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Dashboard of Eco-innovation

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Abstract

In this paper, we shall develop a conceptual framework to characterise different kinds of eco-innovations and arrive at the respective implications for their management and governance. The different dimensions of eco-innovation are conceptualised and gathered together in the Dashboard of Eco-innovation which is used to assess the innovation process of an automated vacuum waste collection system. The case is explored and described using the developed Eco-innovation Dashboard. The dashboard builds the bridge between different disciplines and approaches, for instance, technology development and design, user-driven innovation, strategic management of products and services and governance and the role of the public sector in innovation process.

Introduction

The scale of environmental problems, coupled with social inequalities and competitiveness challenges within the global economy, have raised increasing awareness of the need to change and renew existing technological production and social behavioural patterns. At best, such awareness may produce innovative responses that gradually move society along the path towards sustainable development. Tools for such transformation have been developed, for instance, in the field of environmental management and design, namely within frameworks such as eco-efficiency (e.g. Smidheiny, 1992), industrial ecology (Frosch & Gallopoulos, 1989; Côte, 1994) and design for environment (e.g. Kurk & Eagan, 2007) and more recently within the concept of eco-effectiveness (Braungart et al, 2007), natural capital and biomimicry (Hawken et al, 1999). Furthermore, the urgency for change has led to increasing application of the term 'innovation' in environmental management and policy. Despite the promise of eco-innovations, the term is also used in diverse contexts with different underlying connotations that may eventually diminish its practical value.

In this paper, we shall develop a conceptual framework to characterise different kinds of eco-innovations and arrive at the respective implications for their management and governance. We shall identify and describe different dimensions for studying innovation processes which address environmental issues - namely the design, user, product/service and governance perspectives. Lastly, the different dimensions are gathered together in the *Dashboard of Eco-innovation* which will be used in the case study to assess the innovation process of an automated vacuum waste collection system.

1. Defining Eco-innovation

Any attempt to understand eco-innovation can benefit considerably from the emergence of a stream of innovation studies covering a wide range of different disciplines, such as institutional and evolutionary economics and technological change theories, industrial economics, systems analysis and operations research, sociology and political sciences, actor-network and communication theories, organizational change and knowledge management, among others. However, the effective use of different disciplines in the management of eco-innovation also calls for a coherent theoretical framework.

There is extensive evolutionary literature on technological change and related drivers and barriers (see, e.g., Dosi et al., 1988; Arthur, 1994; Nelson and Winter, 2002). Such approaches have been extended recently to cover institutional aspects too, such as legislation, norms, standards and routines (Nelson and Sampat, 2001). This evolutionary viewpoint - addressing both technological and social change - offers a useful framework for micro-level management and macro-level economics and innovation policy. The increasing application of this approach is largely based on the way it conceptualises innovation: (i) it acknowledges innovation as an endogenous phenomenon within the economy and (ii) it characterizes innovation as knowledge, whose creation and exploitation is highly dependent on available resources such as capabilities and time.

On the basis of these premises, we understand innovation to be a technological and/or social systemic change process which consists of the invention of an idea for change and its application in practice. Expanding on this definition of innovation, we define eco-innovation as referring to an innovation that improves environmental performance. While it is namely environmental impacts that define eco-innovation, economic and social impacts play a crucial role in its development and application and hence determine its diffusion path and contribution to competitiveness and overall sustainability. Indeed, there are many factors affecting eco-innovation and only one of those is environmental motivation (others are for example the characteristics of the sector and the existence of technological opportunities). Furthermore, 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 discussion over whether the innovation was initiated/adopted as a result of environmental motivation (see also Berkhout, 2005).

However, agreeing on the actual improvement of environmental performance is not always easy. Environmental performance comprises different dimensions such as resource use and impacts on water and air. For instance, the use of catalytic converters in combustion engines reduces volatile organic compound emissions but increases carbon dioxide emissions due to lower fuel efficiency. In this case, the environmental improvement depends on how one values different kinds of emissions and the use of resources. Therefore, just like environmental performance, eco-innovation too is a value-based concept open to discussion about its impacts on society. Furthermore, innovation once regarded as environmentally friendly can subsequently be considered even harmful if information about its negative impacts is received. For example, Chlorofluorocarbons (CFC, HCFC), which are compounds containing chlorine, fluorine and carbon were once widely used in industry, for example as refrigerants, propellants, and cleaning solvents. Only after decades of use was it discovered that they had an adverse effect on the ozone layer and climate change. Today, their use has been prohibited by the international Montreal Protocol. Similarly, the combustion engine car was initially thought to provide environmental benefits by replacing horse traffic and thus reducing dung-related problems in city centres. Only much later did the harmful impacts of emissions produced by combustion engines and other negative impacts of car traffic come to be understood.

