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Analysis

IT for green and green IT: A proposed typology of eco-innovation

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ABSTRACT

This article is in support of the development of an ecological economic framework. It discusses, from an interdisciplinary perspective, the increasing use of green IT and their applications (IT for green). IT and sustainable development have had a concomitant rise and reach. The future world emerging from their respective interpretations enables, in both cases, a shift from today's questionable industrial capitalism towards post-industrial capitalism. This paper addresses the following questions: What is known about green IT and IT for green? Are smart solutions (buildings, energy grids, transport) always beneficial to an ecological economy? And, if so, in what ways? In the first part of this article, we analyse the economic, social and environmental impact of IT and argue for the need for green applications of green IT in order to achieve sustainable outcomes. The second part focuses on the managerial dimension of eco-innovation theory and presents one of the distinctive features of green applications of green IT: the collective organisation of innovation. A typology of eco-innovation aimed at reconciling IT development and green growth is then proposed explicitly addressing four kinds of changes towards sustainable development: technological, social, institutional and organisational innovation.
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Since the late 1970s, with the increase of global threats to the environment, the idea that the economy can no longer be studied independently from the reproduction of the natural environment has gradually spread. This is the very foundation of ecological economics (Costanza and Daly, 1987). It is in that context that the concept of sustainable development, which gradually emerged as a new development paradigm, arose in 1987. Though initially a constraint, it has become an opportunity, as it combines three advantages in today's uncertain times: a response to climate and energy challenges; a way out of a possible crisis; and a potential growth path.[1]

The radical technological breakthrough represented by the emergence of IT[2] in the 1970's is now acknowledged by all. Its spreading in the 1990s to all areas of the economic and social spectra has led to many changes. Its development is based on strong knowledge content and is based on intangible capital. They are the source of the new economy, which is also referred to as the knowledge economy or the post-industrial economy.[3]

IT are to the latter what the deployment of electricity was to the industrial model (Muet, 2006). It is not difficult to see how one might perceive the new paradigm of development or ecological economics as having entered its technological revolution stage. This became evident in 2005 with the production of a plethora of government, intergovernmental and sector-based reports, as well as scholarly work combining IT and sustainable development (Faucheux et al., 2010). In this respect, the Tunis Commitment, from the second World Summit on the Information Society (WSIS), is revealing when it declares that it "represents a unique opportunity to raise awareness about the benefits that IT can bring to humanity and the manner in which they can transform people's activities, interaction and lives, and thus increase confidence in the future",[4] as the European Commission's announcement of its support of the use of IT to achieve energy efficiency targets across all economic sectors by 2015 (C(2009) 7604 final).

Yet, if IT and sustainable development are closely intertwined, rebound effects are, in many cases, a likely result (Greening et al., 2000). Their direct and indirect effects must be known, anticipated and evaluated. However, IT and their relationship to sustainable development are most often addressed in a broad way, which sometimes lacks rigour when it comes to their relationship to economic, social and environmental change.

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[1] According to HSBC Global Research (2009), 430 billion dollars in recovery plans have been devoted to sustainable development, also called green energy: an average of 15% of the total world recovery plan, including 38% for China, 12% for the USA and 35% for France.

[2] Information technologies (IT) cover all the techniques used in the processing and transmission of information, mainly information technology, telecommunications and the Internet (OECD, 2009).

[3] IT are the source of half the productivity gains of the EU between 2005 and 2009 and represent 25% of GDP growth in 2008.

[4] http://www.itu.int/wsis/docs2/tunis/off/7.html.

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This article avoids this pitfall by integrating the following elements to its methodological framework:

i) Two concepts are used depending on the nature of IT:
 - Green IT defined as IT sector's own activity and its impact on environmental efficiency.
 - Green applications of IT or IT for green defined as the impact of IT on other sectors' environmental productivity, particularly in terms of energy efficiency and carbon footprint.

ii) The hypothesis that green applications drive positive externalities, only when green IT is used. Given the study presented on the impact of IT on sustainable development, we argue that green IT can only lead to sustainable growth if IT themselves are green. In that case, they can be understood as equivalent to an eco-innovating contribution to ecological economics (Rennings, 2000). An eco-innovation is an innovation (as defined by Schumpeter (1934)) that reduces environmental burdens and contributes to improving a situation according to given sustainable targets. In addition to this, because demonstrating the ways in which green IT has an impact on the production and consumption of IT remains complex, the integration of elements of management of eco-innovation systems to the economic analysis of eco-innovation is required.

