The Origins and Purpose of Eco-Innovation

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Since the early moments of the industrial revolution, technical change has always been associated with humankind's ability to dominate the natural world. When the modern notion of innovation was formalised by Schumpeter and his followers, it was defined in terms of the expansion of capitalism and its capacity to manipulate the natural environment.[1] The Austrian economist states that the very engine of capitalist expansion is innovation, which continu-

ously disrupts the way goods and services are produced and delivered. Only in the late 1960s did the connection between innovation and sustainability begin to attract the interest of the academic world. A crucial contribution to the sustainability debate was provided by the famous and controversial Report *Limits to Growth*, commissioned by the Club of Rome. The main argument of the authors was 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 Neoclassical Economics School, reckoned that technology was the only solution for all environmental issues. Despite these 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, focussing on the concept of environmental externalities, and Ecological Economics, focussing on the relationships between the economic system and nature[4]. Although those two approaches differ on several points, there is no doubt that in both schools of thinking the debate about sustainability has a strong technological

[1] J.A. Schumpeter, *The Theory of Economic Development: An Inquiry into Profits, Capital, Credit, Interest, and the Business Cycle*, Harvard University Press, Cambridge 1934.

[2] D. Meadows, J. Randers, *Limits to Growth: The 30 Year Update*, Chelsea Green, White River Junction, Vermont 2006.

[3] Newsweek, 13 March 1972, p. 103.

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

component. As a consequence, the last three decades have seen an increasing interest in an interdisciplinary approach drawing on innovation studies, evolutionary economics, governance and sociology[5]. The notion of innovation has 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 its formulation back to the 1972 UN Stockholm Conference on the Human Environment. They also suggest that the first use of the phrase "sustainable development" can 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). According to Dresner,[7] the concept was first used in 1980 by the International Union for the Conservation of Nature and Natural Resources in their *World Conservation Strategy Report*. The Report advocated "the integration of conservation and development to ensure that modifications 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 has spread all around the world thanks to the *Brundtland 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

[5] E. Paredis, "Sustainability Transitions and the Nature of Technology," in *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.

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

[8] N. Faber, R. Jorna, J. Von Engelen, "The Sustainability of 'Sustainability': A Study into the Conceptual Foundations of the Notion of 'Sustainability'", in *Journal of Environmental Assessment Policy and Management*, 7, 1, 2005.

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 implicitly adopts the idea of limits to development and growth, at least insofar as they are "imposed by the present state of technology". The idea behind Sustainable Development is that socio-technological change can eventually stretch the limits defined by environmental constraints. Sustainability becomes a goal reachable through a social and technological transformation of modern industrial society. The Brundtland Report establishes a fundamental and definitive distinction between two different currents of environmentalism: the "cult of wilderness", concerned with the preservation of wild nature, and "the gospel of eco-efficiency", which relies on technology to address environmental issues by improving energy and material-use efficiency.[10]

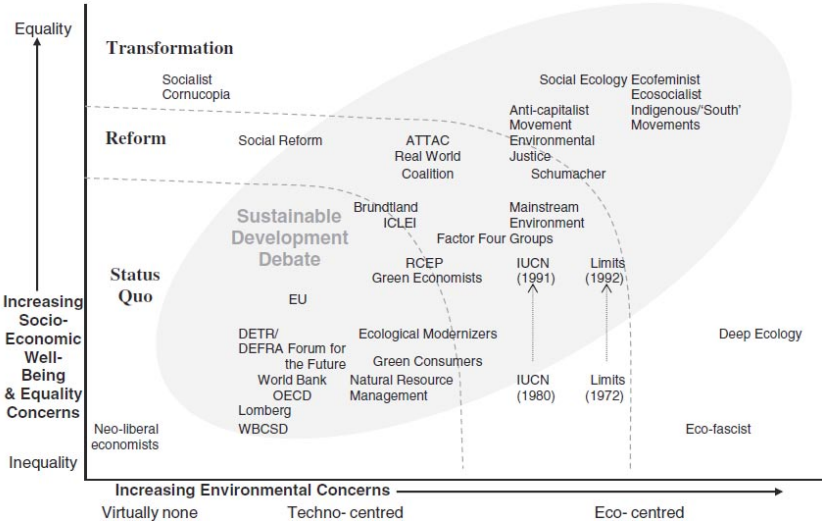
The concept of Sustainable Development thus inevitably leaves room for a huge variety of interpretations. Hopwood et Al.[11] have attempted to map the main approaches used in the Sustainable Development debate (see Figure 1). Their map has two dimensions: one is the equality dimension; the second is related to environmental concerns. The proponents of different approaches are classified in three main groups: the "status quo" or mainstream group, who claim 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 advocating a "reform process" of the existing economic system incorporating social and environmental ideas – this group includes the main environmental organizations and the

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

[10] J. Martinez-Alier, *The Environmentalism of the Poor: A Study of Ecological Conflicts and Valuation*, Edward Elgar, Cheltenham 2002.

