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Diversity of eco-innovations: Reflections from selected case studies☆

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ABSTRACT

An analytical framework is developed in this paper in order to explore the diversity of eco-innovations according to several key dimensions (design, user, product service and governance). The framework is used to analyse a set of case studies of eco-innnovation processes. The diversity of the analysed eco-innovations appears to be considerable: each of them involves different kinds of combinations of elements pertaining to those dimensions. Albeit the design dimension is decisive to determine the environmental impacts of the innovation, all dimensions can play a significant role in the management of eco-innovation. Our findings suggest that the capacity of eco-innovations to provide new business opportunities and contribute to the transformation towards a sustainable society depends on the interplay of those dimensions and the engagement of key stakeholders in the innovation process.

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1. Introduction

In recent years, the term 'eco-innovation' has been increasingly used in environmental management and policy, although in diverse contexts and with different underlying connotations that may eventually reduce its practical value. The definitions of eco-innovation seem to be quite general and, thus, many kinds of innovation can be defined as eco-innovations. This raises the important issue of further classifying eco-innovations in order to better understand their specific characteristics.

Eco-innovations can be a relevant tool for wiring up the innovation system. They may contribute to the renovation of the whole innovation system, taking into account social, ecological and economic aspects. The long-term survival of the economic system depends on its ability to create and maintain sustainable economic processes, which do not involve short-term value creation at the expense of long-term wealth. This paper sheds light on the concept of eco-innovation. By identifying the different dimensions of eco-innovations, showing their diversity and addressing both their process and outcome-oriented impacts, we hope to show the wealth of ways in which eco-innovation processes can trigger economic and environmental improvements in their different dimensions.

Accordingly, the paper is organised as follows. The next section describes our approach to eco-innovation and develops a typology to classify and characterise eco-innovations along several dimensions in order to clarify their different types and their corresponding roles in the transition towards sustainable development. Section 3 discusses the methodology and provides a set of detailed case studies of eco-innovations. The main findings and implications of these case studies with respect to the dimensions of eco-innovation are discussed in section 4. The paper closes with some concluding remarks.

2. Understanding eco-innovation and its dimensions

Defining eco-innovation is not an easy task although several attempts have been made in the literature (see Box 1). In general, these definitions emphasize that eco-innovations reduce the environmental impact caused by consumption and production activities, whether the main motivation for their development or deployment is environmental or not.

Focusing on the actual environmental impact of eco-innovations rather than on their environmental protection intentionality has its pros and its cons. A clear drawback is deciding which innovations in practice actually reduce the environmental impact of products and production (VINNOVA, 2001). But there are also problems with

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Box 1. **Definitions of eco-innovation and sustainable innovation.**

- "Eco-innovation is any form of innovation aiming at significant and demonstrable progress towards the goal of sustainable development, through reducing impacts on the environment or achieving a more efficient and responsible use of natural resources, including energy" (European Commission, 2007).
- Environmental innovation is innovation that serves to prevent or reduce anthropogenic burdens on the environment, clean up damage already caused or diagnose and monitor environmental problems" (VINNOVA, 2001)
- "Eco-innovation is the creation of novel and competitively priced goods, processes, systems, services, and procedures designed to satisfy human needs and provide a better quality of life for all, with a life-cycle minimal use of natural resources (materials including energy, and surface area) per unit output, and a minimal release of toxic substances" (Europa INNOVA, 2006).
- "Eco-innovation is the process of developing new products, processes or services which provide customer and business value but significantly decrease environmental impact" (Fussler and James, 1996).
- "[Eco-innovation is] Innovation which is able to attract green rents on the market" (Andersen, 2002).
- "Sustainability-driven" innovation is "the creation of new market space, products and services or processes driven by social, environmental or sustainability issues" (Little, 2005).
- "Sustainable innovation as a process where sustainability considerations (environmental, social, financial) are integrated into company systems from idea generation through to research and development (R&D) and commercialisation. This applies to products, services and technologies, as well as new business and organisation models" (Charter and Clark, 2007).
- Environmental innovations are new and modified processes, equipment, products, techniques and management systems that avoid or reduce harmful environmental impacts (Kemp and Arundel, 1998; Rennings and Zwick, 2003).
- "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 and Pearson, 2008).
- "Eco-innovations are innovation processes toward sustainable development" Environmental innovations are "… measures of relevant actors (firms, …, private households), which: (i) develop new ideas, behaviour, products and processes, apply or introduce them, and (ii) contribute to a reduction of environmental burdens or to ecologically specified sustainability targets" (Rennings, 2000).
- In a broad sense, environmental innovations can be defined as innovations that consist of new or modified processes, practices, systems and products which benefit the environment and so contribute to environmental sustainability (Oltra and Saint Jean, 2009).
- Eco-innovations are all measures of relevant actors (firms, politicians, unions, associations, churches, private households) which develop new ideas, behaviour, products and processes, apply or introduce them and which contribute to a reduction of environmental burdens or to ecologically specified sustainability targets (Klemmer et al., 1999).
- Technological environmental innovations (TEIs) may help to reduce the quantities of resources and sinks used, be they measured as specific environmental intensity per unit of output, or as average consumption per capita, or even in absolute volumes. Overriding priority, however, is given to improving the qualities and to changing the structures of the industrial metabolism. Rather than doing less of something, TEIs are designed to do it cleaner and better by implementing new structures rather than trying to increase eco-productivity of a suboptimal structure which has long been in place. TEIs are about using new and different technologies rather than using old technologies differently. TEIs can be characterised as being upstream rather than downstream, i.e., upstream in the manufacturing chain or product chain respectively, as well as upstream in the life cycle of a technology (Huber, 2004).
- Innovation is "the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations" (OECD, 2005). Eco-innovation is generally the same as other types of innovation but with two important distinctions: 1) Eco-innovation represents innovation that results in a reduction of environmental impact, whether such an effect is intended or not; 2) The scope of eco-innovation may go beyond the conventional organisational boundaries of the innovating organisation and involve broader social arrangements that trigger changes in existing socio-cultural norms and institutional structures (OECD, 2009a,b).
- Eco-innovation is "the production, assimilation or exploitation of a novelty in products, production processes, services or in management and business methods, which aims, throughout its lifecycle, to prevent or substantially reduce environmental risk, pollution and other negative impacts of resource use (including energy)" (European Commission, 2008).
- Environmental technologies include all those whose use is less environmentally harmful than relevant alternatives (European Commission, 2004).