iii) Methodological pluralism as established in ecological economics with contributions of neoclassical and evolutionary approaches would be very valuable for IT eco-innovation research (Witt, 2009). We intend to open up this framework to managerial changes. Eco-innovation, which spreads concomitantly in clusters, is studied drawing on the theme of eco-city, and bringing together the sectors with the greatest impact in terms of CO^2 emissions, and significant social repercussions (construction, transport, energy). These sectors were chosen based on about twenty surveys[5] (qualitative, of semi-directional type) with stakeholders (in Europe and the USA) involved in major technological and environmental prospective activities (ECF, 2010; IPTS, 2003). We argue that, in that context, green IT belongs to a collective innovation perspective (Allen 1983) referring to various stakeholders and internal and external factors influencing the process of eco-innovation. A neo-institutional approach has been used to explain this additional feature of eco-innovation with an emphasis on business ecosystems' interactions, social innovation and user acceptance.

This contribution discusses the increasing use of green IT and their green application in support of the development of ecological economics from an interdisciplinary perspective. In the first part, we analyse the economic, social and environmental impact of IT on sustainable development. We argue that the complex effects IT have on sustainable development leads us to an examination of IT as an eco-innovation that experiences changes at technical, social and institutional levels. The second part defines the different determinants of eco-innovation, derived or generated by green IT as well as IT for green. This article examines the ways in which eco-innovations' determinants interrelate in ecological economics to explicitly address technological, social, institutional and managerial changes.

1. The Arguable Effects of IT on Sustainable Development

The effects of IT on the three dimensions of sustainable development can directly be assessed on the technology or indirectly on IT's application as they occur at different stages of its lifecycle. Their real or estimated global impact is difficult to identify as it occurs at different levels of influence. Drawing on Faucheux et al. (2010), we can, however, distinguish: first order effects, with an impact resulting from all stages of production through to the end of IT equipment and infrastructure's lifecycle, and second order effects, with an impact linked to the development of IT and their uses. This distinction will enable us to establish different types of sustainable impact according to their effects, but also in relation to the position of various stakeholders in terms of responsibility and engagement. These different strategies are the basis of an analysis in terms of business ecosystems that is discussed in the 2nd part of this article. Third order effects are systemic changes that emerge from the aggregated effects of a large number of private or public IT stakeholders.

1.1. The Economic Benefits of IT

According to Pilat (OECD, 2008), investment in IT increases the capital stock and improves labour productivity. Fast technological progress in the production of goods and services of IT can contribute towards the development of capital and labour efficiency, or multifactor productivity (MFP) in the IT production sector as well as in the global economy. IT are also likely to intensify the effects of network/external effects, such as reducing transaction costs and accelerating innovation, which can also improve MFP. They are also able to both rapidly create a crisis and be responsible for increased market volatility.

1.1.1. First Order Effects Are Generally Positive, but Unevenly Distributed across Countries

The IT sector has contributed towards 16% of global GDP growth between 2002 and 2007 and has seen its share in the latter year rise from 5.8 to 7.3%. This contribution is expected to reach 10% between 2007 and 2020 (The Climate Group, 2008), with an increased weight for emerging and developing countries.

The digital economy is becoming the most dynamic sector of the global economy. In most developed countries, its growth rate is double that of their total economy. This evolution is reflected in the increase in the number of jobs created in this sector (an average of 20% between 1995 and 2005 in OECD countries).

The IT sector has become in terms of R&D the greatest investor and employer in Europe, the USA and Japan. For OECD countries, it accounts for 26% of all private sector R&D, employs 32% of its researchers and is responsible for 21% of all patents (Turlea et al., 2009). In fact, total expenses of the private sector's IT R&D is even greater when outcomes generated by other R&D sectors (e.g. transport) contributing to the IT sector are taken into account. The weight of this additional expense is estimated at a third more than that of the IT sector per se. Given the weight of R&D in IT, businesses' positions within this sector are changing rapidly and significantly with the emergence of new markets (e.g. mobile telecommunications and fibre optics) and challenging established competitive positions.

1.1.2. Second Order Effects Are Both Providers of Opportunities and Obstacles According to Sectors, Businesses and Countries

Investment in IT hardware and software has a significant impact on productivity (higher than in the industrial sector) (Clayton 2006). However, the use of electronic business processes, integrated or multiple, has a dual effect on manufacturing and services businesses: in the first instance, positive effects come mainly from the management of purchases and supply chain; and the effects arise primarily from customer relations (Legner and Schemm, 2008).

The 2006 survey conducted by Watch, the e-business observatory, gives an overview of IT for European businesses and underlines the persistent gap between SME and large companies (EC, 2006). The use of IT in French SME and small businesses is significantly low (Eurostats 2007).

The use of IT is changing the way businesses think about their markets. It is a source of inspiration for new business models turned

[5] These surveys were conducted during the second quarter of 2009.