Basically, innovation refers to the change in the way something is done. Hence, for the purposes of characterising innovation - including eco-innovation -, we consider addressing change as a useful starting point. Here, we distinguish radical and incremental changes which are brought about by eco-innovation or which are essentially required for its successful application and diffusion within society (Könnölä & Unruh, 2007):

- Incremental changes refer to gradual and continuous competence-enhancing modifications that preserve existing production systems and sustain the existing networks, creating added value 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 added value.

Distinguishing between the two can be complicated, however, due to the fact that what is radical at one level of analysis of the system may appear incremental at a higher level of analysis (Unruh, 2002). The shift from hard disk drives to flash memory, for example, can be radical for disk drive manufactures, but incremental for the larger personal computer value network in which memory is an embedded component. Nevertheless, it has been suggested that only 10% of all new innovations produce radical changes (Rothwell & Gerdiner, 1988; Griffin, 1997).

2. Dimensions of eco-innovation

Evolutionary economists consider innovation arises through a systemic process that refers to the interconnectedness of different actors and internal and external factors influencing the innovation process. Typically, innovation emerges through a complex interplay of supply and demand. Therefore, it is also often arguable what the actual cause and effect are when the success of any innovation is discussed. Due to this systemic nature of innovation, it is worth exploring the multiple dimensions of the innovation process including both causes and effects.

Fundamentally, just like any innovation, in the case of eco-innovations too different dimensions of change can be identified which together explain factors of success or failure. Therefore, we shall look at different dimensions of innovations; firstly design issues and then user and product service perspectives and finally the role of governance.

3.1 Design dimensions of eco-innovation

The design stage of product and process development, recognised as a key for determining costs and profitability, is also an unparalleled window of opportunity to address environmental objectives. During this early stage, key materials, process, and energy source decisions largely determine the environmental impacts of a product for its entire life cycle. Integration of environmental factors into design is an emerging trend known as design-for-the-environment (DfE), ecodesign, or life-cycle design (e.g. Barbiroli & Raggi, 2003; Kurk & Eagan, 2007). While pollution prevention, cleaner production and eco-efficiency (Schmidheiny, 1992) have provided DfE with approaches on minimising negative environmental impacts, eco-effective management (Braungart et al., 2007) has been conceptualised to offer an alternative perspective which, in contrast, encompasses maximising positive impacts on the environment.

Indeed, in view of the environmental perspective, it is possible to distinguish two different design perspectives on innovations.

- The first perspective is to consider human actions incompatible with the natural environment, referring to negative impacts of human-made systems such as agricultural and industrial production and transport systems. Hence, environmental management should focus on minimising such impacts on the environment.
- The second perspective is to consider incompatible human actions as ‘design failures’ and to focus on redesigning human-made systems towards positive impacts on the environment and society, for example through the remediation of polluted land and water systems or the reforestation of areas suffering desertification.

With these two perspectives of negative and positive impacts on the environment (or more specifically on the eco-system comprising both the natural environment and human-made systems and activities), we can construct a design framework for eco-innovation. Incremental vs. radical change is located on the horizontal axis and the negative vs. positive impact on the vertical axis. The resulting framework suggests that redesign for positive impact combined with radical change lead to, at best, ecological, social and economic sustainability. More specifically, within this framework, three different design approaches can be defined to identify the role and impacts of the eco-innovation (see, Figure 1), including:

- Component addition
- Sub-system change
- System change.