Source: Own elaboration.

a definition that focuses on the intention of the innovators. As industry moves on from end-of-pipe solutions to integrated technologies and product innovations, the environmental motivation for the innovation may become entangled with other motivations. It may also be difficult to establish the relationship between the dedicated environmental activities of firms and the environmental performance of industry (op.cit.). In short, it is certainly more difficult to verify an environmental motivation than an environmental result, although the latter may also prove challenging.

Of course, the above does not rule out the fact that there might be technologies designed to reduce the environmental impact of production and consumption activities in addition to technologies that produce environmental gains as a gratis side-effect.[2] As stressed by OECD (OECD, 2009a), eco-innovation may be environmentally motivated, but may also occur as a side-effect of other goals, such as reducing production costs. Following Kemp and Foxon (2007), the first category may be called "environmentally motivated innovations", whereas the second could be called "environmentally beneficial normal innovations". Our definition of eco-innovation encompasses both types of eco-innovations.

In addition to the environmental impact and environmental motivation aspects, some authors consider that a crucial element of eco-innovation is its "novelty" (VINNOVA, 2001; European Commission, 2008). Others observe that the use of the term innovation as novelty departs from the Oslo Manual (OECD, 2005) about innovation which states that innovation does not require in-house investment in creative activities such as R&D, i.e. that firms can innovate by adopting technology developed by other firms or organizations, even when it involves technology that has been around for some time and is not leading edge (Kemp and Foxon, 2007). Similarly to Kemp and Pearson (2008), our notion of eco-innovation is related to an innovation which is novel to the firm, i.e., things done in a different way, whether technologically and organisationally. This definition emphasizes the eco-innovation's institutional context, through the notion of novelty to a specific group. As argued by Morand (2008), this is relevant because innovativeness is highly context-dependent: what is innovative for a certain group at a certain time in a certain place may be totally trivial for another group at another time elsewhere.

Eco-innovation is defined in this paper as an innovation that improves environmental performance (Carrillo-Hermosilla et al., 2009), in line with the idea that the reduction in environmental impacts (whether intentional or not) is the main distinguishing feature of eco-innovation. From the social point of view, it does not matter very much if the initial motivation for the uptake of eco-innovation is purely an environmental one. This approach avoids discussing whether the innovation was initiated/adopted as a result of environmental motivation (see also VINNOVA, 2001; Kemp and Foxon, 2007; Berkhout, 2005).

Basically, innovation refers to the change in the way something is done. Hence, for the purposes of characterising innovation – including eco-innovation –, addressing change is deemed a useful starting point (Carrillo-Hermosilla et al., 2009). For the purposes of this paper, we distinguish between radical and incremental changes which are brought about by eco-innovation:

- Incremental changes refer to gradual and continuous competence-enhancing modifications that preserve existing production systems and sustain the existing networks, creating added value added in the existing system in which innovations are rooted.
- Radical changes, in contrast, are competence-destroying, discontinuous changes that seek the replacement of existing components – or entire systems – and the creation of new networks, creating value added.

Various terms have been proposed to discern levels of "radicalism" of innovations. For example, Freeman and Perez (1988) distinguish between incremental innovations, radical innovations, changes of technology system and changes in technoeconomic paradigm. The later is similar to a technological revolution whereby changes go beyond changes in specific products or processes. This type of pervasive technological change is influenced by and, in turn, influences institutional and social changes. Christensen (1997) distinguishes between sustaining innovations and disrupting innovations. The later are those innovations that render obsolete existing structures and systems. Disruptive products tend to underperform in mainstream markets but have certain features that are highly valued by specific customers. As a product improves, it might then break out of its original, small niche and replace the dominant product, as happened in the case of gas turbines.

This distinction between radical and incremental innovation can also be related to environmental functions.[3] It is increasingly and generally acknowledged that a focus on incremental innovation along established paths does not suffice for achieving demanding environmental sustainability goals such as mitigating climate change. A need for radical technological change or even system innovation has often been expressed (e.g. Tukker and Butter, 2007; Smith et al., 2005; Nill and Kemp, 2009). More systemic changes generally embody higher potential benefits than modification (OECD, 2009a). More integrated sustainable manufacturing initiatives such as closed-loop production can potentially yield higher environmental improvements in the medium to long term, compared to simple modifications in processes and products (such as small, progressive product and process adjustments). For example, Tukker and Butter (2007) distinguish between system optimizations, singular innovations and system-level innovations. The former leads to only a few dozen percentage points of sustainability improvement. Singular innovations that change elements of production-consumption chains may lead to improvements of 50 or 75%, whereas system-level innovations lead to radical reductions of environmental pressure.[4]

Our attempt to conceptualise eco-innovation draws on an evolutionary perspective of innovation (see, e.g., Dosi et al., 1988; Arthur, 1994; Nelson and Winter, 2002; Witt, 2009), according to which innovation arises through a systemic process that refers to the interconnectedness and dynamic interaction between different actors and internal and external factors influencing the innovation process. These premises invite us to explore the wide array of eco-innovations and to examine the occurred changes in several dimensions of eco-innovations, which namely consist of the design, user, product-service and governance aspects (Carrillo-Hermosilla et al., 2009).