Table 1
The main eco-innovations allowed by IT for green in the field of a sustainable city.

Areas of applications	Applications	Economic perspectives
Energy efficiency	• Regulation, metering, remote management • Low consuming technologies • Storage and management of micro-energy • Efficient distribution	This area benefits from an economic, political and regulatory context which is favourable at an international level, making it a very attractive market. The USA, the countries of Northern Europe, Germany and Japan have gained a head start.
Sustainable building	• Thermal modelling • Thermal, acoustic insulation • Intelligent building, home automation, remote management	This is a huge market driven by an economic and a regulatory environment at an international level. It implies that those in the building sector find new technological partners.
Renewable energies	• Solar and wind production • Hydrogen • Electricity storage • Energy conversion • Decentralised distribution	The economic context is very favourable. These eco-innovations will start to be widely distributed around 2020. Europe is less advanced than the USA or Japan in this area.
Clean transport	• Sensors • Monitoring networks • Flow model • Regulation, metering, remote management.	The economic regulatory and political context is very favourable at an international level. This market will expand rapidly from 2015. Europe, especially France, is in a good position, but not ahead of Japan.

towards virtual markets or customised markets. It gives consumers the opportunity to enhance their position and encourage greater corporate social responsibility. Meanwhile, electronic commerce has reduced transaction costs and improved the competitive functioning of the market.

According to stakeholders involved in major international prospective activities, a certain number of future innovations, eco-innovation,[6] will be linked to progresses in all sectors of IT. This refers to IT for green defined in introduction and analysed in Section 2.1. This constitutes a lever for businesses' competitiveness to such an extent that many agree on the fact that new growth, often described as green, can only be generated by these eco-innovations, which are at the centre of a current economic race (Faucheux and Nicolai, 2006). Table 1 summarises the main eco-innovations enabled by IT for green in the context of eco-cities as well as their economic and competitive dimensions.

Eco-innovation is thus a real option in the fight against climate change and to foster economic recovery. Some specialists (California Clean Tech Open, 2008) describe the potential of IT for green as “the biggest growth opportunity of the 21st century”. These are thus proving inseparable from competitive advantage and international competitiveness, both at a micro and macro-economic level (Beise and Rennings, 2005).

1.2. The Social Impact of IT

The impact of IT on the social realm is less well defined and probably more difficult to measure than its impact on the economic realm. Separating economic and social impacts isn't always obvious. This is why IT are increasingly present in social surveys. These surveys reveal that IT are changing the ways in which people act and work (Statistics Finland, 2006), the jobs they do, their daily activities, such as their shopping and banking habits or their interactions with government services (ABS, 2006), their spending habits, their use of time and the ways in which they communicate with their families or in groups (ONS, 2006). Furthermore, IT have an impact on health (Pew, 2006), crime and education.

1.2.1. The Main First Order Social Impacts Are Linked to Unequal Employment Opportunities in the IT Sector and to the Digital Split[7]

In Europe, the annual IT sector employment growth rate is around 8%. Each job created in this sector can be linked to the creation of four others in the entire European economy, either upstream in the suppliers' sector or downstream in the software industry service sector. At a macro-economic level, the increased use of IT leads to the creation of highly skilled jobs, and the loss of less skilled jobs in other sectors. The marginalisation of unskilled workers is a significant threat to social cohesion that may become more critical as IT's development expends to all sectors of the economy. Owing to the application of IT green, new skilled professions will be on the rise, in the construction or heritage management sectors for example, with the development of intelligent buildings or in the car industry with the development of carbon-free cars (electric or hybrid) and other transport services. This implies anticipating and supporting an ambitious lifelong training programme (Rennings and Zwick, 2002).

Obstacles to global access to IT (what is known as the digital split) could also reinforce existing patterns of exclusion (Elie, 2001). The digital split is not just about access to the Internet and its use, but to all IT (computers, interactive digital television, multimedia, mobile telecommunications, digital photography and digital video). There is a pressing need for data and indicators to measure the level of access as the currently available information on which international comparisons is based pertains almost exclusively to the use of the Internet and, to a lesser degree, to the use of mobile phones (Eurostats, 2010). For people, obstacles can range from inconvenience to more significant losses, such as unequal opportunities in the labour market. For countries or territories, obstacles include the lack of infrastructure, likely to result in greater economic gaps.

