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Towards operable criteria of eco-innovation and eco-ideation tools for the early design phases

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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 criteria of eco-innovation and tests the understanding of a set of 7 Eco-ideation Stimulation Meso-mechanisms, named ESM. A qualitative experiment based on focus groups and on a case based reasoning approach delivers operable criteria of eco-innovation and redefines at the same time what eco-innovation is. The exhaustive aspect of eco-innovation dimensions to explore covered by the ESM set is confirmed too.

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Keywords: Eco-innovation; eco-ideation; sustainable development; meso-mechanisms

1. Context

Our society is increasingly concerned with the environmental consequences of mass consumption. The world population consumes about 50% more natural resources than 30 years ago [1]. 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 [2,3], the concept remains ill-understood, limiting its dissemination in companies. As an example, 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 [4].

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. Companies have to integrate these different dimensions to their system from the early design phases and with a specific process of idea generation. This phase during which ideas with great potential for reducing environmental impact are generated [5] is also called eco-ideation. At the end of the creativity session, the group comes up with a set of eco-innovative ideas.

In the early design phases, there is a difficulty to select the ideas with the highest environmental potential because the term "idea" means that the system is not well-defined yet. In other terms, it is not possible to do an LCA analysis because of the system information lack. Furthermore, the deliverables of a creativity session can be vague ideas, just concepts. In fact the precision level of ideas generated depends on the eco-ideation tools used. According to Tyl [6], there are tools with micro level mechanisms which lead to specific and technical ideas, but which scope of use is limited to the product space. At the other extreme, generic tools with macro level mechanism propose to carry out a review of different

creativity axes, but do not operationally guide the designer towards concrete solutions.

These questions on how to evaluate or characterize the ideas of eco-innovation not yet well-defined to select the most promising ones require actionable criteria of eco-innovation.

The ALIENNOR research project should lead to an open eco-innovation platform embedding eco-ideation mechanisms and a database of 300 eco-innovation cases [7]. The selection of eco-innovation cases also requires a clear and operable eco-innovation definition. The available information about these eco-innovation cases are often described with outlines, performance claims, interests and functionalities in use, a new technology, etc. Very rarely, the data for an LCA analysis are available. So, the problem of selection of eco-innovation cases meets the problem of evaluation / characterization of the most promising eco-innovative ideas at the end of the eco-ideation process.

This article aims at investigating the criteria of eco-innovation. It starts with a state of the art of eco-innovation definitions, strategies and tools, in particular the Eco-innovation Stimulation Meso-mechanisms (ESM), and with the results of a fast workshop about eco-innovation examples (section 2). In section 3, a qualitative experiment based on focus groups and on a case based reasoning approach is presented to investigate eco-innovation criteria and to check the understanding of ESM tools. Results showing bottom-up criteria of eco-innovation and the good understanding of ESM are presented in section 4, and are discussed in section 5.

2. Issues

2.1. 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 [8] or the Eco-Compass [9]. The creative operation roughly consists in performing a brainstorming session on each axis of the diagram or the wheel. These tools use macro level mechanisms of eco-ideation.

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 [10,11], but also mixed with biological patterns [12]. These tools use micro level mechanisms of eco-ideation.

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, didactic and precise [6]. A TRIZ-oriented tool to generate sustainable ideas, called EcoASIT, was proposed [6]. 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 [13].

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 [14], the 8 archetypes of sustainable business models [15], the adaptation of the Canvas Business Model [16] for sustainability by Joyce [17], etc., the authors propose an original set of Eco-ideation Stimulation Meso-mechanisms, named ESM. This set of ESM leads to an exploration of systemic dimensions related to the sustainable development, still under-exploited, but very promising (locality, stakeholders, etc.) [7]. After trials and in order to have a homogeneous content, the original 8 ESM set has been reviewed and restricted to 7 (the concept of rebound effects will be ultimately used in evaluation of ideas). Table 1 describes each of these ESM.

Table 1. Presentation of the set of 7 ESM.

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.).

If these ESM deliver ideas that are sufficiently well defined related to the sustainable development dimensions, it is now necessary to specify the eco-innovation criteria to characterize / evaluate these ideas.

2.2. State of the art on eco-innovation definition

Diaz-Garcia et al. summarized 8 different definitions of eco-innovation appearing in key studies between 1996 and 2013 [2]. 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 [9], 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 [18]. Mathieu et al. add that eco-innovation creates positive externalities on one or several dimensions of sustainable development [18].

With O'Hare and Mc Aloone [19], 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 [14]. In a practical way, Bocken et al. [15] 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 [20].

Diaz-Garcia et al. [2] 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. [18], 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, but it is necessary to identify more actionable criteria than the sustainable development dimensions to characterize what an eco-innovative system is.