2.1. *Design dimensions of eco-innovation*

We consider design as a crucial dimension of proactive planning that addresses both how to improve existing systems and how to create or transform to an entirely new system. From an environmental perspective, two different design rationales to innovations can be distinguished: one considers human actions incompatible with the natural environment and focuses on minimizing those environmental impacts. The other focuses on redesigning human made systems to reduce the environmental impacts of production and consumption activities. When these two perspectives are combined with the incremental/radical nature of technological change and the degree of impacts to the system, three different

[2] An example of an "environmentally motivated" innovation is Carbon Capture and Storage (CCS), which deals with emissions from fossil-fuel based generation by storing them underground. Its addition to coal-based generation plants does neither improve the competitiveness of the adopter nor the efficiency of the process (indeed, it increases its energy consumption, i.e. the so-called "energy penalty"). It is only motivated by the implementation of carbon abatement policies.

[3] See also 2.1.

[4] However, it is beyond the scope of this paper to provide a full discussion of this literature. See (Nill and Kemp, 2009; Van den berg and Kemp, 2008) for further details.

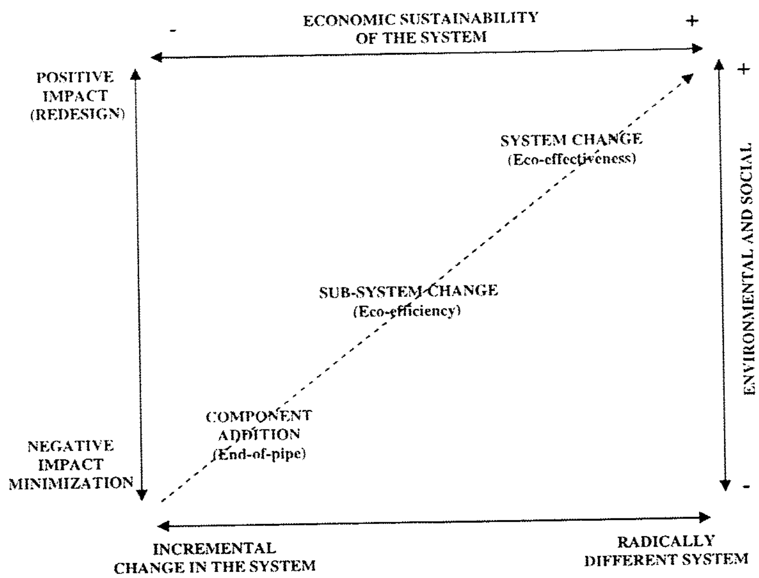


Fig. 1. Typology of eco-innovations according to the radical or incremental nature of produced technological change and the level of impacts to the system (Source: Author's own figure).

approaches can be proposed to identify the role and impacts of eco-innovations (Fig. 1).

Component addition (development of additional components to improve environmental quality, as with "end-of-pipe" technologies): Component level changes minimize and repair negative impacts without necessarily changing the process and system that generate those impacts in the first place. If the innovation is an additional component to the system, extra costs to the process are likely to be incurred. Since the industrial revolution, the implementation of these technologies has led to major improvements in local air quality and water purification. However, if these technologies do not change the main process, they will only solve part of the problem.[5] Notwithstanding, when existing production systems cannot be changed quickly enough, this type of eco-innovation can be a valuable tool for dealing with the problem, "gaining time" to have cleaner but currently incipient technologies to mature.[6]

Sub-system change (e.g. eco-efficient solutions and optimisation of sub-systems): They reduce negative impacts by creating more goods and services while using fewer resources and generating less waste and pollution. This approach comes down specifically to the term "eco-efficiency" (Schmidheiny, 1992), which envisions the production of economically-valuable goods and services while reducing the ecological impacts of production (i.e., producing more with less). The concept of eco-efficiency provides practical, action-oriented guidance on how to combine environmental issues in business. But its goals, however admirable, are often regarded as insufficient in so far as increases in environmental efficiency tend to be erased by subsequent growth (rebound effect).[7]

System change (redesign of systems, e.g. towards eco-effective solutions): Changes in the system and its components and sub-systems are designed with a view to reduce the environmental impacts on the ecosystem and society at large.[8] This approach builds on the analogy between natural and socio-technical systems traditionally proposed by industrial ecologists (e.g. Frosch and Gallopoulos, 1989; Socolow, 1997; Ayres and Ayres, 2002; Lifset, 2005; Cohen-Rosenthal, 2004), who focus on the design of industrial systems in order to incorporate principles exhibited within natural ecosystems and shift from linear (open loop) systems – in which resources move through the system to become waste – to closed loop systems in which wastes become inputs for new processes.

The systemic approach to environmental design leads to two alternative design perspectives: closed and open cycles (McDonough and Braungart, 2002; Braungart et al., 2007). The former refers to the design of the uptake of products back to industrial production processes at the end of their useful life to produce equally or more valuable new products. Open cycles refer to the design of products that are biodegradable and become nutrients to new cycles within the ecosystem. Moving towards eco-effectiveness is likely to provide the highest opportunities to improve sustainability, because new solutions are looked for beyond existing production systems. Eco-effective system level changes go beyond improvements in existing activities and challenges companies and society at large to redefine their production and behavioural patterns (see Section 2.4 on the governance of eco-innovation).

