The Origins and Purpose of Eco-Innovation

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Abstract

Nowadays, eco-friendly technologies are considered a strategic objective in industrialised countries. Rising demand for more sustainable products and services from civil society has become a major challenge for policy makers. The present article aims to provide a historical perspective on the concept of eco-innovation, its different meaning and its position in the modern debate around sustainability. The first part of the article is dedicated to exploring the origins of the notion of eco-innovation, drawing on the Sustainable Development debate. The second part attempts to shed light on the purpose of eco-innovation and its implications for a desirable sustainable transition in modern industrial societies. This part illustrates the essential differences between mainstream economics and the School of Ecological Economics. Finally, the third part attempts to describe the social and institutional changes necessary to foster eco-innovation.

Where does Eco-Innovation come from? A Historical Perspective

Since the early moments of the industrial revolution, technical change has always been associated with the humankind's capacity for dominating the natural world. When the modern notion of innovation was formalised by Schumpeter and his followers, it was defined in terms of Capitalism expansion and its capacity to manipulate the natural environment[1]. The Austrian economist states that the very engine of capitalist expansion is innovation that continuously disrupts the way goods and services are produced and delivered. The connection between innovation and sustainability began to attract the interest of the academic world

[1] J.A. Schumpeter, The theory of economic development: an inquiry into profits, capital, credit, interest, and the business cycle. Harvard University press, Cambridge, Mass 1934.

only at the end of the 1960s. A crucial contribution to the sustainability debate was provided by the famous and controversial report commissioned by the Club of Rome: "Limits to Growth". The main argument of the authors is that economic growth cannot continue infinitely because of the limited carrying capacity of the Planet[2]. Moreover, the work implicitly suggests that technology cannot solve the problems caused by infinite material growth on a finite planet. The report caused an outcry among mainstream economists but set the scene for a fruitful debate about sustainability. One of the influential critics of the report, Robert Solow, stated in an interview with Newsweek in 1972 that "*the authors load their case by letting some things grow exponentially and others not. Population, capital and pollution grow exponentially in all models, but technologies for expanding resources and controlling pollution are permitted to grow, if at all, only in discrete increments*[3]". Solow, one of the most important scholars of the "Neo-Classic Economics School", reckoned that technology is the only solution for all environmental issues. Despite the criticisms, the importance of the "Limits to Growth" Report was that it triggered a debate around sustainability that flowed into two main branches of thinking: Environmental Economics focused on the concept of environmental externalities and Ecological Economics focused on the relationships between the economic system and nature[4]. Although those two approaches differ on several points, there is no doubt that the debate about sustainability has a strong technological component in both schools of thinking. As a consequence, the last three decades have seen an increasing interest in the interdisciplinary approach that draws on innovation studies, evolutionary economics, governance and sociology[5]. The notion of innovation assumed a fundamental importance in the debate around sustainability and is often invoked as an essential tool to guide the transition to a sustainable society.

The eco-innovation concept itself is related to the concept of sustainable development. Van Dieren et Al.[6] date back its formulation to the decade of '70s during the 1972 UN Stockholm Conference on the Human Environment. They also suggest that the first use of the phrase "sustainable development" could be traced back to the 1980 "World Conservation Strategy", defined by the former IUCN (now the World Conservation Union), the United Nation Environment Programme (UNEP) and The World Wildlife Fund (WWF).

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[2] D. Meadows and J. Randers, Limits to growth: the 30-year update. Chelsea Green, White River Junction, Vermont 2006.

[3] Newsweek, March 13, 1972, page 103

[4] J. Martinez-Alier, Introducción a la economía ecológica, Rubes Edit. Barcelona 1999. & H. Daly and J. Farley, Ecological Economics. Principles and Application. Pearson Education, Washington, D.C 2007.

[5] E. Paredis, "Sustainability Transitions and the Nature of Technology," Foundations of Science, 16, 2, 2011, pp. 195-225.

[6] W. van Dieren, Taking nature into account: a report to the Club of Rome : toward a sustainable national income. : Springer, New York 1995, p. 332.

According to Dresner[7], such a term was first used in 1980 by the International Union for Conservation of Nature and Natural Resources in their World Conservation strategy report. The report advocated for "*the integration of conservation and development to ensure that modification to the planet do indeed secure the survival and well-being of all the people*". Despite this early definition the notion of sustainability remains a fuzzy concept to this day. According to Faber et Al.[8], in the literature there are more than 50 definitions of sustainability. Sociologists, economists and ecologists, just to mention a few disciplines, all have their favourite perspective. More recently the concept of a Sustainable Development spread all around the world thanks to the Brundland report, commissioned by the UN. The report defines Sustainability as the capacity to guarantee a decent future for the next generations. Development should meet "*the needs of the present without compromising the ability of future generations to meet their own needs. The concept of sustainable development does imply limits – not absolute limits but limitations imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activities*"[9]. Such a definition adopts implicitly the idea of limits to development and growth, at least linked to the limit of the present state of technology. The idea behind a Sustainable Development is that the socio-technological change can eventually stretch the limits defined by environmental constrains. Sustainability becomes a goal reachable through a social and technological transformation of the modern industrial society. The Brundland Report establishes a fundamental and definitive division between two different currents of environmentalism: the "Cult of wilderness", concerned by the preservation of wild nature, and "the gospel of eco-efficiency", which relies on technology to address environmental issues improving energy and material-use efficiency[10],

The concept of sustainable development, thus, irreparably leaves room for a huge variety of interpretations. Hopwood et Al.[11] have attempted to map the main approaches used in the Sustainable Development debate (see Figure 1). Their map has two dimensions: one is the equality dimension; the second is related to environmental concerns. The approaches are classified in three main groups: those who belong to the "status

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[7] S. Dresner, Principles of sustainability. Earthscan, London 2008.

[8] N. Faber, R. Jorna, and J. Von Engelen, "The sustainability of 'sustainability' - A study into the conceptual foundations of the notion of 'Sustainability'," Journal of Environmental Assessment Policy and Management, 7, 1, 2005.

[9] G. H. Brundtland, "Report of the World Commission on Environment and Development: Our Common Future". UN, New York 1987.

[10] J. Martinez-Alier, The environmentalism of the poor: a study of ecological conflicts and valuation. Edward Elgar, Cheltenham, Uk 2002.

[11] B. Hopwood, M. Mellor, and G. O'Brien, "Sustainable development: mapping different approaches," Sustainable Development, 13, 1, 2005 pp. 38-52.

quo" or mainstream group claiming that the sustainable transformation is mainly a technological problem to be solved within the present economic system through the free-market dynamic. A second group advocates for a "reform process" of the existing economic system, which should include social and environmental instances. This group contains the main environmental organizations and the majority of the scholars who deal with sustainability in the academia. The third group invokes a radical transformation of the existing economic system as well as political and social institutions.