1.2.2. Social Impacts Linked to the Use of IT (Second Order Effects) Should Not Be Overlooked Either

They transform lifestyles and the organisation of labour. This is especially true of teleworking (Ecofys, 2008). Teleworkers represent an average of 13% of the workforce in Europe and 25% in the USA. Denmark is the leader with nearly 20% of its workforce engaged in regular or occasional teleworking. In France, the rate is only of 7%, which is why “Digital France 2012”, the French government's digital economy development plan, outlines a range of incentives to increase

[6] “Any action taken by stakeholders aimed at developing new ideas, new behaviours, products or processes, to apply and develop them so that they can contribute to a reduction in environmental damage or pertain to objectives of sustainability” (Klemmer, Lehr and Lobbe, 1999).

[7] The term “digital split” refers to the unequal access to IT between individuals, regions or countries in terms of

this rate (CGTI, 2008). If teleworking is linked to economic benefits such as reduced overheads for businesses, it can also be linked to social benefits, such as reduced commuting time, more flexible working hours, greater work-life balance, the inclusion of traditionally excluded groups (e.g. mobility impaired people for instance) and opportunities to work from remote locations. However, it is not without a negative impact: it suits a project-based work culture that is not yet mainstream; traditional hierarchical management models are replaced with other forms of control; and new structures may lead to increased levels of stress due to unusual working hours (nightshifts, weekends, etc.) (Askenazy, 2005). The global impact is also very difficult to define as the substitution effects vs. the induction effects linked to green applications have only partially been evaluated and are contingent upon the solution offered (Hilty, 2008).

As the Internet reaches all nations and spheres of activity, many voices can be heard that challenge the socio-economic and political control of this technical device and request that it be managed internationally and in compliance with principles of Participatory Governance for Sustainable Development (Raboy and Landry, 2004). Indeed, the Internet's physical core is only located within five countries (the USA, Japan, the UK, Spain and Sweden). Information pertaining to objects, such as origin, place of production, technical or health checks, etc., is still traceable over the Internet. These are thus major issues, not only in terms of nations' sovereignty, but also in terms of individual freedom. Thus, the social effects of IT linked to the production as well as to the use remain mostly undefined.

1.3. IT's Environmental and Health Effects

1.3.1. Numerous Studies on the Environmental Impact of IT Production (First Degree Effect) Highlight the Following Elements

The over-consumption of non-renewable and toxic resources, especially of heavy metals[8] (lead, mercury, cadmium, beryllium, etc.), during the phase of extraction of raw materials used in the production of IT is frequently identified as a source of problem.

Production processes require the use of products that are highly toxic and dangerous for the environment and people's health. For example, brominated flame retardants[9] are linked to neurological and blood diseases or certain types of cancers (Hilty et al., 2005). High levels of energy and water consumption are also necessary. Although much of this water can be recycled, none of the microchips producers seem to do so. It is not uncommon that newly built data centres consume more energy than the cities where they are located. In 2008, the total energy consumption of IT equipment and services represented about 8% of the electricity consumed in the EU. The IT sector itself generates 2% of carbon emissions in Europe, 1.75% resulting from the use of IT products and services and 0.25% from their production (BioIS, 2008). Material flow studies show that only 2% of them could be found in IT products (Erdmann et al., 2004).

Similarly, according to several ACV studies,[10] the production phase represents between 15 and 25% of the total energy consumption for IT's lifecycles (based on agreed lifecycle spans). A number of manufacturers of computers and other electronic goods are no longer satisfied with this situation. Aware that there is a genuine issue of acceptability and competitiveness for their products, they are rising to the challenge, as evidenced by the emergence of green IT (see 2.1).

Waste from electrical and electronic goods, linked to the end of IT lifecycles, represents a significant environmental problem difficult to manage because of its increasing volume and its very specific nature (SVTC, 2004). In 2007, in France, it was estimated that 16 kg of electrical and electronic products per capita/year were placed on the market, while only 2.5 kg per capita/year were recycled. The recycling target imposed by the European Waste Electrical and Electronic Equipment (WEEE) directive (2002/96/CE) requires that 4 kg per capita/year be recycled for each member country, with an obligation for producers to finance the recycling efforts. Some European countries are proactive in this area. This is the case for Scandinavian countries (15 kg per capita/year), the UK (10 kg per capita/year) and Germany (8 kg per capita/year). Several components of IT waste are now recycled, but the organisations that collect and recycle these products remain limited in terms of efficiency and structure. In the USA, three quarters of computers are stacked in garages or in storage (PNUE, 2005). When computers are discarded, they end up in landfills or in incinerators or, more recently, exported by some countries to Asia or Africa. The report entitled “Exporting Harm: The High Tech trashing of Asia”[11] states that 50 to 80% of IT waste collected on the West Coast of the USA[12] is placed in containers and loaded onto ships for China, Pakistan or India at a 10 times lower recycling cost, but with drastic health and environmental consequences. In France, the recycling processes are complex and involve a range of players. The dismantling is often given to rehabilitation companies. The various components are then handled by companies specialised in recycling metals and plastics. Local organisations' participation is often difficult to determine and environmental burdens are non-negligible.