[11] B. Hopwood, M. Mellor, G. O'Brien, "Sustainable Development: Mapping Different Approaches," in *Sustainable Development*, 1, 2005, pp. 38-52.

Figure 1. Sustainable development debate map[12]



majority of the scholars who deal with sustainability in the academia; and a third group invoking a radical transformation of the existing economic system as well as political and social institutions.

These perspectives address a wide range of concerns and offer as many solutions. The Status Quo and Reform groups, each one with different intensity, adopt an intrinsic *Instrumentalist* approach that advocates the design and deployment of environmentally friendly technologies capable of stretching the limits imposed by the present socio-technical setting and minimise the impact of human activity on the ecosystem. This approach is based on the idea, originated by the Brundtland 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 the "Instrumentalist approach to technology", considers technology as an isolated and independent phenomenon. Technology is an instrument with-

[12] Ibid., pp. 2-11.
[13] Ibid., pp. 2-6.

out any other purpose beyond 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 the surrounding social context. Instrumentalism is overwhelmingly present in "Status Quo" approaches and has a big influence among "Reform" supporters. The term "eco-innovation" was born within this theoretical framework and is rooted in the positivist faith in technology as the universal solution to human problems. In-between Status Quo and Reform supporters stand the Green Economists or Ecological Modernisers, who advocate moving to an "ecological modernisation" of industrial societies through eco-innovation. Still, even for these scholars this process is far from being a mere technological change. Because markets fail to deal with environmental externalities, their Ecological Modernisation has many political implications.[15] Governments and local authorities need to be an active part of the process and, as is always the case in innovation dynamics, 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 the instrumentalist approach claim that mainstream perspectives fail to deal with social and institutional dimensions. Some of those critics argue that the direction of innovation 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 "Transformation" zone in the chart, are influenced by the so-called *Substantivist* approach. Their main argument is that technology is an automatic

[14] Ibid., pp. 2-5.

[15] M. Jänicke, "Ecological Modernisation: New Perspectives", in *Journal of Cleaner Production*, 16, 5, 2008, pp. 557-565.

[16] The dematerialization of economy is 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.

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

and unstoppable process that continuously reshapes social life as a whole by introducing new values.[18] Technology is not neutral; on the contrary, it might have a tremendous impact in changing all of society. According to this perspective, sustainability ultimately depends on new socio-cultural values rather than technologies and competitive markets.[19] Not only is technology non-neutral in nature, but it has social and environmental costs. Moreover, it is not easily transferable to other contexts, such as developing countries, because it might exacerbate ecological degradation and destroy local cultures, leading to environmental conflicts.[20] Table 1 summarises the conceptual implications of technology and eco-innovation in the three macro-approaches illustrated so far.

The advocates of the Status Quo approach view technology within an Instrumentalist framework, so they basically rely on market 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 this process. They mostly consider technology as a neutral phenom-

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

[19] W. Sachs (ed.), *The Development Dictionary: A Guide to Knowledge as Power*, Zed Books, London 1992.

[20] Ibid., pp. 2-10.

enon 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 major social implications, and that fostering sustainability implies a change in values and different power structures, as well as proper adaptation of technological processes to local contexts.

What do we mean by eco-innovation?

In the last two decades there has been a tremendous increase of academic works setting forth different formulations of eco-innovation.[21] However, a perusal of the literature strongly suggests that notions like eco-innovation, sustainable innovation and green innovation are used by different scholars to describe very similar things. Surprisingly, it is almost impossible to find an accurate definition of "sustainable innovation", "green innovation" or "environmental innovation". On the contrary, many different definitions have been proposed for "eco-innovation". One of the first definitions is by Fussler: "Eco-innovation is the process of developing new products, processes or services which provide customer and business value but significantly decrease environmental impact".[22] Klemmer[23] gives 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.

[21] F. Tietze, T. Schiederig, C. Herstatt, *What is Green Innovation? A Quantitative Literature Review*, The XXII ISPIM Conference - Sustainability in Innovation: Innovation Management Challenges, Hamburg 12-15 June 2011.

[22] C. Fussler, P. James, *Driving Eco-Innovation: A Breakthrough Discipline for Innovation and Sustainability*, Pitman, London 1996.

[23] U. Klemmer Lehr, K. Lobbe, "Environmental Innovation. In: K. Rennings, 2000. Redefining Innovation: Eco-Innovation Research and the Contribution from Ecological Economics", in *Ecological Economics*, 32, 1999, pp. 319-332.