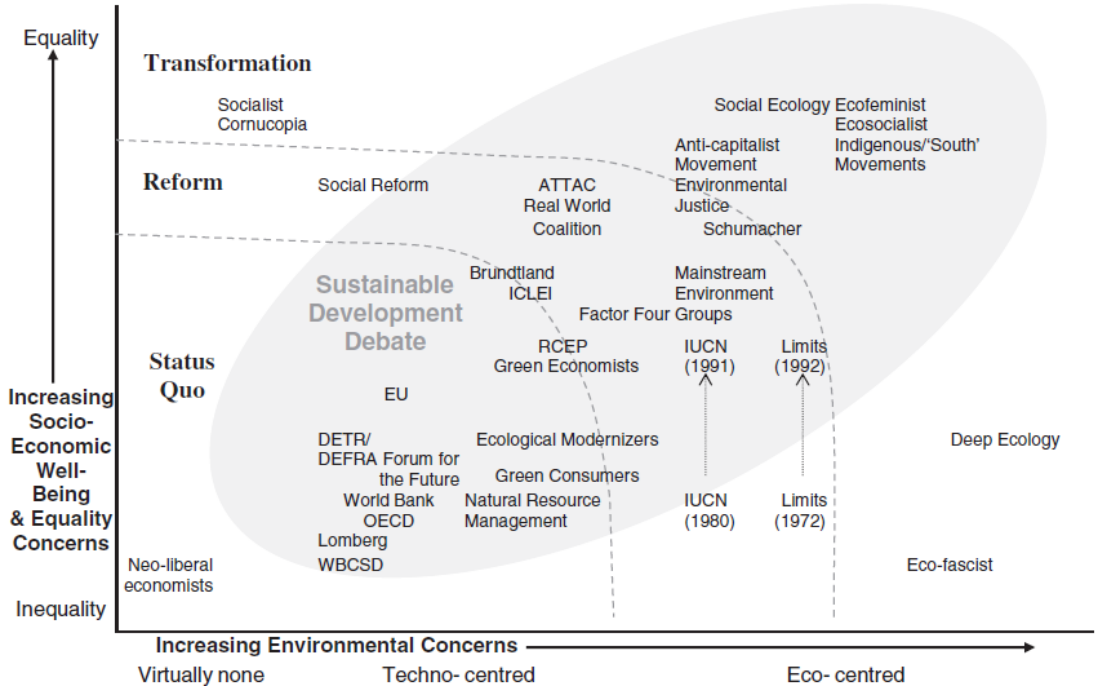

Figure 1: Sustainable development debate map[12]

Those perspectives cover a wide range of concerns and offer as many solutions. The Status Quo and Reform groups, each one with different intensity, follow an intrinsic *Instrumentalist* approach that advocates for the design and deployment of environmental-friendly technologies that should be able to stretch the limits imposed by the present socio-technical setting and minimise the impact of the human activity on the ecosystems. They are based on the idea, originated by the Brundland report, that environmental and economic development are not incompatible and technology is the greatest hope to achieve an ecological transition[13]. That position, also known as "Instrumentalist approach to technology", considers technology as an isolated and independent phenomenon. Technology is an instrument without any other scope but its instrumental function. Feenberg argues: "A hammer is a hammer, a steam turbine is a steam turbine, and such tools are useful in any social context"[14]. Instrumentalists consider technology neutral in relation with

[12] Ibid pp3-11

[13] Ibid pp3-6

[14] Ibid pp2-5

the surrounding social context. Instrumentalism is overwhelmingly present in the "Status Quo" approaches and has a big influence among the "Reform" supporters. The term eco-innovation was born in this theoretical framework and is rooted in the positivist faith in technology as universal solution of human problems. The edge between the Status Quo and Reform supports is occupied by Green Economists or Ecological Modernisers, who advocate moving to an "Ecological modernisation" of industrial societies through eco-innovation. Nevertheless, even according to these scholars, this process is far from being a mere technological change. Because markets fail to deal with environmental externalities, this Ecological Modernisation has many political implications[15]. Governments and local authorities need to be an active part of the process and, as it always occurs in the innovation dynamic; Ecological Modernisation is likely to encounter many opponents among those stakeholders that receive large benefits from the present socio-technological regime. Moving to the top-right of the chart, critics of instrumentalism approach claim that mainstream perspectives fail in dealing with social and institutional dimensions. Some of those critics argue that the innovation direction should be shifted from labour-saving to resource-saving technology and this is not taking place on a global scale. What is more, mainstream supporters of sustainable development believe in a dematerialization of economy[16] that is still far from being achieved in the real world[17]. Minority positions, which occupy the area of "Transformation" in the chart, are influenced by the so-called *Substantivism* approach. Their main argument is that technology is an automatic and unstoppable process that continuously reshapes the whole social life introducing new values[18]. Technology is not neutral; on the contrary, it might have a tremendous impact in changing the entire society. According to such a perspective sustainability is eventually dependent on new socio-cultural values instead of technologies and competitive markets[19]. Not only does technology have non-neutral nature, but it has social and environmental costs too. Moreover it is not easily transferable to other contexts, such as developing countries, because it might exacerbate ecological degradation and destroy local cultures heading to environmental conflicts[20]. Table 1

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[15] M. Jänicke, "Ecological modernisation: new perspectives," Journal of Cleaner Production, 16, 5, 2008, pp. 557-565.

[16] Dematerialization of economy refers to the absolute reduction in the quantity of materials and energy required to serve economic functions in society.

[17] T. Jackson, Prosperity without growth? The transition to a sustainable economy. Sustainable Development Commission, London 2009.

[18] E. Paredis, "Sustainability Transitions and the Nature of Technology," Foundations of Science, 16, 2, 2011, pp. 195-225.

[19] W. Sachs, "The development dictionary. A guide to knowledge as power. In E. Paredis (Ed), Sustainability Transitions and the Nature of Technology," Foundation of science, 16, 1992, pp. 195-225.

[20] Ibid pp3-10

summarises the conceptual implications for technology and eco-innovation of the three macro-approaches illustrated so far.

Table 1 Sustainable development and the nature of technology: three different approaches

	Technology approach	**Eco-innovation approach**
Status quo	Instrumentalism	Market driven innovation
Reform	Instrumentalism	Ecological modernization, efficiency, transfer of clean technologies to developing countries
Transformation	Substantivism	New values, different power structures, appropriate technologies

The Status Quo promoters deal technology with an *Instrumentalist* framework and basically rely on markets forces to drive eco-innovation. The so-called reformists argue that an ecological modernization is needed to achieve a sustainable transition and further political and social reforms are necessary to foster such a process. They mostly consider technology as a neutral phenomenon and advocate a global diffusion of clean and energy-efficient technologies all around the world. Lastly, the supporters of a Radical Transformation argue that technology has big social implications. Fostering sustainability implies changing values and different power structures as well as a proper adaptation of technological process to local contexts.

What do we mean by eco-innovation?