1.3.2. The IT Usage and Implementation Phase (Second Order Effects) Is Not Free of Environmental Externalities Either, but These Are Less Well Defined than the First-order Effects

In Europe, a significant percentage of domestic electricity consumption is linked to the use of IT. It was estimated at 8% of total electricity consumption in 2005, and will be increasing regularly till 2020 (BioIS, 2008).

In France, the share of electricity consumption of IT is estimated at 13.5% of the total level of consumption, and this despite the regular improvement of energy efficiency equipment (IDATE, 2010; BCG, 2010). The carbon footprint[13] of IT in 2007 was 830 MtCO^{2}e, which represents 2% of the estimated total emission from human activity measured for the year, which represents a 6% increase per year until 2020 (The Climate Group, 2008). The share of carbon footprint linked to the use of IT is about four times greater than that linked to their production.

This footprint is expected to triple over the next 20 years according to a “business as usual” scenario of economic development. The exponential growth of data centres will be the main culprit.

At the same time, the replacement of traditional technologies by IT leads to a reduction in the amount of resources consumed in manufacturing goods as described in the virtualisation or dematerialisation of hardware (Haake and Gueorguievsky, 2010): music stored and transmitted on the web, digital photography, transaction via the Internet, e-commerce, etc. However, the consequences of the spread of e-commerce, and e-work, may also be the cause of rebound effects[14] (Faucheux et al., 2002). For example, teleworking changes our relationship to urban and rural spaces and provides tertiary industry sector workers with new opportunities, such as the choice of

[8] That is why the European Commission developed the RoHs guidelines (Restriction of certain Hazardous Substances in electrical and electronic equipment) in 2002 to limit its use by 2006.

[9] Polybrominated biphenyls, PBB, polybrominated diphenylethers, PBDE, tetrabromobisphenol-A, TBBPA or TBBA.

[10] See for example Babbitt et al. (2009) ; Choi et al. (2006) for environmental impact assessments of the IT industry.

[11] http://svtc.org/wp-content/uploads/technotrash.pdf.

[12] The USA have also refused to ratify the Basel convention (adopted in 1989 that came into force in 1992) which prohibits all exports of hazardous wastes to developing countries.

[13] The carbon footprint measures the amount of carbon dioxide (CO^2) emitted by burning fossil fuels, by businesses or by living beings.

[14] Concerning the rebound effect, Pearce (1998) highlights that improving energy efficiency doesn't necessarily lead to reduced energy consumption (quite the contrary) for a couple of combined reasons: the substitution effect (replacing cheaper energy with other energy commodities through a reallocation of income) and the income effect (cheaper energy makes money available for other energy commodities).

place of residence, which may have a negative impact on urban, town and country planning and, thus, on transportation energy costs.

Finally, IT has an important role to play in promoting eco-innovation in other sectors such as transport, building or energy distribution, and thus enabling greater energy and environmental efficiency within those sectors that are amongst the largest contributors to greenhouse gas emission. That is why, although an increase in CO^2 emission is expected for the IT sector, this should be offset over time, by a drop generated by their implementation across all sectors. The overall environmental effects are generally extremely difficult to assess and are largely dependent on third order effects (i.e. users' behaviour). The networked development of eco-innovations becomes a defining aspect of IT when taken into consideration within the managerial approach of the analytical framework of eco-innovation.

2. Green IT and IT for Green: Catalysers and Drivers of Eco-innovation

IT are thus increasingly exerting pressure on the environment while also being a source of potential social problems. Furthermore, they significantly alter the economic structures and contribute to economic growth in an ambivalent manner. The medium to long term aggregated impacts (which can be described as cumulative effects) linked to their mainstreaming in most parts of economic and social sectors are difficult to identify, because at each level of sustainable development the first and second order effects vary according to the country, the era, the sector, etc., as well as the scope of analysis and the type of IT innovations examined.

However, in view of the above, it appears that many positive externalities, not only at an environmental but also at an economic and social level, are to be expected from the mainstreaming of IT for green, and to a greater extent if green IT is to become mainstream too. If we are to combine IT for green with green IT to achieve an ecological economy (OECD, 2009), it is important to better understand the nature of eco-innovations that are likely to be generated from it.