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 they fail to clearly define it, so that it remains a rather vague notion; on the other, they explicitly state 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 this programme is aimed at financing eco-innovation. The document guidelines state 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 energy".[27] Again the

[24] M.M. Andersen, *Eco-innovation: Towards a Taxonomy and a Theory*, Entrepreneurship and Innovation DRUID Conference, Copenhagen 17-20 June 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, C.-T. Wen, "The Influence of Green Innovation Performance on Corporate Advantage in Taiwan," in *Journal of Business Ethics*, 67, 4, 2006, pp. 331-339.

[27] This definition is found in the Guideline Document for the *Competitiveness and Innovation Framework Programme* of the European Commission, downloadable from http://ec.europa.eu/environment/etap/files/guidelines_for_cip_eco_innovation.pdf.

concept of sustainable development is evoked to define the ultimate goal of eco-innovation. The European Commission initiative INNOVA provides a more elegant definition: "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 is a step forward because it includes two important ideas. The first is that eco-innovation is a specific kind of innovation, whose aim is not just to create new markets or replace obsolete ones, but mainly to satisfy "human needs". The second regards the environmental implications of innovation dynamics.

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] This definition contains a clear reference to organizations and in-

[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, 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, Brussels 2007.

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

stitutional settings as a 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".

All the mentioned authors conceive eco-innovation as a means to achieve a more responsible and efficient use of resources and minimise the impact of human activity on the environment. Four essential concepts emerge from the literature on eco-innovation:

- Eco-innovation is mostly situated within the boundaries of Innovation Theory. The object of innovation is always a process, product, service or method;
- Most authors think that eco-innovation should be market-oriented. It should be a win-win process capable of preserving the environment and, at the same time, improving the competitiveness of firms;
- Though the concept of environmental impact is quite vaguely defined, all the definitions share the idea that human action is 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?

As the literature clearly shows, two different visions of sustainability underlie the current debate: Ecological Modernisation (or Sustainable Development) and Ecological Economy. The first 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 the parallel evolution of economic systems and the environment. This process is

[31] V. Oltra, M. Saint Jean, "Sectoral Systems of Environmental Innovation: An Application to the French Automotive Industry", in *Technological Forecasting and Social Change*, 76, 4, 2009, pp. 567-583.

driven by innovation within a free-market dynamic to the purpose of gaining economic advantages. At the same time, it is influenced by forces, usually consisting of institutions, civil society and governments. In mainstream economics literature, which is dominated by the neoclassical school, the general consensus is that the source and purpose of eco-innovation are situated within a free market dynamic where regulations and restrictions are only tolerated as a means to make up for negative side-effects of the market such as, for instance, environmental degradation. Eco-innovation is often presented as a novel instrument, capable of reactivating the stagnant economic growth of industrialised countries. Neoclassical approaches reckon that pollution and environmental degradation are the result of externalised costs of industrial processes. Whenever a company performs a harmful action on the environment, it charges the consequences of eco-systemic degradation to society as a whole. In a nutshell, unsustainable behaviour is regarded as a cost that is externalized by the firms and charged to society. This branch of neoclassical theory is known as Environmental Economics. Exponents of this school consider eco-innovation an essential instrument to minimise the externalisation of cost and gain competitive advantages under strict environmental regulations. [32]

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 these approaches, however, is in their respective views of the role of technology. The proponents of sustainable development 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 vehicle

[32] M.E. Porter, C. Van der Linde, "Toward a New Conception of the Environment-Competitiveness Relationship", in *Journal of Economic Perspectives*, 9, 4, 1995, pp. 97-118.

emissions, for instance, might easily be made nil by increasing road traffic. This paradox is known as the "dilemma of the N-curve".[33] As a consequence, eco-innovation should not be regarded as any other kind of innovation and analysed using a reductionist approach. Eco-innovation requires a systemic approach, a broader framework of analysis including global parameters that are usually neglected in the study of classic innovation. The ecological approach is just a minority position within the present economic and environmental debate; however, it provides intriguing and useful insights for students of eco-innovation. The following sections illustrate the major contribution of Ecological Economics to Innovation Theory.

Eco-innovation in production and consumption: practical implications according to the Ecological Economics School

Ecological Economics deploys a multidisciplinary approach and addresses the failure of mainstream economics in dealing adequately with nature, justice and time. As I mentioned above, one of the most important contributions of Ecological Economics has been the inclusion of natural boundaries in economic analysis.[34] A simplified model of the economic cycle proposed by ecological economists is shown in Figure 2. It is composed of two main elements: 1) Processes; 2) Consumption.