In the last two decades there has been a tremendous increase of academic works focused on different formulations of eco-innovation[21]. However, the analysis of the literature strongly suggests that notions like eco-innovation, sustainable innovation and green innovation are used for very similar topics by different scholars. Surprisingly, it is almost impossible to find a precise definition of "sustainable innovation", "green innovation" and "environmental innovation". On the contrary, many different definitions have been proposed for "eco-innovation". One of the first definitions of eco-innovation appears in the work of Fussler. It is stated that *"Eco-innovation is the process of developing new products, process or services which provide customer*

[21] F. Tietze, T. Schiederig, and C. Herstatt, "What is Green Innovation?–A Quantitative Literature Review," in The XXII ISPIM Conference - Sustainability in Innovation: Innovation Management Challenges, 2011.

and business value but significantly decrease environmental impact"[22]. Klemmer[23] provides a similar definition specifying the actors involved:

"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."*

Andersen[24], who is more interested in a market-oriented approach to eco-innovation, provides a different perspective claiming that "*[Eco-innovation is] innovation which is able to attract green rent on the market*". Actually, her main argument is that firms are always seen as polluters rather than eco-innovators. Along the same lines Keeble et Al.[25] state that *"Sustainability-driven innovation is the creation of new market space, product and services or processes driven by social, Environmental or sustainability issues".* On the one hand these scholars introduced the concept of social sustainability, though it is not clearly specified and remains a quite vague notion. On the other hand, they state explicitly that sustainable innovation requires new markets. Many other scholars are satisfied with a general definition advocating "green products and green processes". Chen et Al.[26], for instance define eco-innovation *"as hardware or software innovation that is related to green products or processes, including the innovation in technologies that are involved in energy-saving, pollution-prevention, waste recycling, green product designs, or corporate environmental management".*

In 2007 the European Commission started a programme for Innovation funding titled "Competitiveness and Innovation Framework Programme". A vast portion of the programme is dedicated to finance eco-innovation. The guidelines document they states that *"Eco-innovation is any form of innovation aiming at significant and demonstrable progress towards the goal of sustainable development, through reducing impact on the environment or achieving a more efficient and responsible use of natural resources, including*

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[22] C. Fussler and P. James, Driving eco-innovation: A breakthrough discipline for innovation and sustainability. Pitman, London 1996.

[23] U. Klemmer Lehr and K. Lobbe, "Environmental Innovation. In: Rennings, K., 2000. Redefining innovation — eco-innovation research and the contribution from ecological economics." Ecological Economics, 32, 1999 pp. 319-332.

[24] M. M. Andersen, "Eco-innovation towards a taxonomy and a theory," in DRUID Conference Entrepreneurship and Innovation, 2008.

[25] J. Keeble, D. Lyon, D. Vassallo, G. Hedstrom, and H. Sanchez, Innovation High Ground: How Leading Companies are Using Sustainability-Driven Innovation to Win Tomorrow's Customers. Arthur D. Little, 2005.

[26] Y.-S. Chen, S.-B. Lai, and C.-T. Wen, "The Influence of Green Innovation Performance on Corporate Advantage in Taiwan," Journal of Business Ethics, 67, 4, 2006, pp. 331-339.

energy[27]*".* Again the concept of Sustainable development is recalled to define what the ultimate goal of eco-innovation is. The European Commission initiative INNOVA provides a more elegant definition saying that *"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 minimal release of toxic substances*[28]*".* This definition represents a step forward because it includes two important ideas. The first one is the idea that eco-innovation is a specific kind of innovation not only designed to create new markets or substitute obsolete ones, but mainly to satisfy "human needs". The second notion is about the environmental setting that surrounds the innovation dynamic.

An alternative definition is proposed by Kemp[29]: *"[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*". An analogous definition was also proposed by the OECD in 2009. The OECD observer document says that eco-innovation is "*the creation or implementation of new, or significantly improved, products (goods and services), processes, marketing methods, organisational structures and institutional arrangements which - with or without intent - lead to environmental improvements compared to relevant alternatives*"[30]. Such a definition contains a clear reference to organizations and institutional settings as specific typology of eco-innovation. Finally, Oltra[31] defines it *"as innovations that consist of new or modified processes, practices, systems and products which benefit the environment and so contribute to environmental sustainability"*

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[27] The definition is in the in the Guideline Document for the "Competitiveness and Innovation Framework Programme" of the European Commission. The entire can be downloaded from http://ec.europa.eu/environment/etap/files/guidelines_for_cip_eco_innovation.pdf

[28] The definition was published in the Thematic Workshop, Lead Markets and Innovation, 29-30th June 2006, Munich, Germany. More information about the Eco-innovation Observatory of INNNOVA can be found at http://www.eco-innovation.eu/

[29] R. Kemp and P. Pearson, "Final report MEI project about measuring eco-innovation," Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006) - Project No: 044513, Brussel, 2007.

[30] OECD, "Sustainable Manufacturing and Eco-innovation: Towards a Green Economy," Paris, 2009.

[31] V. Oltra and M. Saint Jean, "Sectoral systems of environmental innovation: An application to the French automotive industry," Technological Forecasting and Social Change, 76, 4, 2009, pp. 567-583.

All the mentioned authors conceive eco-innovation as a process of novelty creation that should be able to lead to a more responsible and efficient use of resources and minimise the impact of human activity on the environment. Four essential concepts come out from the eco-innovation literature:

- Eco-innovation is mostly situated within the boundaries of Innovation Theory. The innovation object, indeed, is always a process, product, service or a method;
- Most of the authors think that eco-innovation creation should be market-oriented. It should be a win-win process able to preserve the environment and, at the same time, improve firms competitiveness;
- Though the concept of environmental impact is quite vaguely defined, all the definitions underlie the idea that human action represents a burden on the environment that should be reduced;
- Finally, some authors advocate a broader view of eco-innovation including institutional and social aspects.

The purpose of eco-innovation: green growth, sustainable development or ecological equilibrium?

In the literature it is evident that the debate underlines two different visions of sustainability: Ecological Modernisation (or Sustainable Development position) and Ecological Economic framework.

The first one is fundamentally based on the Schumpeterian idea of innovation as engine of economic growth and capitalist expansion. According to this theoretical framework, eco-innovation is the outcome of a co-evolutionary process that continuously takes place between economic systems and the environment. This process is driven by novelty creation within a free-market dynamic with the scope of creating economic valuable innovations and, at the same time, it is influenced by other sources of pressure. Those forces are usually identified in institutions, civil society and governments. The analysis of mainstream economics literature, dominated by the "neo-classical school", suggests that source and the scope of eco-innovation is situated in a free market dynamic where regulations and laws are only tolerated to adjust market failures, for instance, environmental degradation. The argument of eco-innovation is often presented as a novel instrument to reactivate the stagnant economic growth of industrialised countries. Neo-classical approaches reckon that pollution and environmental degradation are the result of externalised costs of industrial process. Whenever a company performs a harmful action on the environment, it charges the consequences of eco-systems degradation to the entire society. In a nutshell, the unsustainable behaviour is considered a cost that is externalized by the firms and charged on the society. This branch of neo-classical theory is known as Environmental Economics. The supporters of this school consider eco-innovation an essential instrument to minimise the externalities cost and gain competitive advantages when strict environmental regulations are put in place[32].