[5] For example, catalytic converters reduce the toxicity of emissions (nitrogen oxides, monoxide, hydrocarbons) from an internal combustion engine, but increase fuel consumption and carbon dioxide emissions. The catalytic converter is an add-on solution adopted instead of a cleaner and more efficient combustion engine which would offer fuel economy benefits as well as lower emissions.

[6] For example, carbon capture and storage is an approach to mitigating global warming by capturing carbon dioxide from large point sources such as fossil fuel power plants and storing it underground instead of releasing it into the atmosphere.

[7] For example, improvements in combustion engine efficiency have led to major improvements in the fuel consumption of vehicles. However, at the same time, the number of vehicles and total fuel consumption have continued to increase, along with their harmful environmental impacts.

[8] Note that, although our definition of eco-innovation encompasses eco-innovations with or without an environmental motivation, the focus on this dimension (design) is mainly on eco-innovations with a dominant environmental orientation.

2.2. User dimensions of eco-innovation

In order to develop eco-innovations, companies should be able to anticipate the acceptance of eco-innovations in the market. They should involve users in their development with the aim to benefit from their creativeness to develop new products and services and to ensure that they will accept and take them up. Indeed, users play a key role not only in applying innovations but also in identifying, making improvements and developing new innovations. Some of these are subsequently adopted by manufacturers and sold as commercial products. So it may be crucial for companies to know which users are capable of contributing to the different phases of the innovation process and how to interact with them. But this user-producer interactions perspective should be complemented with the consideration of the influence of market demand on new product development, as stressed by Pujari (2006).[9]

Accordingly, two user dimensions of eco-innovation are worth considering:

User development: Von Hippel (2005) defines users as firms or individual consumers that expect to benefit from the use of a product or service, in contrast to manufacturers, who are expected to benefit from selling a product or service.

Empirical studies reveal that some users are very active in the innovation process as they adopt the roles of inventors and (co)-developers (Hienerth et al., 2006). This phenomenon has been apparent in different areas such as scientific instruments (Riggs and Von Hippel, 1994), CAD software (Urban and Von Hippel, 1988) and sporting equipment (Luthje et al., 2005). Although those studies have shown that many users engage in developing or modifying products, they also reveal that, when considering the radical nature of user-driven innovations, the new products have a rather low to medium degree of innovativeness. This might be explained by the specific barriers to users in the context of radical innovations. Cognitive limitations may prevent them from delivering valuable inputs. In the idea-generation phase, users can be 'functionally fixed' to their current use context and are therefore unable to develop radically new ideas. It may also be difficult for them to evaluate concepts and prototypes of radical innovations as no reference product exists. In addition, they might not be able to provide valuable inputs due to the high technological complexities involved. Finally, users are not always willing to contribute to radical innovation projects. This lack of motivation might be related to high anticipated switching costs and the fear that the existing knowledge will become obsolete.

In order to systematically involve users in the innovation process, firms need a special competence to identify which users are capable of providing valuable inputs in innovation projects (Rondinelli and London, 2003). The lead user methodology (Urban and Von Hippel, 1988) seeks to identify and involve potential users in the idea generation and development phase. Lead users differ from ordinary users in that they derive significant benefits if they find innovative solutions and, therefore, are highly motivated to engage in the new product development process.

User Acceptance: As mentioned above, user behaviour plays a crucial role in the application of eco-innovations and their resulting impacts on society. In turn, market focus is a key factor influencing the market performance of greener products (Pujari, 2006).[10] A clear understanding of users' needs and wants is crucial for successful new products. Establishing specific target markets for greener products and assessing market needs are important for market success. This calls for marketing professionals to provide input about those needs and wants (including environmental ones) at early stages of product development. Nevertheless, developing a product which excels in environmental terms while remaining economically and technically competitive is a significant challenge (Pujari, 2006, p. 78).

[9] We are indebted to an anonymous referee for these comments.

[10] The other factors are cross-functional coordination between new product development professionals and environmental specialists, supplier involvement and life-cycle analysis.

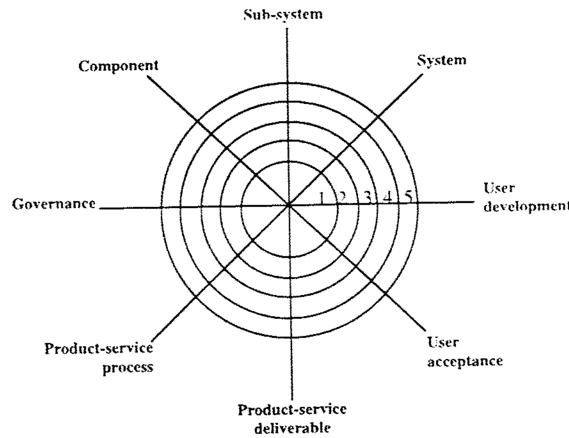


Fig. 2. Eco-Innovation Dashboard for the assessment of the occurred change in eight dimensions of eco-innovation (Source: Authors' own figure).

2.3. Product service dimensions in eco-innovation

The generation of eco-innovations largely depends on the benefits received by the innovator. Successful innovations must provide higher value or reduce costs and, ultimately, either increase revenues from existing customers or attract new customers. On the other hand, the way companies create added value with their products, processes and services can play a crucial role in the innovation process and its environmental impacts (Stahel and Jackson, 1993).

To be radical, product service innovation requires a redefinition of the product service concept and how it is provided to customers (Markides 2006). Mont (2002) and Williams (2007), for instance, propose the application of a "product service system" for developing sustainable business models. This refers to "a system of products, services, supporting networks and infrastructure that is designed to be: competitive, satisfy customer needs and have a lower environmental impact than traditional business models". The approach focuses on the delivery of a "function" to the customer that might, in practice, mean the provision of combinations of products and services that are capable of "jointly fulfilling users needs" (Goedkoop et al., 1999).