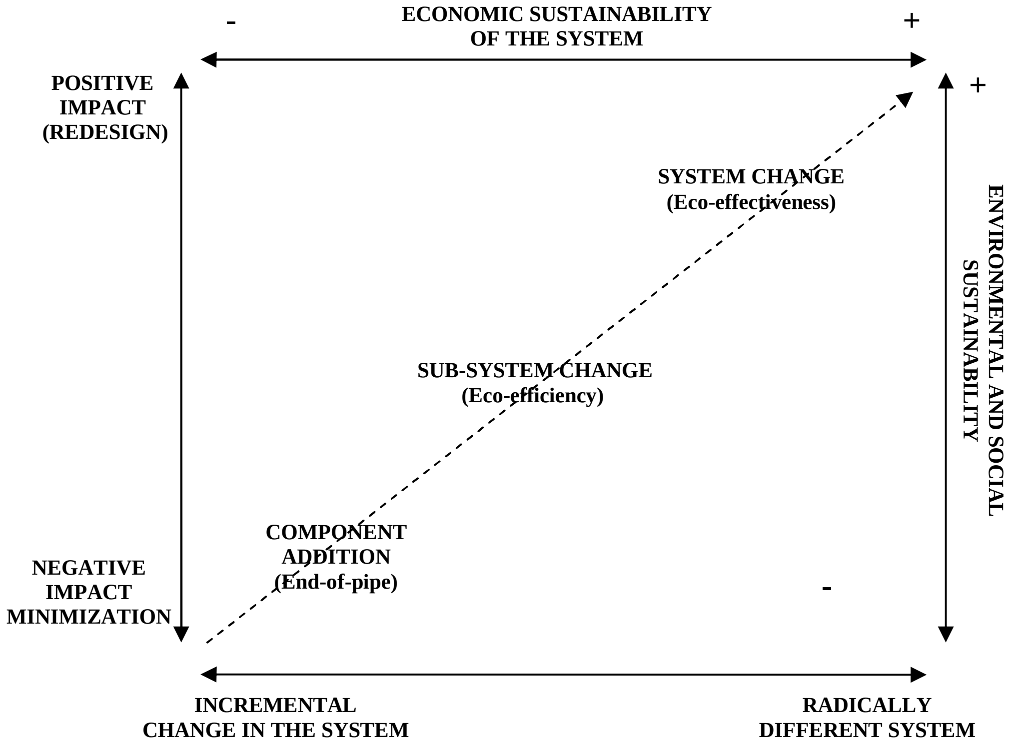

Figure 1. Design framework for eco-innovation in view of radical and incremental change and negative and positive impacts on the environment. The highest sustainability and competitiveness benefits are likely to occur in the top right-hand corner of the figure.

<u>Component addition</u> (development of additional components to improve environmental quality, e.g. 'end-of-pipe' technologies): Component level changes aim to minimize and repair **negative impacts** without necessarily changing the process and system that produces the problem. If the innovation is an additional component to the system, commonly referred as 'end-of-pipe' technologies, it is likely to produce extra costs to the process. End-of-pipe technologies are used to curb the environmental impacts of existing industrial and transport systems, such as air emission filters and plant effluent treatment. Since the industrial revolution, the implementation of these technologies has produced major improvements in local air quality and water purification, particularly in industrialized countries and similar opportunities exist in many

developing countries. However, if these technologies do not change the fundamental process, they will only solve part of the problem. 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 major factor affecting climate change. The catalytic converter is an add-on solution adopted instead of a cleaner and more efficient combustion engine offering fuel economy benefits as well as low-emissions. When existing production systems cannot be changed quickly enough, the component addition type of eco-innovation can be a valuable tool for dealing with the problem. 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 instead of releasing it into the atmosphere. It may prove to be a powerful mechanism for curbing fossil fuel-based carbon emissions and for combating climate change.

Sub-system change (e.g. eco-efficient solutions and the optimisation of sub-systems): The aim is to improve environmental performance through sub-system changes leading to increased efficiency of human-made systems such as power plants or cars. The goal is to reduce **negative impacts** by creating more goods and services while using fewer resources and creating less waste and pollution. This approach is crystallised in the term eco-efficiency, which was coined by the World Business Council for Sustainable Development (WBCSD) in its 1992 publication “Changing Course” (Schmidheiny, 1992). This concept describes a vision of the production of economically-valuable goods and services while reducing the ecological impacts of production. In other words, eco-efficiency means producing more with less (fewer raw materials, less energy, fewer toxic substances, etc.). The concept of eco-efficiency provides practical action-oriented guidance on how to combine environmental issues in business. Eco-efficient markets are rapidly growing and thousands of companies can attest to the major benefits of its application. Eco-efficiency aims to make the old, destructive production system less so. But its goals, however admirable, are insufficient due to the limitations related to the concept. Reduction, re-use and recycling curb rates of pollution and depletion but do not stop these processes. 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. This problem has been defined as the ‘‘dilemma of the N-curve’’ (Jänicke, 2008): increases in environmental efficiency do not lead to sustainability since they tend to be easily erased by subsequent growth processes, provoking a rebound effect in the economy. This dilemma may affect both the component addition and the sub-system change approaches, more than offsetting the environmental contribution of these design changes. Thus, while eco-efficient solutions may be competitive in the short-term, they are likely to maintain existing unsustainable production and behavioural patterns, which are detrimental in the long-term to both the economy and the environment.

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 both their **negative and positive impacts** on the ecosystem. This approach builds on the analogy between natural and socio-technical systems elaborated in industrial ecology (Frosch & Gallopoulos, 1989; Côte, 1994; Graedel and Allenby, 1995; Socolow, 1997; Ayres, 1996); how industrial systems should incorporate principles exhibited within natural ecosystems and shift from linear (open loop) systems - in which resource and capital investments move through the system to become waste - to closed loop systems where wastes become inputs for new processes.

The first two perspectives discussed above (component addition and sub-system change) consider human actions incompatible with the natural environment, referring to negative impacts of human-made systems. This third perspective, in turn, focuses on redesigning human-made systems towards biocompatibility. The designed change contributes to the redesign of the whole system towards greater biocompatibility and added value for the provided service, product or process. Biocompatibility refers to the quality of human-made systems, e.g. materials not having toxic or otherwise harmful effects on biological systems. For example, materials such as lead and mercury are harmful to and hence incompatible with organisms.