[32] M. E. Porter and C. Van der Linde, "Toward a new conception of the environment-competitiveness relationship," The Journal of Economic Perspectives, 9, 4, 1995, pp. 97-118.

The second approach considers the economic process a sub-system of a wider Planet-System. This position implicitly changes the scope of eco-innovation from a development instrument to a systemic tool to reshape the equilibrium between industrial society and nature. The main difference between those approaches however is about the role of technology. Sustainable development supporters reckon that technological change will somehow find a solution to ecological problems whilst Ecological Economists argue that eco-innovation cannot be considered a standalone phenomenon. On the contrary, it is necessary to look at the absolute impact of technological innovation. Reductions in the emissions of vehicles, for instance, might be easily neutralised by increasing road traffic. This paradox is known as Dilemma of N-curve[33]. As a consequence, eco-innovation should not be considered a normal kind of innovation that can be analysed using a reductionist approach. Eco-innovation requires a systemic approach, a broader framework of analysis able to include global parameters that normally are neglected in the study of classic innovation. An ecological approach represents just a minority position within the present economic and environmental debate; however it provides intriguing and useful insights to the study of eco-innovation. The following sections are dedicated to illustrate the major contribution of Ecological Economics to the Innovation Theory.

Eco-innovation in production and consumption: some practical implications from the Ecological Economics School

Ecological Economics is characterised by a multidisciplinary approach and aims to cope with the shortcomings of mainstream economics in dealing adequately with nature, justice and time. As it was already mentioned, one of the most important contributions of Ecological Economics has been the inclusion of natural boundaries in the analysis of the economy[34]. An over simplified model of the economic cycle proposed by ecological economists is shown in Figure 2 and is composed by two main elements:

- Processes
- Consumption

Every human activity underlies a process. Producing food, extracting minerals and transforming raw materials are all processes. The output of a process can be a product or another process and always involves a specific sequence of tasks. Not only does the notion of process include the design and production, but also delivery processes like transportation and distribution. The automobile industry, for instance, is composed of an extremely complex system of processes that include the extraction of natural resources, energy and eventually the distribution and sale of a product commonly known as “car”.

[33] M. Jänicke, “Ecological modernisation: new perspectives,” Journal of Cleaner Production, 16, 5, 2008, pp. 557-565.

[34] Ibid pp2-4

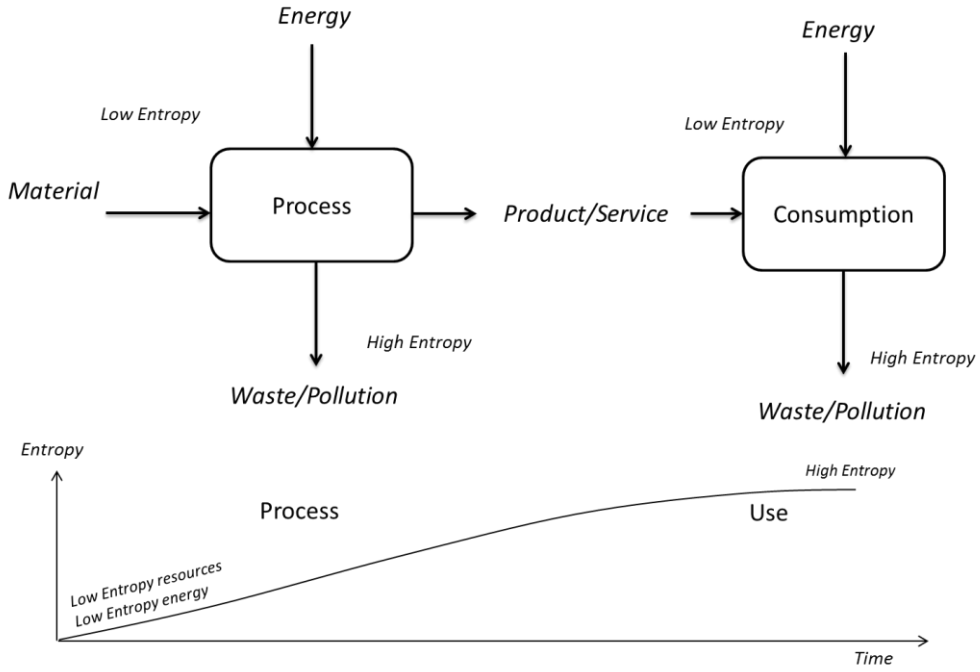

Figure 2: General Product/Service delivery model

The external boundaries of this chain of processes/consumption are defined by the limits of the planet. Moreover, the whole dynamic of this continuous exchange of energy, material and wastes does not escape from the Laws of Thermodynamic. The whole system, indeed, can be seen as a mechanism fed by low entropy, which releases high entropy back to the system. Human activity can actually be compared by an organism that absorbs low entropy to maintain its internal equilibrium and releases high entropy back to the environment[35]. According to the 2nd Law of Thermodynamics, the high entropy released into the system cannot be reused with the same efficiency of the original process because energy degrades along the process. In other words, all processes in nature are not reversible**,** on the contrary, they have a determined direction. That is why a living organism cannot feed itself with its wastes. If such an organism existed, it would be a classical example of *Motus Perpetuum* and it would clearly infringe the Laws of Thermodynamics. This is also true for economic systems because, in one way or another, they eventually are based on environmental services and products. Hence, economies evolve following a determined direction that means that they change by energy dispersal[36]. As the entropy of a closed system can only increase, eventually all low entropy sources come from the sun. The awareness of the ineluctability of the entropic process has important consequences. First of all, it imposes certain limits to the system. In order to maintain an internal equilibrium, *conditio sine qua non* for the survival of the life on the planet, the system should be able to acquire low entropy from an external source without compromising the non-renewable sources within it. If

[35] N. Georgescu-Roegen. The entropy law and the economic process. Harvard University Press, Cambridge, Mass 1971.

[36] A. Annila and S. Salthe, "Economies Evolve by Energy Dispersal," Entropy. 11, 2009, pp. 606-633.

the extraction of high entropy exceeds the regenerative capacity, the system will inevitably encounter an "Entropic Death", which is a state where no-process can take place. These considerations lead to important conclusions:

- There are limits to the use of non-renewable resources like fossil fuels, metals, minerals, fresh water and so on. Recycling is only a partial solution because every cycle always implies an increase of Entropy in the system.
- There are thresholds for the use of non-renewable sources above which an over exploitation can cause unpredictable nonlinear effects.
- The perturbation of the dynamic equilibrium of ecosystems, that means reservoir degradation, soil erosion or climate change can lead to non-linear unpredictable changes. We are not fully aware about human society's resilience and the discussion about a safe operating space for humanity is a relatively recent debate[37].

