-design experts. Results reveal 5 Starting Problem (SP) to consider and 12 Eco-innovative Principles (EP) to use in order to eco-innovate. It is also showed that the scope of the Lifecycle Design Strategies are mainly focused on the EP related to the SP 3 and that the set of ESMs deals with the EP related to the SP 2 and 3.

For a design method starting from an existing system and using different eco-innovative angles to “deform” it, this paper identifies a no exploited possibility to eco-innovate: the EP 4a and 4b related to the SP “Existing system with functional mismatch”. This type of eco-innovations seem interesting to us, but there is very little literature on the subject. The term « downsizing » is common in industry, but no paper explains its methodological path. Likewise, Jugaad Innovation [Radjou et al., 2013] theorizes about frugal innovation but it is not very operable from a methodological point of view for a company. In design field, Tchertchian [Tchertchian et al., 2014] proposes the concept of functional negotiation for complex systems. In reality, the heart of the eco-innovations coming from EP 4a and 4b is the definition of the basket of functions, and that means to put into question the marketing practices.

On the basis of current knowledge, this paper therefore consolidates the status of the 7 ESMs to eco-innovate. Multiple tests are in progress to improve the set of ESMs towards an efficient use.

As perspective to complete the set of ESMs to eco-innovate, maybe it could be considered to scan the “problems related to a usage dimension” in addition to deforming the solutions space from an existing system. For example, in addition to using ESMs to eco-innovate from a transport system, others ESMs would lead a design team to eco-innovate in working on the problems of mobility (observation of waste out of the scope of the transport system designed, new need or new problem that requires a new system which does not yet exist, a lack in the management of transport systems that affect the global performance of mobility or the consumers behaviour ...).

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