The product service dimension of eco-innovation stresses the relevance of a supply chain perspective in eco-innovation. It calls for a shift in the focus from short-sighted local optimisation to the entire supply chain during the production, consumption, customer service and post-disposal of products (Linton et al., 2007). In practice, the relations between different actors creating added value in products, processes and services can be characterised as value networks rather than value chains (Könnölä and Unruh, 2007). The following two product service dimensions are deemed crucial in the context of this paper:

Change in product service deliverable consists of identifiable changes in the product/service delivered and changes in the perception of the customer relation. For instance, Interface Inc.

transformed its business from selling carpets to offering a service package including renting carpets and their maintenance.

Change in product service process consists of changes in the value-networks (value-chain and other relations) and processes which enable the delivery of the product service. An example of an eco-innovation in product service process is certified forest management that commits the whole value chain to implement sustainable practices.

2.4. Governance dimension of eco-innovation

Eco-innovations, particularly when they are radical and require techno-institutional system-level changes,[11] are difficult to achieve because the prevailing system may act as a barrier to the creation and diffusion of a new system.[12] Such prevailing lock-in conditions have been documented in the emergence of numerous technologies, including the automobile, electricity and the personal computer (Unruh, 2000). If the existing system has become socially and economically pervasive, or if there are other justifications for its maintenance, such as national security, governments may encourage its expansion through a variety of mechanisms including subsidies, incentives or outright ownership (e.g. Unruh, 2000; Freeman and Perez, 1988).[13] Overcoming such lock-in conditions, which act as a barrier to eco-innovation, may require major governance innovation both in the private and public sectors.

Innovations in environmental governance refer to all institutional solutions in, both, the private and public sector aimed at resolving conflicts over environmental resources. Institutional solutions refer to changes in norms and values potentially leading to new organisational or structural changes in a company, government or society at large. From the public sector point of view those solutions can deal with one of the functions of environmental governance, including: exclusion of unauthorized users, regulation of authorized resource use and the distribution of the respective benefits (market based instruments), provision and recovery of costs, monitoring, enforcement, conflict resolution, and collective choice (Paavola, 2007). From the perspective of a company, the governance dimension invites managers to explore the wider role of business in society, i.e., to renew their relationships with other stakeholders, particularly with the government. The term "governance" pinpoints the importance of public-private collaboration when addressing eco-innovation.

Radical innovations in governance have emerged, in particular, where industrial federations and overarching organisations have been created bottom-up to coordinate the functioning of governance solutions (Ostrom, 1990; Sengupta, 2004). In contrast, top-down processes generate many formal multi-level governance solutions. Such bottom-up and top-down processes can also come together, as it is the case in the combination of the global regime to mitigate climate change and national and regional mitigation efforts.

We consider that, particularly at the system level, the governance of eco-innovation has a crucial role to play, despite the fact that transitions towards radically different systems are complex societal co-evolutionary processes, typically led by a series of gradual and parallel adaptations rather than visionary management or coordination. Still, visionary coordination of policies, regulation, corporate strategies and social learning may overcome some barriers and foster new innovation efforts, providing sufficient impetus towards system transition.[14] Here, it is crucial to link long-term visions with the short and medium term strategies to generate favourable industrial, policy and social conditions leading to common action towards the system change.

Expanding on the above discussion, eco-innovations involve a combination of elements pertaining to the dimensions of design, product/service business model, user and governance. While the relative importance of those dimensions varies, eco-innovation – by definition – should have a positive impact on the environment. Hence, in so far as the design dimension is decisive to determine the environmental impacts of the innovation, it is crucial in labelling it eco-innovation.

However, the innovation processes leading to changes in the design dimension are also likely to emerge from other eco-innovation dimensions. Therefore, all the dimensions play a significant role in understanding the multi-faceted nature of eco-innovation and the diversity of eco-innovations. When they are addressed together, they form a comprehensive framework for the analysis of eco-innovation (Carrillo-Hermosilla et al., 2009).

Once the key dimensions of eco-innovation have been identified and described, their relative importance in specific eco-innovations should be assessed. In order to better characterise those eco-innovations and illustrate our approach, we assess the dimensions of selected eco-innovations by using a Likert scale with five levels of scores, with 1 meaning an incremental change and 5 a radical one (zero represents no change). If the dimensions are presented together with the scores for evaluating the degree of change, then it is possible to construct a dashboard to visualise the characteristics of each eco-innovation (Fig. 2). When an eco-innovation is assessed in all dimensions using the Likert scale, the scores can be connected. The resulting area characterises the specific eco-innovation being assessed (see Section 4).

3. Method and data

There are many ways of eco-innovating. The study of eco-innovation can benefit significantly from empirical analyses which grasp the details of specific eco-innovation types and, particularly, their dimensions. A case study approach is ideal for generating theoretical and pragmatic insights from empirical observations when little is known about a phenomenon and when there is disagreement within the literature (Eisenhardt and Graebner, 2007). Case studies are able to capture the details of eco-innovations, which are unnoticed in top-down, aggregate quantitative analyses. We decided to conduct multiple case studies, since multiple cases can increase the external validity, and, ultimately, the generalizability, of research findings (Cook and Campbell, 1976; Patton, 1990).

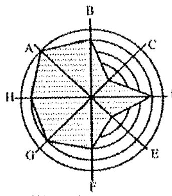
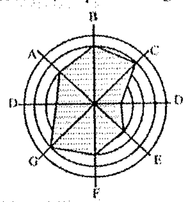
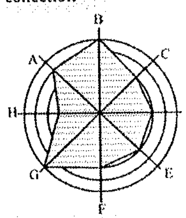
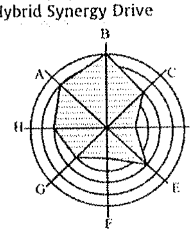
[11] The terms "socio-technical systems" (Geels, 2002), "innovation systems" (Edqvist, 1997), and "transition" (Rotmans et al., 2001) have also been used to describe a similar kind of fundamental transformation processes of the co-evolution of technological and institutional systems.