The idea of taking into consideration the positive impacts of human activities as a design criteria has been particularly developed in connection with the concept of eco-effectiveness which addresses such system-level aspects (McDonough and Braungart, 2002; Braungart et al. 2007). *Eco-effectiveness* seeks to design industrial systems that copy nature and its healthy abundance. An eco-effective solution maximizes biocompatibility and product or service usefulness together. Here, the central design principle is *waste equals food*. Within this concept, the systemic approach to environmental design leads to two alternative design perspectives (McDonough & Michael Braungart, 2002; Braungart et al. 2007): i) closed cycles - referring 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 and ii) open cycles - referring to the design of products that are biodegradable and become nutrients to new cycles within the ecosystem.

Eco-innovation is most often related to the design dimension which largely defines what kinds of impacts the innovation has on the environment. In this discussion, eco-innovation is typically linked to concepts of end-of-pipe technologies and eco-efficiency which provide practical action-oriented guidance on how to combine environmental issues in business and to curb rates of contamination and depletion - but not to stop these processes. Eco-effectiveness brings in a new perspective which tackles designing a product which may return to industry and its materials are used to make equally or more valuable new products. To sum up, the design of eco-innovation consists of three different dimensions: component additions, sub-system changes and system changes. The characteristics and examples are provided in Table 1.

Dimensions of eco-design:	**Characteristics:**	**Examples:**
Component addition	Development of additional components to reduce negative impacts on environment, e.g. end-of-pipe technologies.	The use of catalytic converters in combustion engines. Carbon sequestration and storage in connection with fossil fuel-based power plants.
Sub-system change	Contributes to the environmental performance improvement of the sub-system to reduce negative impacts on the environment, e.g. eco-efficient solutions and the optimisation of sub-systems.	Efficiency improvements in combustion engines.
System change	(Re-)design of the system in view of its impacts on the eco-system, taking into account the positive and negative impacts on the environment, e.g. with eco-effective solutions.	A passenger car running on renewable energy and designed to be disassembled, and returned to the soil or to industry.

Table 1. Three design dimensions of eco-innovation with examples.

3.1.1 User dimensions of eco-innovation

In order to develop eco-innovations, companies should also have the competence to involve users so as to benefit from their creativeness and to ensure that they will accept and take up new products and services. Users play a key role not only in applying innovations but also in identifying and developing new innovations. It has been demonstrated that many users - both individuals and firms - develop new products to serve their own needs. Some of these are subsequently adopted by manufacturers and sold as commercial products. Thus, user innovation can greatly influence the rate and direction of innovation in some industries and service providers (von Hippel 1988), towards environmentally benign practices. So it may be crucial for companies to know which users are capable of contributing in the different phases of the innovation process and how to interact with them.

User development: Von Hippel (2005) defines users as firms or individual consumers that expect to benefit from using a product or a service. In contrast, he differentiates manufacturers who expect to benefit from selling a product or a service. A firm or an individual can have different relationships to different products or innovations. For example, he uses the example of Boeing as follows:
"The Boeing is a manufacturer of airplanes, but it is also a user of machine tools. If we were examining innovations developed by Boeing for the airplanes it sells, we would consider Boeing a manufacturer-innovator in those cases. But if we were considering innovations in metal-forming machinery developed by Boeing for in-house use in building airplanes, we would categorize those as user-developed innovations and would categorize Boeing as a user-innovator in those cases."

Furthermore, a review of empirical studies reveals that some users are very active in the innovation process by taking on the roles of inventors and (co)-developers (Baldwin et al., 2006). This phenomenon has been apparent in areas such as scientific instruments (Riggs and Von Hippel, 1994), CAD software (Urban and Von Hippel, 1988) and sporting equipment (Luethje et al., 2005). Users have also played an important part in developing eco-innovations - in particular, car sharing to reduce urban traffic has led to new businesses that encourage efficient use of car fleets. The spread of environmental management systems and, more generally, environmental awareness among companies has led to the search for eco-innovative solutions too. For example, Wal-Mart, the largest grocery retailer in the United States, has opened three stores as experimental laboratories. These stores were constructed using recycled building materials and energy-saving lighting methods. Features include a 100 % integrated water-source heating, cooling and refrigeration system, motion-sensing LED lights and an advanced daylight harvesting system. The application of these features means consuming 20% less energy than regular stores. New partnerships have produced a truck designed with forward-thinking aerodynamics, transmission, tyres, a high-efficiency auxiliary power unit and emissions controls in order to make the fleet 50% more energy efficient by 2015.