2.1. Green IT and IT for Green: What Are We Talking about?

2.1.1. Green IT Refers to IT with Low Environmental Impacts (in Terms of First and/or Second-order Effects)

We expect the IT sector to innovate in order to reduce its use of toxic substances and consumption of natural resources, especially energetic resources throughout their products and services' lifecycle. The European Commission is encouraging IT businesses to use eco-efficiency and eco-design processes (IP-09-393, March 2009) by implementing eco-labels and standards in the form of voluntary codes of conduct. Systemic improvements in production processes are sought throughout IT sector's entire value chain, including operations, manufacturing, service delivery and management of the supply chain. Increasingly, computer manufacturers are playing the green card and many of them have achieved the environmental standard ISO 14004 (renovated in 2004). In France, collaborative projects have emerged between NGOs, local authorities and IT companies. This is the case with lifecycle extension policies based on the recycling of computers and mobile phones.

The term "IT for green" refers to the mainstreaming of IT in other sectors with, if we limit ourselves to the main applications within eco-city, smart buildings, intelligent transport or intelligent energy grids. It is these green applications, provided they resort to green IT, which are truly able to reduce the overall environmental footprint and especially to create structural change, enabling the well-known decoupling between economic growth and climate change. According to The Climate Group (2008), IT for green could significantly increase efficiency across all sectors of the economy and deliver CO^2 emission savings of 15% of the total of "business as usual" emissions in 2020. The IT sector has a powerful role to play by enabling other sectors to become more efficient by promoting dematerialisation, smart logistics, smart buildings and smart grids for instance.

As a case in point, a key motivation for the implementation of a smart grid is a more efficient use of existing electrical generation, transmission and distribution infrastructures. This could help the distribution sector improve its management of energy supply and demand.[15] A smart grid is presented as a set of software and hardware tools that allows generators to deliver energy more efficiently by reducing the need of surplus and enabling two-way paths and information exchange with consumers to address requests in real time. According to Rifkin (2008), the key to the future of energy lies in local decentralised energy production from renewable energy sources, which the smart grid integrates. Finally, the smart grid's third objective is to control demand. Within the context of a collective platform developed around the management of incremental and radical innovations, industries, local authorities and individuals would then become producers as well as consumers of their own energy. This would occur based on given pathways, irreversibility and discontinuous sources and unpredictable events. Electric Power Research Institute (EPRI), an American electricity sector think tank, concluded in its "Perspectives for the future" that this type of distributed production is bound to bloom in the same way the computer industry did. In future, producers and energy processors will have to work with IT specialists. For example, Intel invested over $100 million in 5 industrial electric grid industry companies to provide solutions for individuals and businesses with data centres or in the delivery of electricity and metres management. Intel is thus positioning itself at all levels of the energy sector, from energy production to its distribution and use. But how can heterogeneous parties, producing and using green IT, be defined as collective eco-innovation managers?

2.2. A Typology of Eco-innovation Stemming from an Economic Approach to Green IT for Green

The definition of eco-innovation most commonly used within the ecological economics movement focuses on three points: an issue of double externality; the importance of a regulating framework; and the importance of social and institutional aspects of eco-innovation. The methodological pluralism drawn from ecological economics enables us to highlight eco-innovating green IT's following characteristics:

- Type of innovation (or intensity). A spectrum of innovations ranging from incremental to radical, based on the degree of novelty associated to new practices. These time-based modifications are evaluated in terms of incremental or radical changes (Freeman, 1992).
- The scope of innovation. Taking into account changes in production processes such as added eco-innovation, which intervenes in a curative manner, and integrated eco-innovation, which avoids environmental degradation (Frosh, 1995). Lock-in effect of technological trajectories, irreversibility and path dependencies or given technological trajectory are some of the different aspects that need to be taken into account in green IT.
- The nature of skills to be developed. Depending on the level and scope of innovation, the need for knowledge and new skills differs, thereby influencing the innovation process (Nonaka and Takeuchi, 1997). With the dissemination of IT, skills are developed at a distance and change the ways in which we acquire knowledge (Miles and Snow 1986) within dynamic capabilities[16] networks

[15] See the document referring to the European Technology Platform Smart Grid on http://www.smartgrids.eu.

[16] Dynamic capabilities are defined as a business's capacity to integrate, build and reorganise internal and external competencies in order to better deal with changing environments.

Table 2
Characteristics of eco-innovations applied to green IT and IT for green.