From this perspective, the soaring industrial development of human society represents a critical perturbation of the system because of its extensive use of low entropy reservoirs, like oilfields and ores, which are virtually impossible to restore in a human temporal scale. However, looking at the history of human beings, the industrial era represents a minimum portion. For millennia humans have been coevolving with the environment without seriously jeopardizing the ecosystem equilibria. In its dynamic equilibrium, natural environment is characterised by a complex system of nested feedback cycles, which allow the evolution of all the elements that compose it. Even though the system is continuously changing and evolving, it always fluctuates around a dynamic state of equilibrium. This dynamic, see Figure 3, is based on a continuous flow of energy and material between the main external source of low entropy, which is the sun, and natural sinks that have a limited regenerative capacity.

[37] J. Rockstrom et al., "A safe operating space for humanity," Nature, 461, 7263, 2009, pp. 472-475.

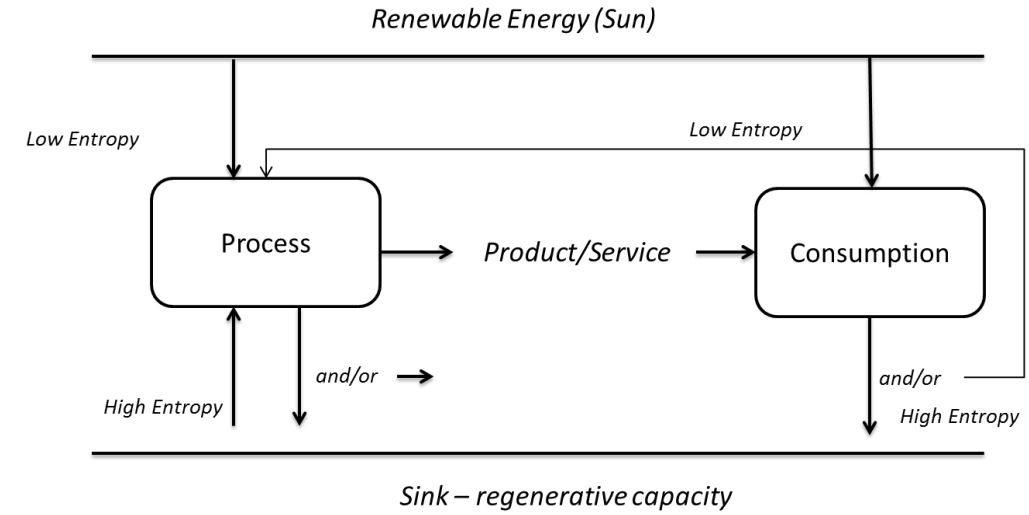

Figure 3: Ecological process of product/service delivery

This mechanism allows nature to flourish, evolve and produce the great diversity that characterises the life of the Earth. All the processes in the system absorb low entropy in form of matter or energy to produce products or services with lower entropy and, at the same time, release into the system high entropy in form of emissions or wastes. The sustainability of the system is guaranteed by the regenerative capacity of the system to recycle waste and emissions to create new processes, products and services. The system does not cease to be entropic, which means that also in this case the entropy increases by every single step in the process. However, the total entropy remains relatively stable. The system, in fact, regulates itself according to the availability of low entropy sources. As long as an external source, i.e. the sun, irradiates low entropy energy, the system is perfectly able to sustain itself indefinitely[38].

The field of action of Eco-Innovation

The reasoning illustrated above suggests that the role of eco-innovation should be to allow the reconciliation between human artefacts and the ecosystem equilibrium. Thus ecological innovation should attempt to move from the present system we are locked-in to an ecological system capable of maintaining an entropic equilibrium. This can be done acting on the key variables of the productive/consumptive system of human ecosystems as shown in Figure 4.

[38] N. Georgescu-Roegen, "Energy and Economic Myths," Southern Economic Journal, 41, 3, 1975, pp. 347 - 381.

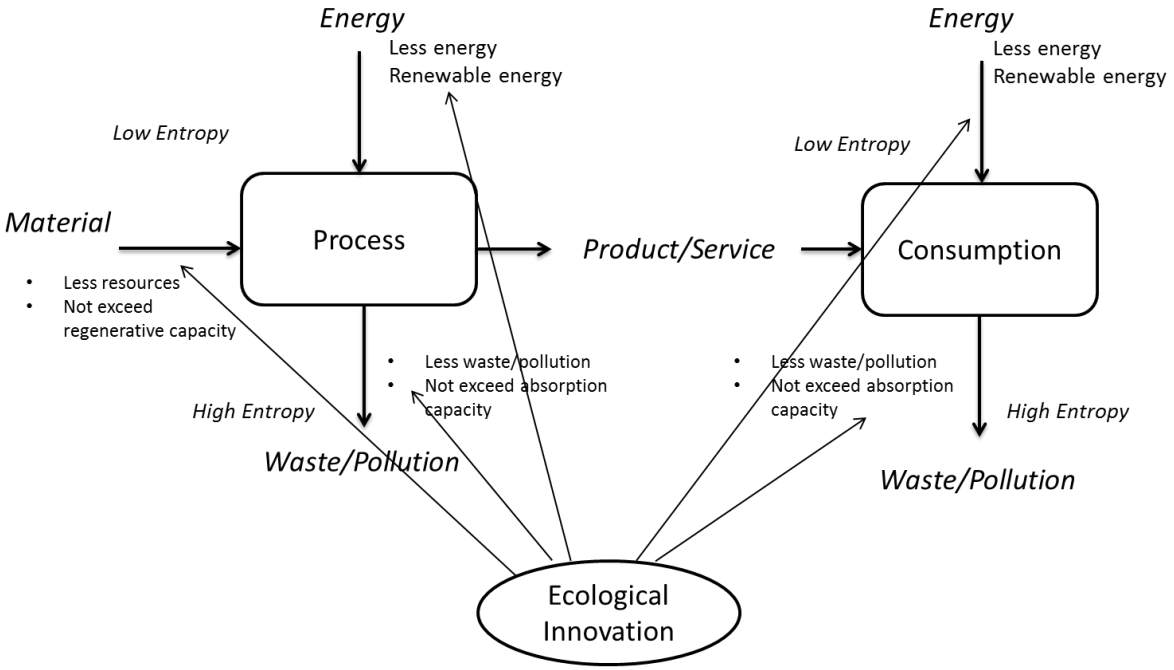

Figure 4: Eco-innovation field of action

Eco-innovation, thus, must point to:

- Less energy in productive process
  - Improving energy efficiency
  - Taking into account the source of energy
- Less energy in the use of product/services
  - Improving energy efficiency of products and services
  - Taking into account the source of energy
- Material Input
  - Reduce the input materials
  - Do not exceed the regenerative capacity of the sinks
- Material Output
  - Produce a minimum amount of wastes, pollution or emissions
  - Do not exceed the absorption capacity of sinks

Incremental and radical Innovation in processes and products

Hence, what are the practical implications of eco-innovation in the Ecological Economic perspective? Basically eco-innovation can occur in three dimensions: Energy, materials and wastes. For instance a specific technology X_i is always the sum of material consumption, energy consumption and waste production:

$$X_i = X_{material} + X_{energy} + X_{wastes}$$

Such a variable could be defined as "*Ecological Efficiency Index*". Even though an accurate measurement of X_i would present serious problems in the real world, it is useful to understand and distinguish different ecological degrees of eco-innovation. Let X_i belong to the space of all possible combinations of $(X_{material}, X_{energy}, X_{wastes})$. Hence we can define Ecological Innovation as new and economically valuable piece of knowledge, which yields a new combination $X_j = X_{material} + X_{energy} + X_{wastes}$, where X_j is greater than X_i.