As stated above, studies have shown that many users engage in developing or modifying products. However, when considering the radical nature of user-driven innovations, the aforementioned studies reveal that the new products have a rather low to medium degree of innovativeness. This observation might be explained by the specific barriers to users in the context of radical innovations. Cognitive limitations may prevent users from delivering valuable inputs. In the idea-generation phase, users can be ‘functionally fixed’ to their current use context and therefore unable to develop radically new ideas. It may also be difficult for users to evaluate concepts and prototypes of radical innovations as no reference products exist. Nor might users be able to provide valuable inputs due to the high technological complexities involved. On the other hand, users are not always willing to contribute to radical innovation projects. This lack of motivation can stem from high anticipated switching costs and from the fear that 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 and to engage them in innovation activities (Rondinelli & London, 2003). The lead user methodology (Urban and Von Hippel, 1988) seeks to identify and involve progressive users in the idea generation and development phase. Lead users differ from ordinary users in two respects. Firstly, lead users encounter needs months or years before the bulk of the marketplace. Secondly, lead users derive significant benefits from obtaining a solution to those needs and, therefore, are highly motivated to engage in the new product development process (Urban and Von Hippel, 1988).

User Acceptance: User behaviour plays a crucial role in the application of eco-innovations and their resulting impacts on society. The pace and scale of the adoption of an innovation ultimately makes the difference between its being successful or not. Already in the 1970s, Midgely (1977) addressed the different types of user behaviour in the uptake of innovations. According to his study, only 2.5% of users could be classed as innovators (Figure, 2). Taking up new innovations is closely related to the relationship between the innovation and the values and routines in the society that it is addressing in its adoption process. Hence, acceptance of the eco-innovation and the changes required in user behaviour can be considered key dimensions for characterising the eco-innovation.

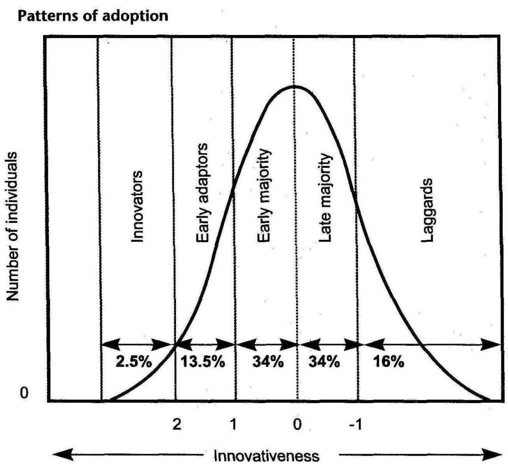

Figure 2 Patterns of adoption of innovations (modified from Midgely, 1977).

To sum up, user dimensions of eco-innovation comprise development and acceptance. Characteristics and examples are provided in Table 2.

Dimensions of user innovation:	**Characteristics:**	**Examples:**
Development	Innovation is initiated and/or developed by the users.	Retailers, e.g. Wal-Mart, developing energy efficient building and transport solutions Car-sharing networks
Acceptance	Changes in user behaviour, practices and processes are crucial to the dissemination of the innovation.	Sorting household waste as part of waste recycling

Table 2. Dimensions of user innovation

3.1.2 Product service dimensions in eco-innovation

The generation of eco-innovation largely depends on the benefits received by the innovator to improve their competitiveness and their aspirations regarding improvements in sustainability performance. The way companies create added value (e.g. the business logic) with their products, processes and services can play a crucial role in the innovation process and its impacts on the environment (Stahel and Jackson, 1993). Successful innovation must provide higher value or reduce costs and, ultimately, either increase revenues from existing customers or attract new customers. In the context of probing the market viability of sustainable services, Halme et al. (2007) identify four key dimensions, comprising i) added value for customers or users, ii) competitive advantage over other alternatives, iii) required capabilities and resources of the providers and iv) financing and the formation of income flow.

To be radical, product service (or business model) innovation requires a redefinition of the product service concept and how it is provided to the customer (Markides, 2006). Mont (2002) and Williams (2007) propose the application of a 'product service system' for developing sustainable business models. It 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).

Product service eco-innovation calls for particular consideration of overall business strategy and logic, including the convergence of supply chains. In doing so, the focus on management and operations shifts from short-sighted local optimisation to the entire supply chain during the production, consumption, customer service and post-disposal disposition of products (Linton et al., in press). This stresses the relevance of a supply chain perspective in eco-innovation. 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 & Unruh, 2006). For the purposes of the overarching framework for eco-innovation, we consider two product service dimensions crucial: firstly, the change in product service deliverable and secondly the change in the value network processes (Table 3).