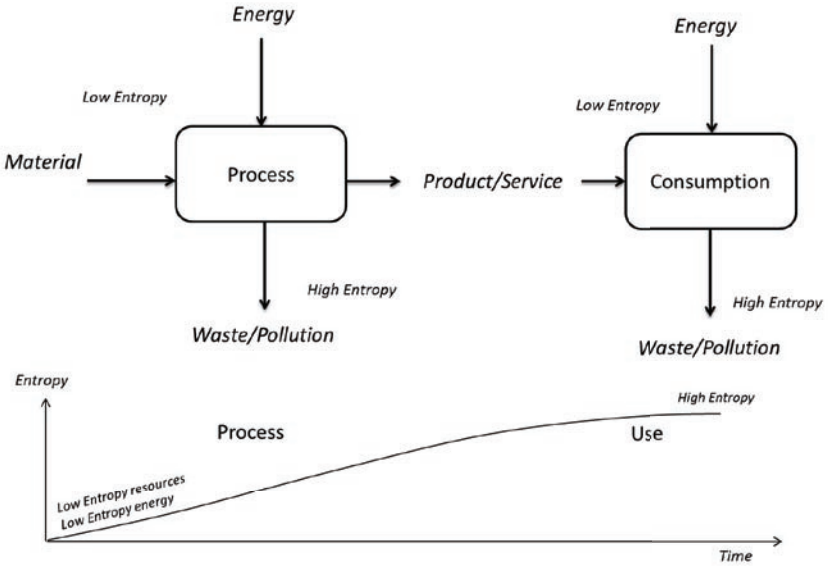
Every human activity is a process. Producing food, extracting minerals and transforming raw materials are all processes. The output of a process can be a product or another process, and always involves a specific sequence of tasks. The notion of process includes not only design and production, but also delivery, as in the case of processes such as transportation and distribution. The automobile industry, for instance, comprises an extremely complex system of processes including the extraction of natural resources, energy, and the distribution and sale of a product commonly known as "car".

The external boundaries of this chain of processes and consump-

[33] M. Jänicke, "Ecological Modernisation: New Perspectives," in *Journal of Cleaner Production*, 16, 5, 2008, pp. 557-565.

[34] Ibid., pp. 1-4.

Figure 2. General Product/Service delivery model



tion are defined by the limits of the planet. Moreover, this continuous exchange of energy, material and waste is subject to the Laws of Thermodynamics. The whole system can be seen as a mechanism that is fed by low entropy and releases high entropy back into the system. Human activity can actually be compared to an organism that absorbs low entropy to maintain its internal equilibrium and releases high entropy back into the environment.[35] According to the Second 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, in nature no process is reversible**.** Processes go in a specific direction. That is why a living organism cannot feed on its own waste. If such an organism existed, it would be a classical example of *Motus Perpetuum* and thus infringe the Laws of Thermodynamics. This

[35] N. Georgescu-Roegen, *The Entropy Law and the Economic Process*, Harvard University Press, Cambridge 1971.

is also true of economic systems because, in one way or another, they are ultimately based on environmental services and products. Hence, economies evolve in a specific direction, which means that they change by energy dispersal.[36] As the entropy of a closed system can only increase, all low entropy sources ultimately come from the sun. 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 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 the extraction of high entropy exceeds 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:

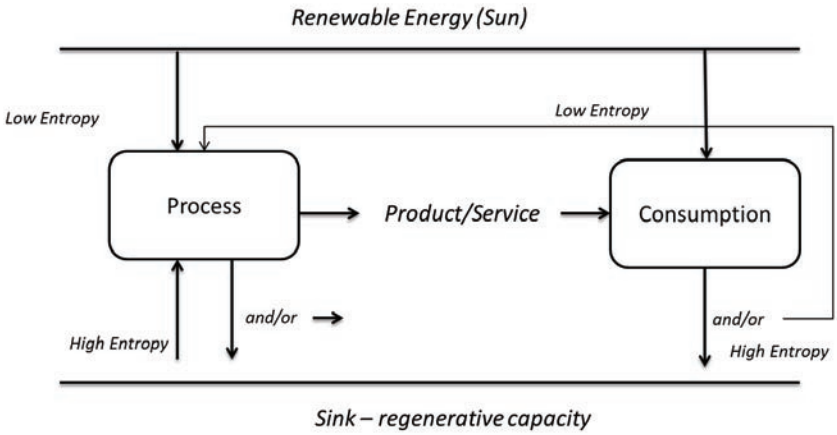
– There are limits to the use of non-renewable resources like fossil fuels, metals, minerals, fresh water and so on. Recycling is only a partial solution because every cycle always implies an increase of entropy in the system.
– There are thresholds for the use of non-renewable sources above which overexploitation can cause unpredictable nonlinear effects.
– The perturbation of the dynamic equilibrium of ecosystems through reservoir degradation, soil erosion or climate change can lead to unpredictable non-linear changes. We are not sure how resilient human society may actually prove to be, and the discussion about "a safe operating space for humanity" is relatively recent.[37]

In this perspective, the soaring industrial development of human society appears as a critical perturbation of the system because of its extensive use of low entropy reservoirs, such as oilfields and ores, that are virtually impossible to restore within a human temporal scale. However, looking at the history of human beings, the indus-

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

[37] J. Rockstrom et al., "A Safe Operating Space for Humanity," in *Nature*, 461, 7263, 2009, pp. 472-475.