[12] See e.g. (Carrillo-Hermosilla, 2006; Carrillo-Hermosilla and Unruh, 2006; Unruh, 2000; Geels, 2002; Jacobsson and Johnson, 2000; Kline, 2001; Carlsson and Jacobsson, 2004; Frenken et al., 2004; Foxon et al., 2005; Scrase and Mackerron, 2009).

[13] The success of an eco-innovation does not only depend on specific instruments offered by the government and specifically targeted at eco-innovations. Indeed, in addition to environmental and technology policies (see OECD, 2009a), other broader policies (i.e., macroeconomic, industrial, education and employment policies) also affect, both, the supply and demand of eco-innovations. Furthermore, not only specific instruments but their design elements and the contextual conditions (such as the "style", stability and flexibility of regulation) are relevant in this regard (see Del Río, 2009). Finally, in addition to policies influencing the supply and demand sides of eco-innovation, the government may act as a matchmaker between supply and demand (Taylor, 2008).

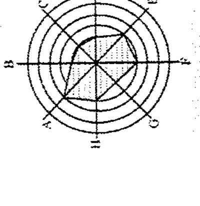
[14] In this context, ecoinnovation is a response to, both existing and expected regulations. The anticipation of regulatory trends by firms developing an ecoinnovation might be very relevant in this regard, as shown by Beise and Rennings (2005).

Table 1
Cross-case comparisons for successful eco-innovations: Dimensions of eco-innovation (Scores – in brackets – reflect how radical the change occurred in these dimensions was, 1 being an incremental change and 5 a radical one).

Case	A. Design of component addition	B. Design of sub-system change	C. Design of system change	D. User development	E. User acceptance	F. Change in product service deliverable	G. Change in product service process	H. Governance change
Ecocement 	(5) Similar manufacturing process as ordinary Portland cement. The incineration and the use of incineration ashes in cement production are new components in cement production and waste management.	(4) It improves efficiency in cement production and waste management systems. It reduces CO2 emissions/tonne cement, extracts chlorine and heavy metals from the process and recycles them.	(1) Efficient and safe, but partial, solution for resource management. The burning of organic waste material is "downcycling", because the waste materials can not be reused for the same or better purposes.	(4) Taiheiyo Cement corporation takes an active role in the development of Ecocement, together with academia and the public sector.	(1) The cement industry relies strongly on the established Portland cement manufacturing technology (dominant design position). Demand generation for Ecocement is the main barrier for its uptake.	(3) Production of a new type of cement and a solution to a major waste disposal problem. However, the innovation does not consist of service dimensions.	(4) Compared to Portland cement, the new value chain includes waste collection and incineration, and separation of incineration waste.	(4) The Japanese authorities developed the technology together with private companies and included Ecocement into the cement standard specification after consultation with stakeholders.
EcoWorx, carpet backing 	(3) It consists of new components such as thermoplastic polyolefin compounds with a fibreglass reinforcing layer.	(4) Environmental performance improvement. Thanks to the hot-melt extrusion technology it is 100% recyclable into new EcoWorx.	(4) In comparison with standard carpet backing, EcoWorx constitutes a re-design as it is a 100% PVC-free and 100% recyclable.	(1) The commercial building industry has had little impact on the innovative phases of the development of EcoWorx, the design changes and building up the reverse logistics system.	(2) The fast uptake of EcoWorx in the commercial building industry was due to customers perceiving that EcoWorx performed well in terms of its environmental impact, functionality and quality.	(3) The new product entails radical changes in product/service deliverable.	(4) The redesign of the product value chain and the building up of the reverse logistics system are radical changes in the product-service process	(2) Legislation and industrial initiatives have supported the implementation of a reverse logistics system. Government and industry awards have promoted the adoption of EcoWorx. Including environmental issues in Shaw's corporate strategy.
Automated vacuum system for waste collection 	(4) New patented components enable the development of the vacuum system.	(5) The vacuum waste collection system is a radically new approach in waste collection compared to conventional systems.	(3) Vacuum systems radically change the way the waste is sorted and collected, hence, they also provide partial solutions to sorting, reusing and recycling waste.	(3) The system has been developed through active piloting in the municipalities to offer a radically different system of waste collection.	(3) Households and industrial users have to change the way they sort and dispose of waste.	(3) It requires a different way of organising the sorting and collection of waste.	(5) It builds on radically different technologies, expertise and partners throughout the value chain compared to conventional waste collection.	(2) Requires some changes in the waste management practices of clients. Local governments often play a decisive role in demand articulation, authorisations and financing.
Hybrid Synergy Drive 	(4) Some key new components are required with respect to conventional cars. Combination of conventional and electric parts.	(5) Significant energy efficiency gains are achieved, especially in urban traffic conditions.	(3) It changes some aspects regarding the way mobility is provided, but it is only a partial solution to radical system change in transport (drop-in innovation).	(1) The system has been developed by Toyota through a very ambitious R&D plan. Limited role of users in its initial development and greater in later versions.	(3) Some changes are required by users (driving behaviour), but some benefits are privately appropriated (lower energy consumption). Other aspects represent a continuation of current mobility and driving patterns.	(1) No changes in the product service delivered and in the perception of the customer relation.	(2) Some changes regarding the value chain (battery provision and maintenance services).	(4) The adoption of public policies are required. No evidence of technological cooperation between different actors.