Product service dimensions of eco-innovation:	**Characteristics:**	**Examples:**
Change in product service deliverable	Changes in the product service delivered and changes in the perception of the customer relation.	Interface Inc. transformed its business from selling carpets to offering a service package including renting carpets and their maintenance to provide office comfort.
Change in value networks and processes	Changes in the value-networks (value-chain and other relations) and processes which enable the delivery of the product service.	Certified forest management that commits the whole value chain to implement sustainable practices.

Table 3: Product service dimensions of eco-innovation.

3.1.3 Governance dimension of eco-innovation

Eco-innovations, particularly when they are radical and require techno-institutional system-level changes[1,] are difficult to achieve because the prevailing system may act as a barrier to the creation of a new system and the diffusion of innovation (e.g. Kemp and Soete 1992; Jacobsson and Johnson 2000; Unruh, 2000; Kline, 2001; Geels 2002; Carlsson and Jacobsson, 2004; Frenken et al., 2004; Foxon et al., to appear). Such prevailing conditions have been documented in the emergence of numerous technologies, including the automobile, electricity and the personal computer. If the system has become socially and economically pervasive, or if there are other justifications such as national security, government may intervene and encourage system expansion through a variety of mechanisms including subsidies, incentives or outright ownership (Perez, 1983; Freeman and Perez, 1988; Unruh, 2000). Ultimately, they also dramatically intensify the barriers to eco-innovation. Overcoming such lock-in conditions may require major governance innovation both in the private and public sectors.

Environmental governance innovation refers to all new and applied institutional and organisational solutions for resolving conflicts over environmental resources. Such solutions can deal with one or combined functions of environmental governance, including: exclusion of unauthorized users; regulation of authorized resource use and the distribution of the respective benefits; provisioning and the recovery of costs; monitoring; enforcement; conflict resolution;

[1] The terms ‘socio-technological transformation’ (Geels, 2002), ‘system innovation’ (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.

and collective choice (Paavola, 2007). From the view point of a company, the governance dimension challenges the management to renew its relationships with other stakeholders, in particular with the government. Hence, the management is invited to explore the wider role of business in society. Corporate governance and management systems can be both drivers and barriers to eco-innovate.

Governance institutions can be considered to have at least three functional tiers: i) operational, ii) collective choice and iii) constitutional (Paavola, 2007). Multi-level governance solutions may emerge because an upper level of governance is established to coordinate lower-level solutions, or because lower levels of governance are established to implement higher-level strategies (Paavola, 2007). Radical innovations in governance have emerged, in particular, where federations and overarching institutions have been created through bottom-up processes to coordinate the functioning of governance solutions (Ostrom, 1990; Sengupta, 2004). The opposite - top-down processes - in turn, create many formal multi-level governance solutions. Such bottom-up and top-down processes can also come together, as is the case of the global regime to mitigate climate change and its national and regional implementation efforts. Characteristics and examples of governance dimension of eco-innovation are provided in Table 4.

Governance dimension:	**Characteristics:**	**Examples**
Governance	Environmental governance innovation refers to new institutional and organisational solutions for resolving conflicts over environmental resources both in the public and private sectors.	European Technology Platforms (industry-led stakeholder platform to set and implement European research and development agendas) Environmental management systems (e.g. EMAS Scheme and ISO 14000 Series)

Table 4 Governance dimension of eco-innovation

3.2 Dashboard of Eco-innovation

Expanding on the above discussion, eco-innovation is often a combination of the dimensions of design, product/service business model, user and governance innovations. While the importance of the dimensions in eco-innovation processes varies, eco-innovation - by definition - should have a positive impact on the environmental impacts of the system of which it forms part. Hence, the design dimension is decisive to determining the environmental performance of the innovation and labelling it eco-innovation.

However, the actual innovation processes leading to design changes are also likely to emerge from other innovation dimensions. Therefore, the dimensions can be considered equally important in the management of eco-innovation. When the aforementioned dimensions - including three design dimensions, two user dimensions, two product/service dimensions and one governance dimension - are addressed together, they form a comprehensive but not exhaustive framework for the analysis of eco-innovation (see, Table 5).

Dimensions of eco-innovation:	**Characteristics:**
Design dimension	
1 Component addition	Development of additional components to improve environmental quality, e.g. end-of-pipe technologies.
2 Sub-system change	Improvement of the sub-system to reduce negative impacts on the environment, e.g. eco-efficient solutions and the optimisation of sub-systems.
3 System change	Redesign of systems to be compatible with ecosystems, e.g. towards eco-effective solutions.
User dimension	
4 Development	Innovation is initiated and/or developed by the users.
5 Acceptance	The changes in user behaviour, practices and processes for the application of the innovation.
Product service dimension	
6 Change in product service deliverable	Changes in the product service delivered and changes in the perception of the customer relation.
7 Change in value chain process and relations	Changes in the value-chain process and relations that enables the delivery of the product service.
Governance dimension	
8 Governance	Environmental governance innovation refers to all new and applied institutional and organisational solutions for resolving conflicts over environmental resources both in the public and private sectors .