Concerning the criteria of eco-innovation, specific research on the evaluation of ideas in eco-innovation is rare. In addition to the originality or feasibility of ideas, the eco-innovation process also requires the integration of an environmental criterion, and consequently the evaluation phase becomes more critical, subjective and uncertain [21]. This step is often associated with a quantitative evaluation, such as life cycle analysis (LCA) or simplified LCA [22]. Bocken et al. [23] emphasize that most environmental assessment tools are intended for the downstream design phases.

Few tools for environmental assessment focus on the early phases of the eco-innovation process. The Eco-Compass tool [9] and the LiDS wheel [8] are based on an evaluation diagram to compare different eco-innovative ideas, but even these tools are more appropriate for evaluating detailed concepts than for evaluating large numbers of ideas, characteristics of the early design phases.

As a conclusion, these various works and projects provide limited practical insights to characterize eco-innovation cases or to foster the development of eco-innovative projects. It seems difficult to conclude on a truly actionable definition to validate or invalidate a potential eco-innovative case or idea.

2.3. Results from a fast workshop on eco-innovation

To better identify eco-innovation criteria, a fast workshop (lasting 5-10 minutes) was organized with 28 environmental experts attending the seminar of the French national network of eco-design researchers (EcoSD). The goal was that participants verbalize the most famous eco-innovations in order to extract criteria of them a posteriori. They were invited to give a fast written answer to two related questions: (1) Your Top 3 eco-innovations: give three propositions of an eco-innovation; (2) In front of various pre-defined eco-innovation strategies (those of the 7 ESM), associate,

whenever possible, one or more example of an eco-innovation.

The results and lessons learned are as follows:

- All the participants, who have some knowledge of eco-design, do not seem to define eco-innovation in the same way. The examples given are disparate, there is very little redundancy (2 to 3 at most compared to a total of 65 propositions generated) and, more generally, it is difficult to identify 3-4 outstanding examples, identifiers, serving as "totems" to illustrate what is an eco-innovation. Some people verbalize global strategies to reduce environmental impacts or generate extra value (for instance remanufacturing, eco-technologies or frugal innovation).

- The second part of this fast workshop dealt with the association of ESM with examples. In general, a difficulty to associate one or more examples for each of the mechanisms was noted. Moreover, although the type of eco-innovation expected is oriented by the eco-innovation strategies (those of the 7 ESM), a disparity of the examples was also observed. This could indicate that the wording of ESM is not clearly understandable.

This fast workshop with eco-design experts highlights difficulties in defining eco-innovation, giving precise and shared examples and associating examples illustrating each proposed eco-innovation strategy.

It is necessary to explore the different possible criteria of eco-innovation in another way in order to extract a formalization of eco-innovation that can be used by eco-design experts. There is a need for checking if there is no misunderstanding in the wording of the ESM and the strategies of eco-innovation that they propose.

3. Research methodology

Faced with this double 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 [15,24,25].

This experiment was built on 16 eco-innovative cases. The cases originated from the pre-test (like community-supported agriculture, neighbour social network, Fairphone smartphone, fleet solution, bike sharing, Oslantis platform or Obiflam log), as well as from the French database Efficycle scanning online social and environmental oriented- projects (see Table 2). The rationale was to emphasize the inputs from the community of researchers, and also to broaden the scope of cases (across sectors notably) thanks to the database. The final selection was designed to mix well-known cases (for example the bicycle sharing system) and less known cases (for example the Nautilus water-boiler or the community energy system). This selection of eco-innovation covers the different pre-defined eco-innovation strategies (those of the 7 ESM) and encompasses different human needs (food, transport, energy, etc.) and different industrial / economic sectors (ICT, transport, household appliances, web-platform, etc.).

The experiment took the form of a focus group with the integration of individual sessions to classify or associate items, and generate ideas. The strength of the focus group, through the discussion that is put in place, is to capture questions and deepen ideas / comments / remarks by confronting arguments during exchanges between participants. The limit is that each focus group holds a truth, but it is not possible to generalize it. It was therefore decided to double the groups for a same set of cases. The individual sessions collected the specific opinion of each participant before the discussion.

Table 2. Presentation of the 16 eco-innovation cases.

Case study	Short description
Glowee Lighting	Bioluminescent system without electricity consumption, thanks to natural properties of bioluminescent cells.
Neighbour social network	Social network to share product and services between inhabitants from the same city or district
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
Community energy	Citizen society developing renewable energy projects in the bask territory thanks to citizen funding
Cloud heating system	Water heating system thanks to the energy released by computer and processors systems
Lignine adhesive	Natural adhesive as a substitute of some components used in the manufacture of wood panels.
Wood community	Network of consumers and forest actors to provide wood with a sustainable forest management.
Uber green service	Mobile application for linking users-passengers to drivers with electric or hybrid vehicles
BtoB computer Alt®	Desktop computer focused on the essential needs of users, using recyclable materials, manufactured in France, without packaging, and with a long lifespan.
Fleet solution	Deployment of services around the tyre, for efficiency of professional fleets
Oslantis platform	Crowdfunding and crowd-designing platform to develop in an open source way, used to promote projects with a sustainable dimension
Obiflam log	Heat logs manufactured from sawdust (80%) and coffee grounds (20%).
DIY Furniture	Urban micro-plant inspired from the Fab-lab concept, with a collaborative workspace to share knowledge, and a point of sale for objects and services
Water boiler Nautilus	Bio-inspired water boiler designed to reduce the water and energy consumption.