Typology criteria	Green IT	IT for Green
Scope of innovation. Columns A and B for process dimension (with a rating scale of 1 to 5)	Integrated	Added and integrated throughout the lifecycle product
Innovation intensity. In these two categories (incremental or radical), learning mechanisms are specific depending on product improvement. Columns C and D for taking into account temporal dimension	Still predominantly incremental with codifiable knowledge	Incremental, radical with tacit skills brought into question. New trade-off between degree of codification and speed of knowledge dissemination (O'Callaghan and Andreu, 2006)
Support of innovation: which kind of strategy firms are going to implement: defensive (compliance) or proactive (differentiation)? Column H	Regulatory compliance. Need for legitimacy (DiMaggio and Powell, 1983)	Voluntary innovation with competitive advantage (Dal Bo, 2006). Networked development and business ecosystems.
Application field that describes two options: 1) classical about technological or organisational innovation; and 2) that mentions evolution towards product service dimensions. Columns E and F	Technological	Technological, organisational of use and strategic (service economy)
User acceptance. Generation of eco-innovation depends on the benefits received by the innovator. Column G	Participation of businesses or users in the dissemination of eco-innovation. Ethical motivation and energy efficiency	User development and acceptance. Appropriation of eco-innovation by users is essential

(as defined in Teece, 2007). This implies the need to develop organisations' coordination capacities as well as their ability to integrate mixed inputs into a group system through mindful contributions and representations (Weick and Roberts, 1993).

- Field of application. The scope of innovations' applications is analysed based on the need to take organisational, behavioural and institutional change into consideration, beyond the simple definition of technological innovation. As such, strategic innovations pertaining to green IT objectives or new modes of consumption as well as methods of production are defined (service economy).

Eco-innovation can effectively take on different forms and Table 2 presents these characteristics for IT for green with green IT.

The impact analysis of green applications of green IT has enabled the identification of other key elements essential in defining eco-innovation in a management approach:

- User dimension of eco-innovation. In order to develop eco-innovations, businesses should be able to anticipate the acceptance of innovations in the market. The conditions of acceptance can be seen at the production-diffusion of technology level as well in users' behaviour (Pujari, 2006). This dimension is drawn from a neo-institutional theoretical framework based on the development of collective agreements around the agreed upon dissemination of goods and services. Substitution/induction and rebound effects controlled or at least understood in order to provide a global impact assessment of IT. Within that context, the kinds of relationships between green IT producers and consumers must be taken into consideration in the economic analysis of eco-innovation.
- Support for innovation. In some cases, eco-innovation is triggered by regulations through social pressure. In other cases, different competitive motivations prevail (Azzone and Noci, 1998; Porter and Kramer, 2006). Standard management of eco-innovation's double externality gives rise to technology that is dependent on technology push, market pull and regulatory push. All these elements have been identified in green IT, with an additional response to technological development: the development of a network that voluntarily combines actions and change their environment through regulatory mechanisms (Astley and Fombrun, 1983). Collective strategies thus defined can be seen as IT platforms.[17]

[17] Gawer (2009) defines industry platforms as technological building blocks that act as a foundation on top of which a group of businesses organised in a set of interdependent businesses sometimes called an industry ecosystem, develop a set of inter-related products, technologies and services.

Within that context, an analysis of eco-innovation highlights the dynamics pertaining to the organisation of innovation systems. The analysis of eco-innovation's determinants must be able to integrate the analysis of dynamic clusters of capabilities between producers and consumers of IT. A business ecosystems' theoretical framework (Moore, 1996) is a useful tool to analyse additional characteristics of green IT, such as the “collective” eco-innovation, in as far as the added value comes from the proliferation of relationships, interactions amongst heterogeneous stakeholders with specific skills (Cowan and Jonard, 2003) and able to intervene at different levels and stages of IT's lifecycle. These exchanges between producers and consumers of eco-innovation are the basis of a business ecosystem drawing on solid co-evolution processes between partners and a strategic approach that goes beyond a simple competitive business approach (Freeman, 1995; Lundvall, 1992). Two additional criteria have been included in the typology of the so-called collective eco-innovations enabling the definition of a “platform” integrating rebound, substitutions and inductions effects linked to users' acceptance of IT:

Fig. 1 summarises the position of some eco-innovations based on green IT and green applications for IT depending on all these criteria. We assess the dimensions of the selected eco-innovations by using a 1 to 5 rating Likert scale (where 0 means no change, 1 marginal and 5 radical change). Each eco-innovation could be characterised by these criteria as a mix of green IT and IT for green. Two eco-city examples are included in Fig. 1 to illustrate this typology and highlight the changing profiles of eco-innovations' determinants in relation to given digital business systems: Building Management System (BMS), smart grid.

BMS aims to automate and take control of services in order to provide facilities in the most efficient way possible for businesses, within the constraints of an installed plant. BMS is a “stand alone” computer system that can calculate the pre-set requirements of a building and control the connected plant to meet those needs.