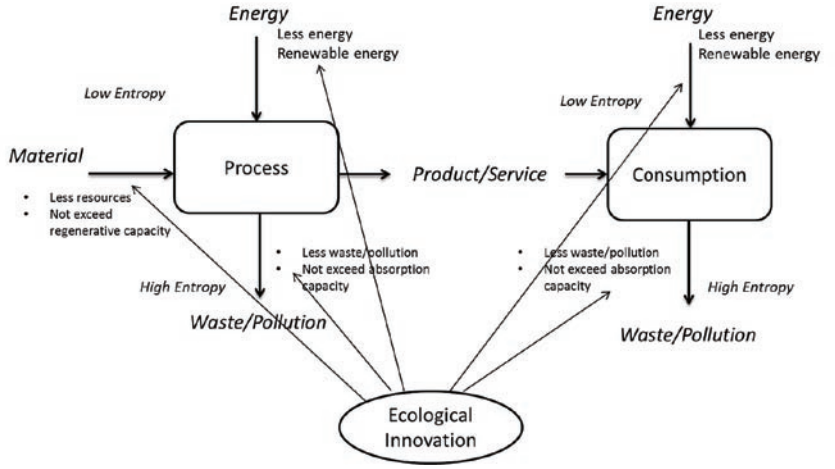
Figure 3. Ecological process of product/service delivery



trial era represents a tiny fraction of it. For hundreds of thousands of years human beings have been coevolving with the environment without seriously jeopardizing ecosystemic equilibria. In its dynamic equilibrium, the natural environment is characterised by a complex system of nested feedback cycles that 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 equilibrium 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 with limited regenerative capacity (Figure 3).

This mechanism allows nature to flourish, evolve and produce the great diversity that characterises life on Earth. All the processes in the system absorb low entropy in the 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 the 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 in this case, too, the entropy

Figure 4. Eco-innovation's field of action



increases by every single step in the process. However, the total entropy remains relatively stable. The system regulates itself according to the availability of low entropy sources. As long as an external source, 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 a reconciliation between human artefacts and ecosystem equilibrium. Ecological innovation should attempt to move from the system we are currently locked in towards an ecological system capable of maintaining an entropic equilibrium. This can be done by acting on the key variables of the productive/consumptive system of human ecosystems as illustrated in Figure 4.

Eco-innovation must thus aim at:

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

- *Less energy in the productive process*
  - Improving energy efficiency
  - Discriminating between different sources of energy
- *Less energy in the use of products/services*
  - Improving the energy efficiency of products and services
  - Discriminating between different sources of energy
- *Material Input*
  - Reducing input materials
  - Not exceeding the regenerative capacity of sinks
- *Material Output*
  - Producing a minimum amount of waste, pollution or emissions
  - Not exceeding the absorption capacity of sinks

Incremental and radical innovation in processes and products

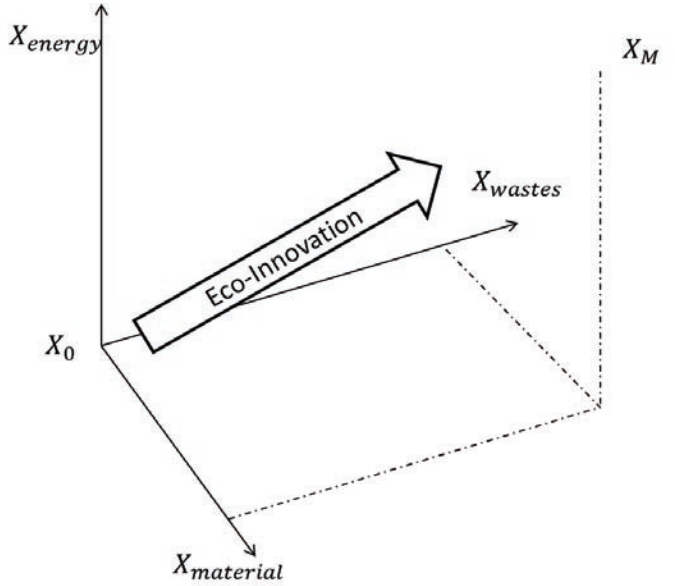
What are the practical implications of eco-innovation in the Ecological Economic perspective? Eco-innovation can basically occur in three dimensions: energy, materials and waste. For instance, the efficiency of a technology, X_i, is always the sum of this technology's material consumption, energy consumption and waste production:

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

We could call this variable *Ecological Efficiency Index*. Even though an accurate measurement of X_i would present serious problems in the real world, the variable is useful as a means to understand and distinguish between different ecological degrees of eco-innovation. Let X_i belong to the space of all possible combinations of $[(X]_{material}, X_{energy}, X_{wastes})$ $[(X]_{material}, X_{energy}, X_{wastes})$. We can define Ecological Innovation as new and economically valuable knowledge yielding a new combination $X_j = X_{material} + X_{energy} + X_{wastes}$ $X_j = X_{material} + X_{energy} + X_{wastes}$, where X_j is greater than X_i.