The experimental approach was conducted in the same community of EcoSD network, with 30 eco-design experts (automotive and sport industry, ICT, consulting, etc.). Half of the participants also took part in the fast workshop.

The experiment was organized with four groups of 7-8 participants, two series of cases, two groups for each series. The cases were split into two series of eight cases (from A to H for groups 3 and 4; from 1 to 8 for groups 1 and 2). People were divided into four teams, expected to be homogeneous (regarding the balance of experience in eco-design, and the affiliations). Each team was facilitated by one researcher who managed the experiment progress.

The two-hour experiment was structured in two parts:

- During Part 1, participants analysed individually the different cases and selected what they considered as the 'best' or 'top', and 'worst' or 'flop' eco-innovations. From this ranking, they also had to formalize three criteria of eco-

innovation. Then, a collective discussion began with the pooling of individual results and was conducted in order to develop a common view of eco-innovation criteria.

- During Part 2, participants associated individually the different cases to one or two eco-innovation strategies corresponding to the ESM wording. Then, a collective discussion began with the pooling of individual results in order to verbalize the shortcomings and enrichments to bring to the set of ESM.

For Part 1, the purpose of classification was twofold: to facilitate the immersion of each participant in the exercise and to verify that the opinions were not too disparate among participants (which would cast doubt on the results about common eco-innovation criteria).

For Part 2, the focus group was an opportunity to challenge the set of ESM: the wording and notions of ESM were understandable if there was a convergence of the association results between ESM and eco-innovation cases by comparing 2 groups of the same series of cases; the set of ESM was not complete if a new axis of eco-innovation was verbalized.

4. Experiment and results

4.1. Results concerning eco-innovation criteria

This section sheds light on how participants appreciated the proposed cases as tops or flops in each group (Table 3). Half of the cases are considered as very similar (in the same trends and same proportions; presented in dark grey), whatever the group. Three cases are discussed (not significant trend; presented in light grey), whatever the group. These cases show the coherence of participants.

Table 3. Top-flop characterization of eco-innovation cases by the participants.

Case index	Group 1		Group 2		Case index	Group 3		Group 4	
	Top	Flop	Top	Flop		Top	Flop	Top	Flop
1	3	4	5	2	A	6	2	6	2
2	1	5	2	6	B	6	1	4	2
3	6	1	5	1	C	5	2	5	2
4	4	1	4	2	D	2	4	3	4
5	1	4	1	4	E	2	6	3	2
6	1	3	3	3	F	1	4	1	4
7	5	2	4	4	G	4	4	1	5
8	1	6	6	0	H	3	3	0	4

Concerning the characterization elements of eco-innovation verbalized individually, the need to reduce the environmental impacts or induce an environmental gain across life cycle was emphasized by most participants. The combination of environmental, economic and social expectations in eco-innovations was claimed by 6 people.

The distinctive results concern the nature of the disruption and the notion of desired mass effect: it was recorded that eco-innovation should result in a radical change of life and foster a change in behaviour and a sustainable consumption from an end-user point of view. From a company's point of view, a new relation between producer and consumer is expected in eco-innovation, a close link must be built. Two participants associated this close link to local production and distribution of systems. Eco-innovation is disruptive in the business model, but eco-innovation needs a new plausible business model; an economic viability; a commercial success.

What is highlighted here is the willingness to create a mass effect in order to give a whole meaning of eco-innovation. So, four participants suggested that eco-innovation should be relevant to as many people as possible.

Lastly, classic markers of innovation were verbalized as a change in technology, organization, user-experience or the added value to the customer.

The second step consisted in a group characterization, each group being prompted to collectively emphasize three to five main features of eco-innovation cases (Table 4).

Table 4. Eco-innovation criteria verbalized by the groups.