Table 5 Framework for characterising eco-innovation.

With the eight different dimensions of eco-innovation now identified, it is worth addressing their relative importance to better characterise the eco-innovation. For this purpose, we propose the assessment of the relative change occurred in each dimension of the innovation process, using the Likert scale with five levels of scores; 1 being an incremental change and 5 a radical one. In this context, zero constitutes no change. If the dimensions are presented together with the scores of change, it is possible to construct a dashboard to visualise the characteristics of each eco-innovation (Figure 3).

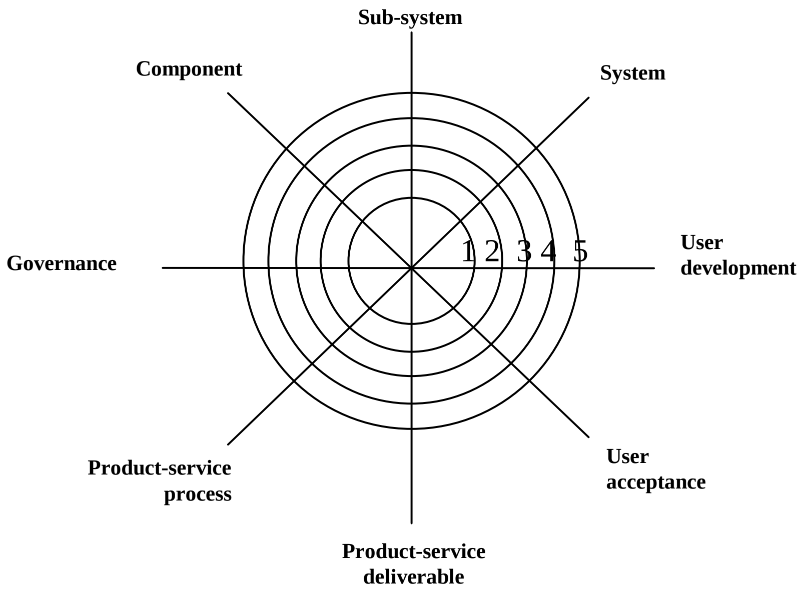

Figure 3 Eco-Innovation Dashboard for the assessment of the occurred change in eight dimensions of eco-innovation. The scores 1 to 5 refer to the Likert scale from incremental to radical change. The greater the area produced the more radical and systemic the eco-innovation can be characterised.

4 Dashboard of Automated Vacuum Waste collection System

In this section, by way of an example, we take the vacuum waste collection system to illustrate the use of the framework in defining the dimensions of eco-innovation. In the case study interviews, published documents and online resources were used to collect information on automated vacuum waste collection systems.

The Automated Vacuum Collection system, also called "pneumatic refuse collection", transports waste at high speeds through underground tunnels to a collector where it is compacted, sealed in containers and then carted away. The system is based on pneumatics (from the Greek 'pneumatikos', coming from the wind) that means the use of pressurized gas to do desired work. The system replaces traditional non pneumatic waste collection, for example with the waste containers and waste collection vehicles.

Hence, this eco-innovation can be characterised especially as a radical sub-system change as it provides a new but partial solution to waste management. Even if automated vacuum waste collection does not resolve the problem of the generation of waste, it supports the environmentally sound and safe collection, separation and reuse of waste. Thus, the systems can play a crucial role in the design of feasible closed-loops in the product life-cycle by providing a solution for producers to get back their products for “up-cycling”. It offers relevant opportunities to develop further the efficient uptake of waste and finally re-entering the waste back to the industrial or natural cycles in line with cradle-to-cradle principles. Furthermore, radical changes occur in product service process as this innovation builds on radically different technologies, expertise and partners all through the value chain compared to vehicle-based waste collection.

The leader in the development of automated vacuum systems for waste collection has been Swedish company Envac Centralsug. Only more recently, other companies such as Oppent in healthcare sector and PneuLogix have developed similar type of systems for waste collection. Thanks to the continuous research and development, the Envac Centralsug has made several patents that have enabled to achieve the leading position in the markets.

The Envac system was first introduced at a hospital in Sweden in 1961, and the company has now completed about 600 installations worldwide. It has over 40 years experience in the development and adaptation of its technology to local standards in over 30 countries. Constant annual growth meant an almost doubling of the company’s revenue between 1999 and 2002. Other companies providing automated vacuum systems for waste collection are for example Oppent and PneuLogix. Oppent offers a similar system. The whole process is completely automated through electronic monitoring systems that control and set all operations. The system can be arranged to encourage sorting, whereby the user is faced with different hatches for different waste types. Oppent is currently focusing on the healthcare sector, but the company expects this technology to be adopted more widely in city areas in the future.