However, it is important to note that in the real word X_M cannot be defined in absolute terms. Indeed, so far I have treated eco-innovation in processes, products or services as an atomic entity. However, every technology is embedded in a complex system of interactions between users, producers, suppliers and other technologies. Speaking

Figure 5. The space of eco-innovation



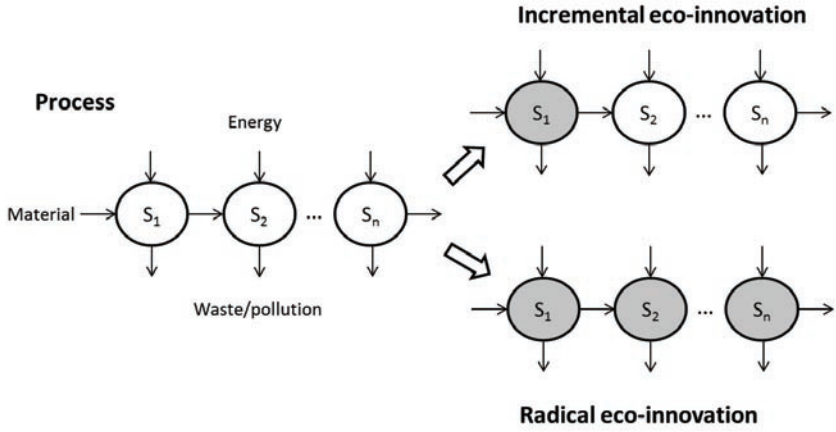
about eco-innovation as an isolated notion is completely meaningless. Because of the dilemma of the N-curve, no technology is sustainable *a priori.* Since the environmental sustainability of a specific system strongly depends on the sustainability of its component technologies, the final outcome will 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 to ask if a specific technology is sustainable if we do not specify under what respect it is sustainable.

Radical and incremental innovation in processes

Let us consider eco-innovation as a process, and a process as a se-

[39] Ibid., pp. 1-5.

Figure 6. Radical and incremental eco-innovation in process



quence of a certain number of steps (Figure 6). Each step is defined by the three above-mentioned parameters: material, energy and waste.

Incremental

An eco-innovation process is incremental if one or more of the three dimensions change in one or more of the steps of the process, and if the final outcome X_j is greater than the former one X_i.

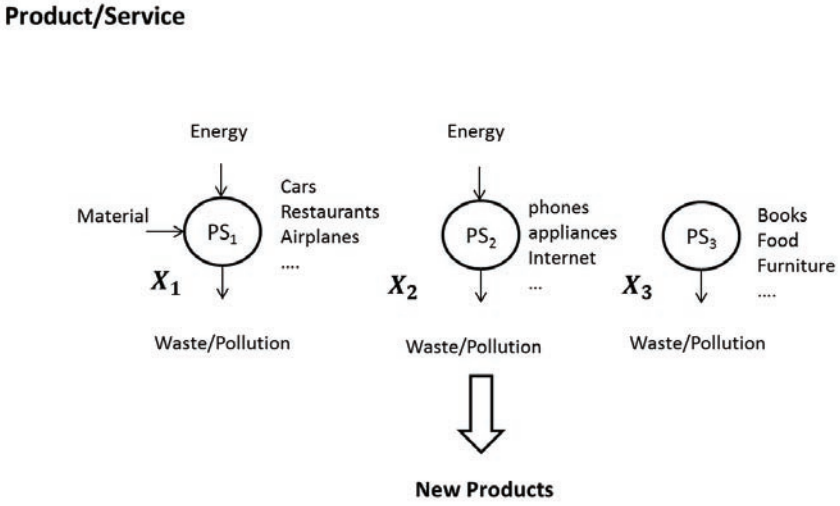
Radical

An eco-innovation process is radical when all the dimensions of all the steps in a given process display 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 in incremental eco-innovation.

Radical and incremental innovation in products/services

As regards product or service eco-innovations, we can distinguish between three categories (see Figure 7): i) products/services that need

Figure 7. Product/service eco-innovation



both material and energy input, and produce waste or emissions; ii) products/services that require only energy to work and produce waste or emissions; iii) product/services that simply produce emissions or waste at the end of their life-cycle.