Group index	Criteria expressed by the groups
Gp. 1	. Newness character (in comparison with a "reference" system)
	. Environmental and commercial success on a large scale
	. Avoidance of the 'anti-criteria' (Green washing, Fake, rebound effect, when an green intention doesn't result in environmental gain or with a delirious price ...)
	. 'Eco-innovation methodological label' which certifies a design process encompassing different dimensions of eco-innovation
Gp. 2	. Systemic vision (global system)
	. Modification of the user experience and usages
Gp. 3	. Reduction of environmental and social impact
	. Result of a work on each step of the value chain
	. Potential of environmental impact reduction on a large scale and gains on the 3 dimensions of sustainable development
	. Scalability of products/systems and Transferability to other usage situations
Gp. 4	. Temporality of market launch
	. In harmony with users' needs and usages
	. Reduction of environmental and social impact on a large scale
Gp. 4	. Reinforcement of the value added to client and functional performance
	. Disruptive character (environmental, technological, organizational, business model...)
	. Wide acceptance by people

These groups works confirmed the double intent of environmental gain and mass effect. In fact, participants considered as relevant the dissemination of the eco-innovation in a wide range of citizens, in order to reach critical mass and have a significant environmental impact reduction. This is in line with recent works on systemic approach of sustainable design [26]. Results also show the multifaceted aspect of the changes in eco-innovation (system, technology, usages, organization, business ...).

4.2. Results concerning the validation of the set of ESM

The second part of the experiment concerns the link between ESM and eco-innovation cases proposed. The results presented in Table 5 show coherence between the two groups for each set of cases. Except 3-4 defects, large percentages are found in the two groups of each series of cases. In some cases, the percentages are lower because they are more distributed. This corresponds to the case which seems to be the result of works on various aspects related to ESM. In this configuration, it seems more difficult to designate which work axis had been determined. It can be concluded that ESM in their formulation and content are understandable.

The group discussion focused on the need for precision in specific cases, the prospects of methodological elements in

order to accompany the ESM but did not reveal new mechanisms seen as unavoidable and missing. This does not prove that the set of ESM is exhaustive (because each focus group delivers its truth and cannot be generalized) but gives a more mature status of this set of mechanisms.

Table 5. Association rate of eco-innovation cases with ESM by participants (expressed as a percentage).

Case index	Group 1							Case index	Group 2						
	ESM								ESM						
	1	2	3	4	5	6	7		1	2	3	4	5	6	7
1	86			57				1	100			25			
2			29	71				2				63			
3				71	57	86		3			63	25	38		
4	29			86				4			25	75			
5	100							5	100			25			
6			29		71	71	29	6					88	88	
7	29			57			71	7	63						50
8				100				8		100	25				
Case index	Group 3							Case index	Group 4						
	ESM								ESM						
	1	2	3	4	5	6	7		1	2	3	4	5	6	7
A		100					60	A		100					
B	100			100				B	43			86	57		
C						40		C	43	57				29	43
D				80				D	57	29	86				
E			40	60		60		E			71	43			29
F	60				80			F	57			29	57		
G			40			40		G			43	43		57	
H						80	80	H						29	86

5. Conclusion and discussion

In conclusion, this article focuses on a practical case-based approach to eco-innovation. 16 cases have been selected to be analysed by four teams. Results consolidate the status of the 7 ESM set (no major misunderstandings in wording and notions; no missing mechanisms observed) and give some new insights about eco-innovation criteria (double intent of environmental gain and mass effect, multifaceted aspect of the changes in eco-innovation).

In order to define what a case of eco-innovation is, it is necessary to specify how to handle from the early design phases the eco-innovation characterization elements identified. The elements "mass effect" and "environmental gain" induced by the disruption can only be observed and characterized a posteriori. How to identify from the early design phases the potential for large-scale environmental gain? What elements should be monitored from the early design phases to ensure that the multi-form changes often observed around an eco-innovation do not affect the desired mass effect?

In other words, the question is to transform the characterization elements of eco-innovation used a posteriori into criteria that can be used from the early design phases of design. Two criteria are proposed in this discussion:

Criterion Environmental Potential: To achieve large-scale environmental gain, two pathways seem possible (Table 6). 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 or via the dematerialization of the offer)

- "indirect" environmental gains by a transition towards a new system with softer environmental impact (democratization of more parsimonious usages, more virtuous mode of consumption that brings about behavioural changes such as local consumption, upgradable systems or the pooling of objects).

Table 6. Environmental Potential Criterion illustrated on the bicycle system.

Case	Type of gain	"direct" environmental gains	"indirect" environmental gains
	Bicycle in bio-materials	Use of « green » Materials	NO
Bike with protection against rain and accidents		NO	Democratization of biking (soft mobility strategy in the city)
Upgradable bike with system to rent it if not used	Rationalization of the materials use over time		Change of consciousness with upgradability and 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.

Criterion Viability of diffusion: Concerning the effectiveness of the mass effect, 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 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 if the Environmental potential criterion is validated (Table 7).

Table 7. Environmental Potential Criterion illustrated on the bicycle system.

Criterion	Environmental Potential	Viability of diffusion
Type of case		
Eco-innovation	YES	YES
Project / concept of eco-innovation	YES	NO
Not eco-innovative concept/project	NO	YES or NO

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