(continued on next page)

Table 1 (*continued*)

Case	A. Design of component addition	B. Design of sub-system change	C. Design of system change	D. User development	E. User acceptance	F. Change in product service deliverable	G. Change in product service process	H. Governance change
Green Hotel Project 	(3) Installation of a computer management system tool applied to rationalise energy consumption.	(1) Marginal changes in the sub-system.	(1) No change in the system.	(1) No development of the eco-innovation by the user, although close user/supplier cooperation to adapt it to the user company.	(2) The "drop-in" nature of the eco-innovation facilitates user acceptance.	(2) It does not involve major changes in the product service delivered and does not change the perception of the customer relation.	(1) Customer loyalty attained with the system, although there is no change regarding the value chain.	(2) No major public governance aspect involved. Concerning private governance, no major changes at the level of corporate strategy or internal organisation of NH were required.

Our unit of analysis is the eco-innovation phenomenon. Information sources include internal company reports, company profiles, product catalogues and field notes. We have analyzed eco-innovations from different countries (Japan, USA, Sweden, Spain) and sectors (Construction, Industrial processes, Resources management, Transport, Services), in order to observe the phenomenon of eco-innovation in all its complexity and diversity, as suggested by the methodology (Eisenhardt and Graebner, 2007; Ellinger et al., 2005).[15] Furthermore, those eco-innovations show different maturity levels and degrees of disruption (incremental versus radical eco-innovation), have faced several barriers to their development/adoption and are affected by different policies. The cases were chosen to describe the diversity of eco-innovations rather than as examples of best practice.

3.1. *Case 1. Ecocement (construction, Japan)*

Ecocement was developed in 1999 by Taiheiyo Cement Corporation, one of the leading Japanese companies in the cement industry today, as a result of a National Project on behalf of the Ministry of International Trade and Industry (MITI). Ecocement is a type of hydraulic cement produced from municipal waste incineration ashes. Thereby, it provides a double environmental benefit: a reduction in the extraction of resources and in the amount of wastes which reach the environment. Ecocement was recognized as making an effective contribution to using and recycling resources and, in 2005, received both the Global 100 Eco-Tech Award at Expo 2005 Aichi Japan and the MITI Minister's Award. It is also attracting attention outside Japan.

3.2. *Case 2. EcoWorx, carpet backing (industrial processes, USA)*

EcoWorx carpet backing technology was introduced in 1999 by Shaw Commercial as a replacement for traditional carpet tile backing made from PVC. With over 500 million square feet in use around the world, EcoWorx is a high-performance backing. In comparison with standard carpet backing, it constitutes a re-design as it is 100 per cent PVC-free and 100 per cent recyclable.

3.3. *Case 3. Automated vacuum system for waste collection (resources management, Sweden)*

The automated vacuum collection system transports waste at high speeds through an underground network of pipes to a centrally located waste transfer station where it is compacted, sealed in containers and then carted away. The system is based on pneumaticsm, i.e. the use of pressurised gas to do the desired work. Resources can be collected several drop-off points in single buildings, restaurants and shopping complexes. The leader in its development was the Swedish company Envac Centralsug, which developed its first pilot projects in the 1960s. Thanks to ongoing research and development, Envac Centralsug has received several patents that have enabled it to achieve a leading position in the market.

3.4. *Case 4. Hybrid synergy drive (Transport, Japan)*

Toyota Prius is the market leader in hybrid vehicles. Toyota patented the Hybrid Synergy Drive system and introduced the Prius in 1997 in Japan, with improved versions in 2000 and 2004. The Prius combines a petrol engine and an electric motor, depending on

[15] A more detailed description of each case can be found in Carrillo-Hermosilla et al. (2009).

the driving conditions. Under urban traffic conditions, only the electric motor drives the vehicle. When the vehicle is on the motorway, the petrol engine powers the vehicle and charges the battery. Therefore, environmental improvements stem from regenerative braking and from shutting off the internal combustion engine when the car is stopped. Toyota's strategy is to sell one million Prius units by 2010, up from 281,265 in 2007.

3.5. *Case 5. Green Hotel Project (Services, Spain)*

The NH Green Hotel Project, developed in partnership with Siemens, arose in 2008 to enhance the rational use of energy sources. The system consists of customising the NH key cards for guests' entry into the hotel rooms. Guests would mark their preferences regarding lighting and temperature when they checked-in and the room would be lit and heated to their tastes. In addition to saving energy, NH managers believed that this system was a further step in the customised service they provided to their clients. It differentiates NH from its competitors.

4. Discussion

The main findings and implications obtained from the analysis of these case studies with respect to the dimensions of eco-innovation are discussed in this section and summarised in Table 1. Scores are also provided to reflect the level of "radicalism" of the change in the considered dimensions.

The *design* dimension highlights the existing diversity of both product and process eco-innovations, from incremental, drop-in innovations to systemic changes.[16] All these eco-innovations contribute to environmental protection, although in different ways and different time frames. Those eco-innovations scoring highly in the design of component addition but low in the design of system change can be expected to optimize existing process, leading to efficiency improvements and costs reductions while simultaneously reducing harmful impacts on the environment. This is particularly the case of the Green Hotel project, in which a new computer tool optimizes the energy consumption of the existing system. A similar case, leading to greater changes in the subsystem but still without a substantial system change is Ecocement, which reduces inputs and energy costs.

As the eco-innovation scores highly in the design of system change, it has the potential to create new alternatives, which is crucial in reshaping existing systems and managing sustainability transitions. The case of EcoWorx, which represents a redesign of an existing product (i.e., a new product) is the most illustrative in this regard.