Similarly to process eco-innovation, product/service incremental eco-innovation occurs when one or more dimensions increase their level of sustainability without changing the general technological setting. Radical eco-innovation occurs, instead, when a new configuration, involving all the sub-systems of a specific technology, arises.

Summarising, the practical implications of eco-innovation are elegantly described by the definition of the concept of eco-efficiency in the report of the 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 do not exist in a vacuum. They are embedded in a network of other processes, products and services that are very difficult to isolate and study separately. Most of the processes and products in the real world are constituted by other processes and products in a very complex way. Eco-innovation involves different layers of these structures. We can distinguish three levels of eco-technological change:

– Add-on component: a change in one step of the process or one dimension of service-products (incremental eco-innovation);
– Sub-system changes: a change of a specific group of steps, processes, products or services (incremental eco-innovation);
– System change: a radical change of all dimensions, new socio-technical regimes that function as closed-loop systems (radical eco-innovation).

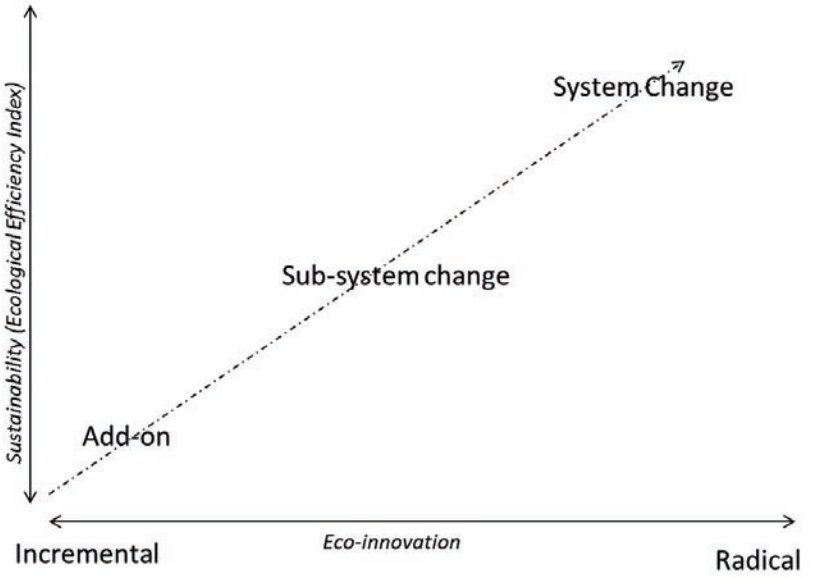
As I remarked above, an increase of efficiency by itself is not enough to guarantee environmental sustainability. Ecological modernization is bound to fail if a valid solution for the N-curve dilemma is not provided. We have seen that most of the mainstream analysts have a blind faith in technological improvements as a means to cope with environmental constraints. 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 value system of our societies. In sum, what we need is social and institutional eco-innovation.

Social and institutional eco-innovation

According to the neoclassical school, innovation stretches the limits of the ubiquitous scarcity that has been affecting humanity

[40] World Business Council for Sustainable Development, *Eco-efficiency. Creating More Value with Less Impact*, Geneva 2000.

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



from time immemorial and provides infinite possibilities to improve men and women's living conditions. If this were true, eco-innovation would provide increasing wellbeing in a sustainable way for the present and future generations. However, the essence of human welfare is typically conceived, at least in the Western paradigm, as having more of everything. The argument is thus that growth always increases welfare. However, since the first formulation of the concept of sustainable development, which dressed up the principle of capitalist expansion in a new fashionable green suit, many criticisms have been levelled at this assumption. According to Herman Daly,[42] mainstream economics tends to overestimate the benefit of

[41] Based on: J. Carrillo-Hermosilla, P. del Rio Gonzalez, T. Könnöla, *Eco-Innovation: When Sustainability and Competitiveness Shake Hands*, Palgrave Macmillan, New York 2009.