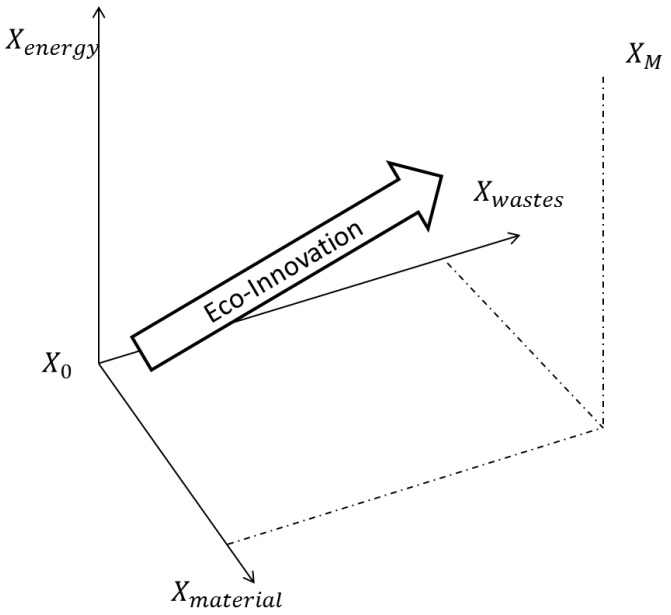

Figure 5: Space of Eco-Innovation

However, it is important to note that in the real word X_M cannot be defined in absolute terms. In fact, up till now we simply defined eco-innovation in processes, products or services as an atomic entity. However, every technology is embedded in a complex system of interaction between users, producers, suppliers and other technologies. Speaking about eco-innovation as an isolated notion is completely meaningless. Because of the N-curve dilemma, no technology is sustainable *a priori.* Since the environmental sustainability of a specific system strongly depends on the sustainability of its composing technologies, the final outcome will eventually be the results of all the interactions of those elements. In other words, sustainability should be always *formulated as a two-place predicate or dyadic operator*[39]. It does not make sense asking if a specific technology is sustainable if we do not specify in which respect it is sustainable.

[39] Ibid pp2-5.

Radical and incremental innovation in processes

Considering eco-innovation in process, we can define a process as a sequence of a certain number of steps (see Figure 6). Each step is defined by the three parameters (Material, energy and wastes) defined above.

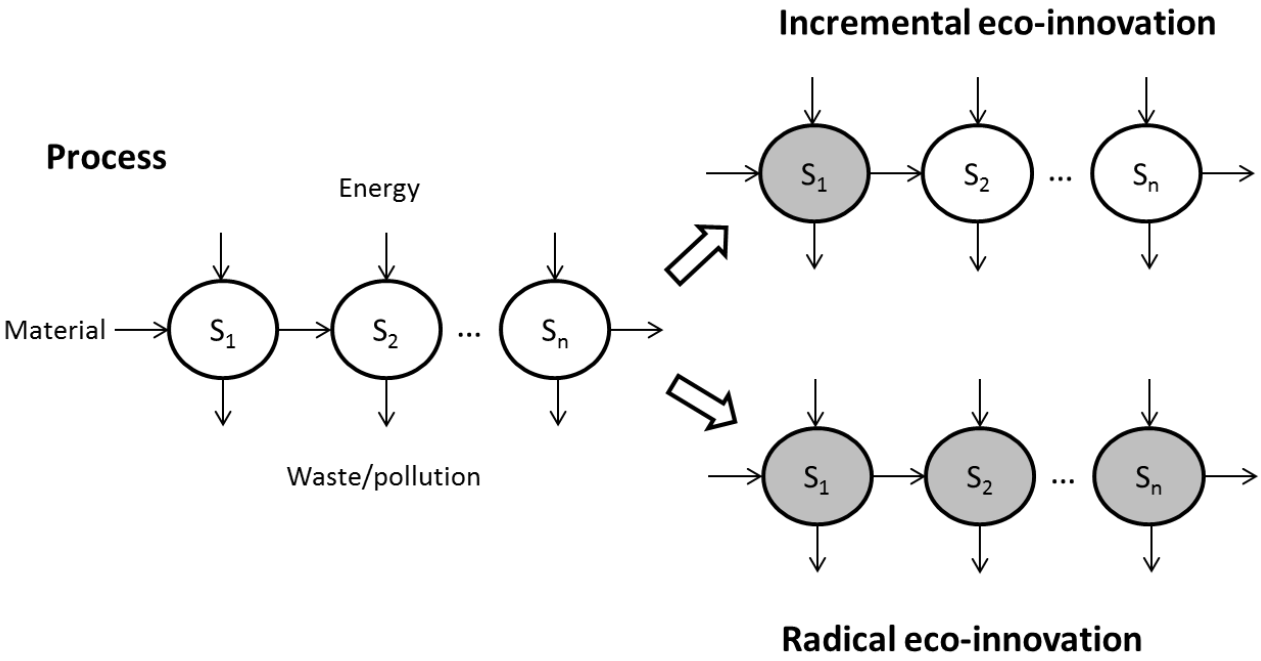

Figure 6 Radical and Incremental Eco-innovation in process

Incremental: we say that a process eco-innovation is incremental if one or more of the 3 dimensions changes in one or more of the step of the process and if the final outcome X_j is greater than the former one X_i.

Radical: when all the dimensions of all the steps of a specific process improve we have a radical innovation. This change usually coincides with the arrival on the scene of a totally new technology. In this case the value of the sustainability improvement is normally greater than an incremental eco-innovation.

Radical and incremental innovation in products/services

Regarding product or service eco-innovations, we can distinguish between three categories (see Figure 7): i) products/services that need material, energy input and produce wastes or emission; ii) products/services that require only energy to work and produce wastes or emissions; iii) product/services that simply produce emissions or wastes at the end of their life.