The ecoinnovation case studies suggests that diversity characterises eco-innovation. Diversity might play a major role on the transition towards a more sustainable economy, i.e., we need eco-innovations which develop and diffuse on different timescales. Component additions and sub-system changes are likely to have direct, short-term impacts on environmental performance. However, it may be just as important to consider how eco-innovations contribute to the transformation of the system they are part of, i.e., redirecting existing systems towards more sustainable paths, as in the contribution of the hybrid synergy drive and the EcoWorks backing to the greening of the transport system or the carpet industry, respectively. In the case of Prius, it improves fuel efficiency but may also facilitate the introduction of electric vehicles.

Therefore, while some "low hanging fruits" can easily be adopted now, other eco-innovations require considerable joint efforts at the development and pre-commercialisation stages. The former allows us to gain time for the later. Thus, dual approaches in both policy and management are worth exploring to ensure incremental performance and environmental improvements in the short term, as well as more systemic and radical changes in the longer term. This calls for a sensible balance between standardisation (which allows cost reductions through economies of scale) and the maintenance of a certain degree of diversity, which can be expensive in the short-term, but cost-effective from a longer-term perspective.

Addressing *user* perspectives brings eco-innovations closer to the markets and, particularly, to lead users. User-led eco-innovations and eco-innovations with greater market focus have a better chance of success in the market place, as illustrated in Ecocement, where the main Japanese cement manufacturer has taken an active and key role in its development. However, this has not led to a significant substitution of dominant technology (Portland cement manufacturing). Regarding the Green Hotel Project, the user (NH) has not been involved in the development of the eco-innovation, but it has collaborated with the supplier (Siemens) to adapt it to the company. This close supplier-user relationship is shared by many successful eco-innovations (Del Río, 2005). In contrast, the cases of EcoWorx, the automated vacuum system for waste collection and the Prius all show a rather limited role of users in the development of the eco-innovation.

On the other hand, a greater market acceptance of eco-innovations is critical for their success. Thus, in order to facilitate the penetration of eco-innovations, it is important to create links and positive trade-offs between the environmental protection attribute of eco-innovations and other critical factors of competitive products and services such as style, design, price and performance, to be gauged from the customer and market assessment studies. For example, the perception that EcoWorx performs well in terms of its environmental impacts but also of its functionality and quality has facilitated its fast uptake in the commercial building industry. The 1997 Prius had "appearance problems",[17] which were corrected in later designs. Technological improvements by Toyota were the result of R&D efforts trying to adapt to the preferences of users, as the company learned from consumer feedback. Our research suggests that, if the eco-innovations can easily be embedded in existing lifestyles routines and production processes (i.e., "drop-in" regarding user needs), user acceptance is easier to obtain, as in the Green Hotel project and the Prius, which combine elements of drop-in with the possibility to privately appropriate the benefits of the eco-innovation. Yet, this does not always occur because the eco-innovation may require changes in habits and user routines without significant private benefits to be appropriated by users, as in the automated vacuum system for waste collection, where households and industrial users have to change the way they sort and dispose of waste.

Regarding the *product service* dimensions, eco-innovations may offer opportunities for the renewal of business concepts. The paramount example is EcoWorx, which led to the creation of a new product, the redesign of the product value chain and the building up of the reverse logistic system, involving radical changes in its product-service deliverable. The vacuum system provides another example. It requires a different way of organising the sorting and

[16] Drop-in refers to innovations which can easily be embedded in existing production processes and require few changes in the selection environment (Kemp, 1994).

[17] "looking oddly stretched and tubular, as if the innovation in the engineering needs to find some expression in the bodywork" (The Guardian, 2004).

collection of waste, which improves the local environment by reducing noise, odours and visual pollution. It builds on radically different technologies, expertise and partners throughout the value chain compared to conventional waste collection. In contrast, the other three cases do not involve significant changes in the product-service delivered and in the perception of the customer relation.

The *governance* of eco-innovation can benefit from the high status recently given to innovation in both policy and business. All the case studies highlight the important role of public policy makers in the development/uptake of eco-innovations. This can take different forms: a more direct involvement in the development of the technology (Ecocement), provision of a supportive policy framework (EcoWorx and Hybrid Sinergy Drive) and/or a decisive role in demand articulation (vacuum system). The only exception is the Green Hotel project, with no major public governance aspect being apparent. Furthermore, successful eco-innovations are highly dependent on the participation of different stakeholders in their development/uptake, i.e., they are likely to result from the cooperation among different units and the formation of partnerships between the public sector, academia and business. The role of public policy makers as facilitators of this multi-agent collaboration might be highly relevant. Ecocement clearly illustrates this point: its development involved intensive collaboration between the private and public sectors and substantial consultation of other stakeholders.

5. Conclusion

This paper has identified the key dimensions of eco-innovation (design, user, product service and governance). An analytical framework has been developed to explore these key dimensions, identify the specific characteristics of different eco-innovations and analyse their variety. This framework has been used to analyse a set of detailed case studies of eco-innovation.

It has been found out that eco-innovations usually involve a combination of elements pertaining to several dimensions. Albeit the design dimension is decisive to determine the environmental impacts of the innovation, the other dimensions also play a significant role in the market introduction of eco-innovations. Ultimately, the capacity of eco-innovations to provide new business opportunities and contribute to a transformation towards a sustainable society depends on the interplay of those dimensions and the engagement of key stakeholders in the innovation process.

It should be noted that the suggested assessment of changes occurring in the eco-innovation process is subjective, not only because of incomplete information but also because of interpretations and the use of the graded scale of changes. Furthermore, albeit the method can be applied to different eco-innovation types, as shown in the empirical part of this paper, it may not be applicable to all eco-innovations.

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