In terms of eco-innovation determinants, the profile examined highlights an innovation added in terms of production process and evolving through time with an issue of double externality (environmental externality's eco-efficiency and interoperable standards for R&D spill overs). But in relation to different stakeholders' acceptance criteria or those of other heterogeneous stakeholders' emerging business model, this eco-innovation significantly lags behind. BMS is a holistic management system that offers tools that enable the reduction of energy consumption not reliant on users' behavioural transformation. Thus, according to the international studies already undertaken, the economic gains made won't be able to meet ecological economics' objectives.

A smart grid is an electricity grid that can intelligently integrate the actions of all the users connected to it – grid managers, IT

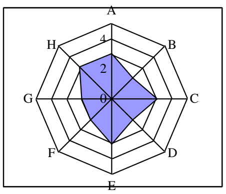
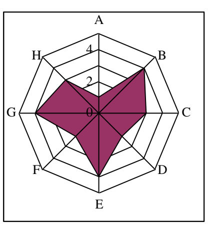
Case studies	Scope of innovation		Innovation intensity		Application field			
	Column A. End of pipe *(rating 0 to 5)*	Column B. Integrated *(rating 0 to 5)*	Column C. Incremental *(rating 0 to 5)*	Column D. Radical *(rating 0 to 5)*	Column E. Technological, organisational *(from 0 to 5)*	Column F. Change in service economy *(from 0 to 5)*	Column, G. User acceptance *(from 0 to 5)*	Column H. Support of innovation *(from 0 to 5)*
Building Management System : IT for green building 	Installation of an electronic management system in order to rationalise energy consumption	Marginal changes	Modelling and simulating energy consumption	Open standards for interoperability between different technology sets.	New sensors, chips for remote monitoring, measures (eco-efficiency)	Create a connected urban environment where buildings are adjustable to human behaviour.	Users behaviour plays a crucial role in the application of eco-innovation and in its efficiency	A way to create competitive advantage. Induction effects vs. substitution effects
Project EEGI, a smart grid implementation http://www.smartgrids.eu/ 		Decentralised energy production system management	Smart meters	Integration of renewables energies	Technological and organisational challenges	Vision for the electricity grids of the future that are flexible, accessible, reliable and economic.	The active participation of SMEs and consumers in power system markets. The management of consumers' behaviour must be included in the business model.	New reflections about active demand and new business models for market players. Rebound effects. New markets development.

Fig. 1. A variety of eco-innovation based on green IT and IT for green: some case studies (extract from Faucheux et al. (2010)).

technicians (middleware such as telecom or embedded systems), energy production experts, car manufacturers, builders, energy providers, unions, consumers and those that do both – in order to efficiently deliver secure electricity supplies and greater control of energy needs. It does pertain to an organised cooperation between different sector parties, from a range of professions and with various strategic approaches enabling a better control of energy demand and supply. This collective innovation is also called open (as defined by Chesbrough (2003)) in as far as a shared invention amongst competitors or other partners leads to sharing results and create new opportunities. For example, in the medium-term, the electric car will take an important position within the smart grid market with a building-block development, probably within the construction sector.

It is worth noting that smart grids find a natural place within users' technological ecosystems that are situated at different levels of the energy supply chain: in the building industry, in the domestic sector as well as at the level of production means. Thus, a collective technological eco-innovation necessarily requires a social innovation reliant on the significant transformation of a particular way of life.

3. Conclusion

Defining green applications of IT green as eco-innovation within a digital business ecosystem framework has highlighted new eco-innovations' determinants. Defining "user acceptance" and "innovation support" has enabled the description of new eco-innovation profiles linked to the creation of collective "platforms" for the collaboration of heterogeneous stakeholders. It is essential to integrate a management dimension within the theory of eco-innovation if we are to be better understand third order systemic effects.

Thus, based on our example, smart grids will foster change amongst grid managers to include relationship management of new economic partners (especially those from the IT sector) and a valorisation of their expertise that will lead to new services. However, the theoretical and empirical work on business ecosystems in the context of green IT is still in its infancy. These platforms impose new business models as well as a finer analysis of what fosters user acceptance, which will help better holistically assess these new technologies. Moreover, conditions for optimum allocation of costs between consumers and producers will need to be examined further.

These questions won't find “universal” answers, because they are dependent on specific national regulatory contexts and each country's stated priorities. Thus, a range of level of cooperation amongst stakeholders participating in the same business network is essential:

- cooperation amongst sector stakeholders is essential to support the emergence of new activities and the integration of players new to the field of energy production;
- cooperation between regulators, beyond the European borders, in order to learn from international experiences to better manage risks;
- finally, support by way of technological, management and organisational public policy development is crucial to foster users' behavioural change. Incentive schemes such as green cards can facilitate adherence to such devices, offering a reward for green homes, by linking them to simple and fun individual power consumption control systems.

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