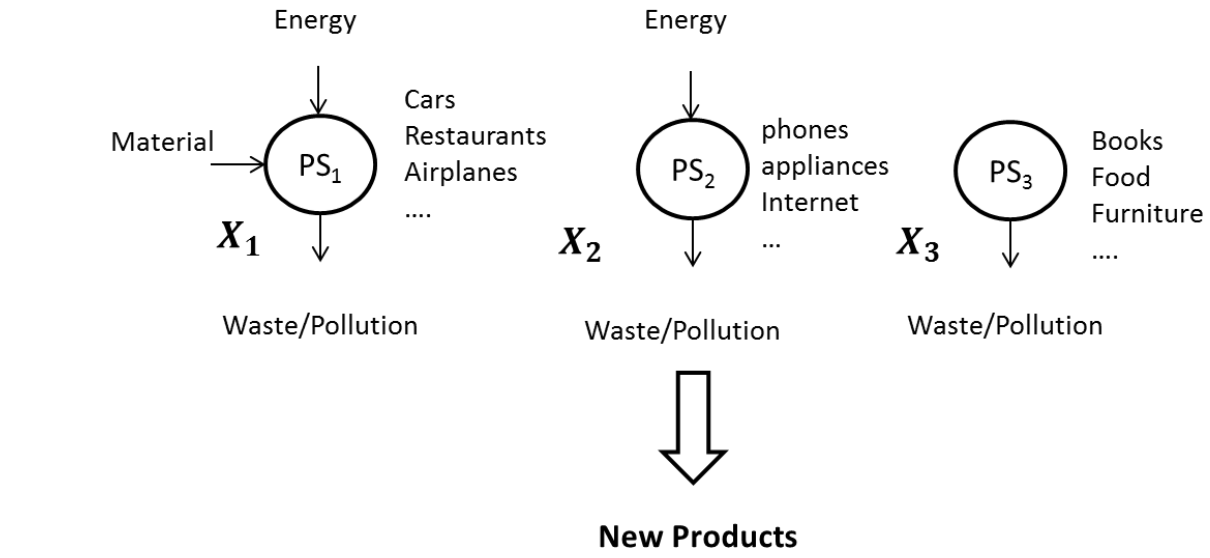

Figure 7: Product/service eco-innovation

Similarly to process eco-innovation, a product/service incremental eco-innovation occurs when one or more dimensions increase its level of sustainability without changing the general technological setting. On the other hand, a radical eco-innovation occurs when a new configuration, which involves all the sub-systems of a specific technology, takes place.

Summarising, the practical implications of eco-innovation are elegantly described by the concept of Eco-efficiency defined in the report of world Business Council for Sustainable Development in 2000. The report states that eco-efficiency is "*the delivery of competitively priced goods and services that satisfy human needs and bring quality of life while progressively reducing ecological impacts and resource intensity, through the life cycle, to a level at least in line with the earth's estimated carrier capacity*"[40]. Eco-efficiency means less environmental impact per unit of product or service value. Nevertheless, in the real world**,** processes and products/services never go alone. Actually they are embedded in a network of other processes, products and services that are very difficult to isolate and study separately. Most of the process and products in the real world are composed by other processes and products in a very complex way. Eco-innovation involves different layers of those structures. We can distinguish 3 level of eco-technological change:

[40] World Business Council for Sustainable Development, "Eco-efficiency. Creating more value with less impact," Geneva, 2000.

- Add-on component: change in one step of the process or one dimension of service-products (Incremental Eco-innovation)
- Sub-system changes: change of a specific group of steps process products or services (Incremental Eco-innovation)
- System Change: radical change of all the dimensions, new socio-technical regimes that such as closed-loop systems (Radical Eco-innovation)

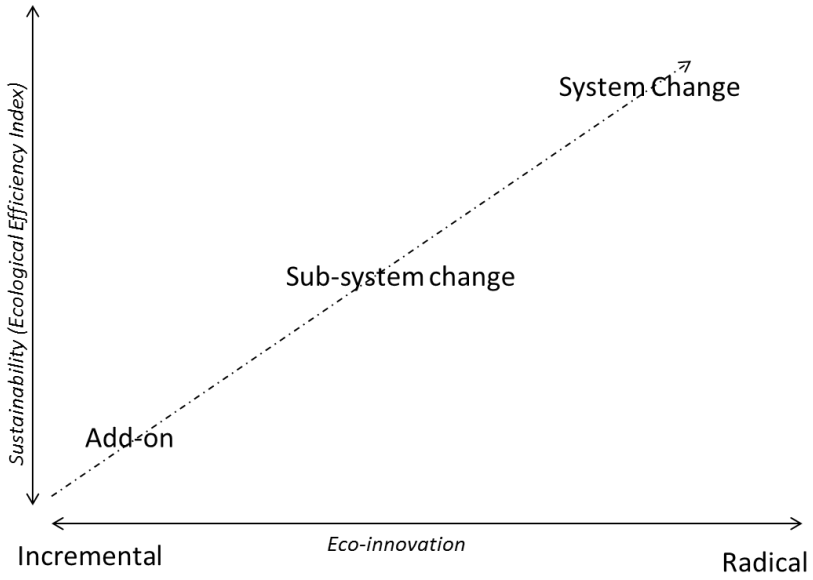

Figure 8: Eco-innovation macro-typologies[41]

As we already stated above, efficiency increase alone is not enough to guarantee environmental sustainability. The ecological modernization is bound to fail if a valid solution for the N-curve dilemma is not provided. We have seen that most of the mainstream analysts have a blind faith in technology development to cope with environmental constrains. However, many others are firmly convinced that a real transition should include major changes in the way we conceive economic growth. Such changes are likely to take place only with a social evolution towards a more sustainable arrangement of the present system of the values that characterise our societies. In sum, 'social and institutional eco-innovations' are necessary.

Social and institutional eco-innovations

According to the "Neo-classic School", innovation stretches the limits of the ubiquitous scarcity that has been affecting humanity from time immemorial and provides infinite possibilities to improve men's and

[41] Based on: J. Carrillo-Hermosilla, P. del Rio Gonzalez, and T. Könnöla, Eco-innovation: When sustainability and competitiveness shake hands. Palgrave Macmillan, New York 2009.

women's welfare. According to this reasoning, eco-innovation would provide increasing wellbeing in a sustainable way for the present and the future generations. Nevertheless the essence of human welfare is widely conceived, at least in the western paradigm, as having more of everything. Hence, the argument is that growth always augments welfare. However, from the first formulation of sustainable development concept, which reinvigorates the principle of capitalist expansion in a new fashion green dress, many criticisms have been advanced to question this assumption. According to Herman Daly[42], mainstream economics tends to overestimate the benefit of economic growth in the long term and, above all, does not take into account the natural and moral limit to growth. He argues that the mainstream tends to neglect or minimise the "opportunity cost of economic growth". Such a cost is essential in economics and is defined as the next best alternative to the one chosen, in other words, as the best of the sacrificed alternatives. Opportunity cost of growth is virtually zero because there is no real alternative to economic expansion to improve human welfare. However, the marginal costs of economic growth are becoming more and more evident in the last decades. Growing more, especially in industrialised countries, is getting more and more expansive and requiring more investments. Thus, it does make sense to question, as the marginal costs of growth have increased, what has happened to the marginal benefits. Studies in many countries show that, beyond a threshold of sufficiency, growth in income does not increase happiness[43]. Actually growth might become uneconomic at the margin, and even makes us poorer, in particular if it leads to less available wealth to share with the poor. The increasing inequalities in US, Europe and emerging economies seem to confirm this conclusion. Consequently, eco-innovation should not be merely considered in its Schumpeterian function that is expanding natural limits through economic growth, but as an instrument to assure social inclusion and welfare sustainability. Social and institutional eco-innovations, thus, refer to those changes that occur in values, relationships and behaviour of producers and consumers. Such changes are hardly measurable because they often imply non-monetary exchanges or can even contribute negatively to the national accounts like GDP. Increasing local food production or self-production, for instance, might lead to a shrinking of import/export flows and at the same time a reduction in energy use due to transportation, packing and commercialization of products processed all around the globe. Change in consumption habits, self-production, conviviality and exchange dynamics outside of the market are all phenomena that are not taken into account by neo-classic approach because they do not imply cash flows. However those social instruments are crucial in many traditional cultures for the survival of millions of people and are regaining importance in developed countries. In this process, rather than market-forces, a very important role is played by civil society. More and more people in the industrialised countries are acquiring awareness about the