[42] H.E. Daly, "The Economic Growth Debate: What Some Economists Have

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". This 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. The 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 have been becoming more and more evident over the last decades. Growing more, especially in industrialised countries, means getting more and more expansive and requiring more investments. Thus it does make sense to ask, since the marginal costs of growth have increased, what has happened to marginal benefits. Studies in many countries show that, beyond a threshold of sufficiency, growth in income does not increase happiness.[43] Actually growth may become uneconomic at the margin, and even make us poorer, especially 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 valued for its ability of performing the Schumpeterian function of expanding natural limits through economic growth, but also as an instrument to ensure social inclusion and welfare sustainability. Social and institutional eco-innovation thus means changing the 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 national accounts such as 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 the use of energy for the transportation, packing and commercialization of products processed all around the globe. Self-production, conviviality and ex-

Learned But Many Have Not", in *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?", in *Journal of Economic Behaviour & Organization*, 27, 1, 1995, pp. 35-47.

change dynamics outside of the market are all phenomena that are not taken into account by the neoclassical approach because they do not involve cash flows. However, these 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 civil society, rather than market forces, plays a very important role. More and more people in the industrialised countries are becoming increasingly aware of the importance of individual actions to foster sustainability from the bottom.[44] Such initiatives have limited impact on the big figures of national accounts, due to their unaccountability as well as the fact that they are undertaken by isolated groups. Nonetheless, while civil society is changing, the same does not seem to happen in formal institutions, which often display tremendous inertia. The nature of institutional change appears to be even more complex when we consider that it involves a larger sphere of human affairs than the mere economic dimension. Many institutions are strongly related to religious beliefs and the evolution of environmental management. Rather than improving economic performance, in many traditional societies institutions aim to preserve the integrity and stability within these societies.[45] Based on the above reasoning, we can assert 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;
– Educated citizens rather than docile customers. People should be

[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", in *Ecological Economics*, 34, 3, 2000, pp. 301-313.

aware of the impact of their actions as technology users on the environment;
– Communication and investment in social capital. Enhancing the faith in the economy of commonality.

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

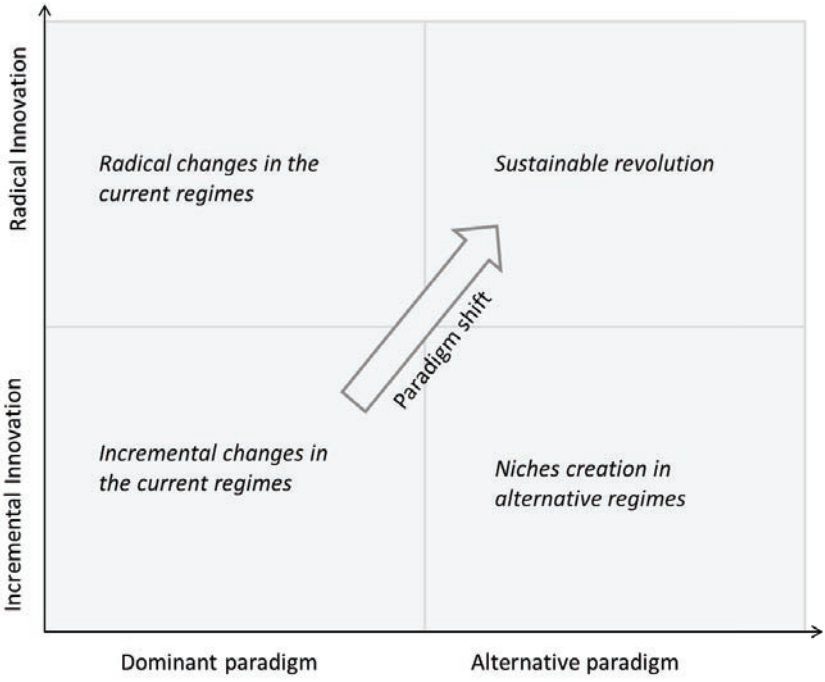
Conclusions

This article explores the origin of the notion of eco-innovation providing new insights from the Ecological Economics approach. The discrepancies between different environmentalism currents and economic schools, social and technical change are 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 overview does not attempt to provide a comprehensive description of the modern debate on sustainability, 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 at a global as well as a local scale. As

[46] G. George, A. Macgahan, J. Prabhu, "Innovation for Inclusive Growth: Towards a Theoretical Framework and a Research Agenda", in *Journal of Management Studies*, forthcoming 2012.

[47] V. Fournier, "Escaping from the Economy: The Politics of De-Growth", in *International Journal of Sociology and Social Policy*, 28, 11-12, 2008, pp. 528-545.

Figure 9. Innovation dynamics for sustainable transition[48]



Tidd and Bessant[49] have shown, innovation moves in a bi-dimensional space that 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, as long as they remain within the boundaries of the dominant paradigm.

The paradigm shift advocated by ecological economists, environmental activists and the occupiers of the area between "reform" and

[48] Based on J. Tidd, J.R. Bessant, *Managing Innovation: Integrating Technological, Market and Organizational Change*, 4th ed., John Wiley & Sons Inc., Chichester 2009, pp. 2-48.

[49] Ibid.

"transformation" groups in Figure 1 requires the rise of an alternative regime that could initially arise in the form of niches to eventually lead to a sustainable revolution. The relevant point in this analysis is not if this transition should or should not occur; the only way to avoid the collapse of modern industrial economy is to change 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.