4.1 Automated Vacuum Waste Collection System in the Eco-innovation Dashboard

By using the Eco-innovation Dashboard, we assess occurred changes in the innovation process of the automated vacuum waste collection system. When the dimensions of the eco-innovation are plotted on the eight axes using the Likert scale 1-5, the given grades can be connected to produce an area characterising the eco-innovation. Hence, locating the grades of change in different dimensions helps characterise the eco-innovation. When the given grades are linked on the board, they produce an area that provides a quick overview of eco-innovation in view of how radical the changes have been in eight dimensions (see Table 6 and Figure 4).

Dimensions of eco-innovation:	**Grade (1-5):**	**Example: the vacuum waste collection system innovation (ENVAC)**
1 Component addition	4	New components enable the development of the vacuum system for waste management.
2 Sub-system change	5	Vacuum systems have been used in many fields. However, the vacuum waste collection system is a radically new approach in waste collection. Considerable improvements in hygiene and noise management in the living environment.
3 System change	3	Only a partial solution to ecologically sound system change. It reduces transport and corresponding emissions. Supports - but does not by itself create - eco-effective management. Bag identification system for waste separation is a promising initiative to close material cycles.
4 User Development	3	The development of the system has been done through active piloting within municipalities.
5 User Acceptance	3	Households learn to use pipes in waste disposal. When bag identification is used, correct use of bags is crucial.
6 Change in product service deliverable	3	Improved service for the end-users. When compared to vehicle-based waste collection, it is difficult to capture new clients but easy to maintain the client base.
7 Change in product service process	5	The vacuum system builds on radically different technologies, expertise and partners all through the value chain compared to vehicle-based waste collection.
8 Governance change	2	Necessitates client (municipalities) co-operation, pro-activeness to change waste management practices when applied in both constructed and planned application areas.

Table 6 Eco-innovation dimensions and the grading of the extent of changes in the innovation process of the Vacuum Waste Collection System.

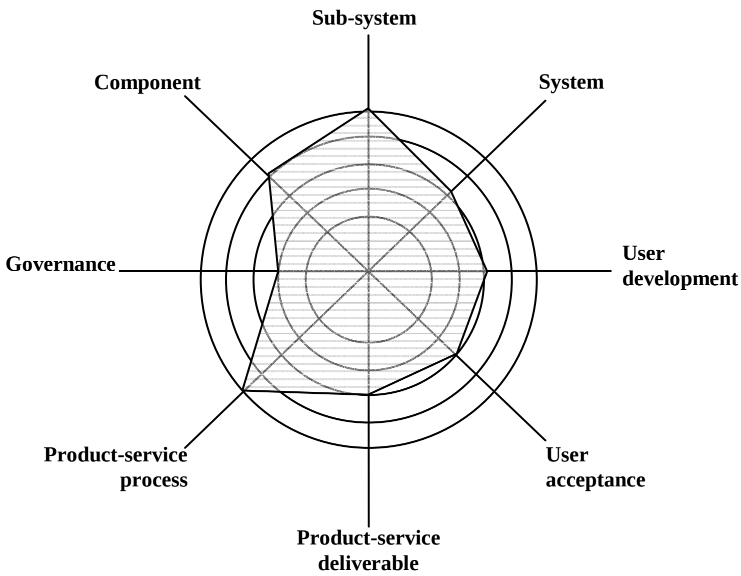

Figure 4 Eco-innovation Dashboard: Automated Vacuum Waste Collection System

1 Discussion

This paper defines eco-innovation as an innovation that improves environmental performance. Building on evolutionary economics, innovation is a systemic change process that brings into the analysis different actors and factors influencing the success or failure of the innovation, we argue that it is also crucial to the management of eco-innovation to understand the wider context in which the innovation occurs.

This paper has sought to provide relevant starting points to analyse the role of eco-innovations not only from its design dimension but in view of user participation, the development of new product and service concepts and governance innovation. It is worth noting that the assessment of occurred changes in the eco-innovation process is a subjective, not only because of incomplete information but also because of interpretations and the use of the graded scale of changes. Still, the characterisation provides support for management and policy to understand the specific nature of each eco-innovation, set development priorities and engage stakeholders crucial to its success. Furthermore, this helps management to identify required internal competences, for instance the design dimension may place emphasis on science and engineering, user dimensions on marketing and communication, product/service dimensions on business management and strategy and governance dimension on policy expertise and corporate governance. The competences needed vary according to the different characteristics of the eco-innovation in question.

Ultimately, the success of eco-innovations in providing new business opportunities and in contributing to a transformation towards a sustainable society depends on the interplay of these different dimensions and the engagement of related key stakeholders in the innovation process. Thus, we hope that the Dashboard of Eco-innovation may support the development of practical tools for the management and governance of eco-innovations.

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