[42] H. E. Daly, "The economic growth debate: what some economists have learned but many have not," Journal of Environmental Economics and Management, 14, 4, 1987, pp. 323-336.

[43] R. A. Easterlin, "Will raising the incomes of all increase the happiness of all?" Journal of Economic Behaviour & Organization, 27, 1, 1995, pp. 35-47.

importance of individual actions in fostering sustainability from the bottom[44]. Nevertheless such initiatives have limited impact on the big figures of national accounts, because of its already mentioned unaccountability, but also because they are undertaken by isolated groups. Nonetheless, while civil society is changing, the same does not seem to happen in formal institutions that are often characterized by a tremendous inertia. The nature of institutional change appears to be even more complex when we consider that it involves a larger sphere of humans' affairs than the mere economic dimension. Many institutions are strongly related to religious beliefs and territorial evolutions. Rather than improving economic performance, in many traditional societies, institutions aim to preserve the integrity and stability within them[45]. Based on the above reasoning we can claim that social and institutional eco-innovations require at least the following elements:

- Cultural and Institutional diversity to assure flexibility and adaptability to changing environments;
- Involvement of local actors and their traditional heritage to assure continuity and ethical motivation;
- Involvement of local actors in the process of decision making about environmental issues favouring the territorial aspects;
- Educated citizens rather than docile customs. People should be aware of the impact of their actions as technology users on the environment;
- Communication and investment in social capital. Enhance the faith in the economy of commonality.

Those concepts can be considered fundamental to build a theoretical, economic framework focused on the conviction that cultural models and local capabilities are fundamental for development as well as for sustainability. This bottom-up process is also known as inclusive development[46]. This process requires rethinking the institutions of the market, repositioning it "*within time and space, embedding it within local contexts so that it has a more immediate reality to participants*"[47].

Conclusions

This article explores the origin of the notion of eco-innovation providing new insights from the Ecological Economics approach. Although the discrepancies among different environmentalism currents and economic

[44] T. Hargreaves, A. Haxeltine, N. Longhurst, and G. Seyfang, "Sustainability transitions from the bottom-up: Civil society, the multi-level perspective and practice theory". CSERGE Working Paper 2011-01.

[45] T. N. Jenkins, "Putting postmodernity into practice: endogenous development and the role of traditional cultures in the rural development of marginal regions," Ecological Economics, 34, 3, 2000, pp. 301-313.

[46] G. George, A. Macgahan, J. Prabhu, "Innovation for inclusive growth: towards a theoretical framework and a research agenda". Journal of Management Studies. Forthcoming 2012.

[47] V. Fournier, "Escaping from the economy: the politics of de-growth," International Journal of Sociology and Social Policy, 28, 11-12, 2008, pp. 528-545.

schools, social and technical change is likely to play an essential role in the transition toward a sustainable society. Creativity and innovation have been an essential source of change in the history of humanity and there is no reason to think that they will not be crucial to achieve a renewed equilibrium between human artefacts and nature. This review does not attempt to provide a comprehensive description of the modern sustainability debate, but rather to include new insights, borrowed from other disciplines, to the discourse around innovation and its role in creating a sustainable world. The challenge for the near future is to understand the potential of eco-innovation as a tool of change on a global as well as at a local scale**,** implementing adequate policies to guide such a change. As Tidd and Bessant[48] showed, innovation moves in a bi-dimensional space, which defines its intensity and potential to pioneer new paradigms (see Figure 9). There is founded evidence that eco-innovation follows a similar dynamic. Most eco-innovations are placed in the comfortable space of the dominant paradigm. It does not really matter if they provide incremental improvements or radical changes if they remain within the boundaries of the dominant paradigm.

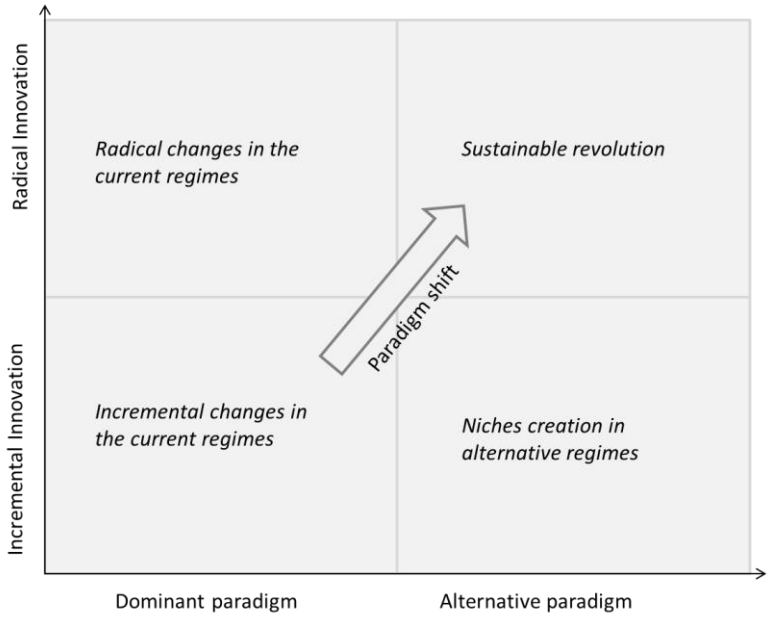

Figure 9: Innovation dynamic for sustainable transition[49].

The paradigm shift advocated by ecological economists, environmental activists and the occupiers of the area between "reform" and "transformation" groups in Figure 1, requires the rise of an alternative regime

[48] J. Tidd and J. R. Bessant, Managing innovation: integrating technological, market and organizational change, 4th ed. John Wiley & Sons Inc, Chichester 2009.

[49] Based on Ibid pp21-48

that can initially appear in the form of niches to generate eventually a desirable sustainable revolution. The relevant point in this analysis is not if this transition should or should not occur; there is no alternative to avoid the collapse of the modern industrial economy without changing its devastating relationship with the environment. The important questions are “how is this transformation going to occur?” and “Who will be the main actors?” These are probably the most important questions of our age.