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Innovation systems and regional clustering: the diffusion of knowledge for sustainability issues

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**Innovation systems and regional clustering: the diffusion of
knowledge for sustainability issues**

Abstract: The innovation systems perspective is primarily concerned with the knowledge flow and diffusion and its positive impact of stimulating economic growth. In innovation systems observed at the regional level there is a tendency of technologically dynamic production to become spatially concentrated in clusters, where individuals and organizations possessing a specialized knowledge and technological capabilities. Consequently, results appear as collective efficiency, a competitive advantage and economic benefits. During the 1980s and early 1990s, Brazil set up an important telecommunications cluster in Campinas region, fostered by government policies, and evolved around a telecom R&D Centre. Several small high-tech firms were established, grew, competed and cooperated with the local infrastructure and multinational corporation (MNC) subsidiaries. These, in turn, increased their local technological efforts and engaged in joint technological programs with local partners. In this paper the relation between innovation and knowledge is illustrated by the high technology cluster of Campinas. It also discusses clustering enabling technology for environmental sustainability issues and regional implications. *Keywords: development; knowledge spillovers; region; innovation systems; sustainability*

**1. Systems of Innovation, Knowledge and Learning
through Interacting**

The concept of innovation counts on the interplay between a series of actors whose actions and interactions are influenced by a set of factors such as the financial system, the legal frame,

skills of human resources, their formal education or scientific activities. By definition, innovation also occurs between experience and the "knowledge not-encoded" incorporated in institutions. The economist Bengt-Ake Lundvall pointed out that innovation "is a ubiquitous phenomenon in the modern economy. In practically all parts of the economy and at all times, we expect to find on-going processes of learning, searching and exploring, which result in new products, new techniques, new forms of organization and new markets" (Lundvall, 2000, p.8).

While innovation is stressed as a cumulative process, a conceptual approach is prevalent in moving towards a systemic approach between learning, knowledge flows and innovation. It supposes the innovative process not as an individual act of learning by a firm or an entrepreneur, but comprising different actors influenced by the nature of the institutions that form the system, as well as by the linkages and flows that connect them to one another.

From the most basic definition of a system as a group of interacting, interrelated, or interdependent elements forming a complex whole, Lundvall (2000, p. 2) argued that a innovation system is social within its sphere of interactions "by laws, social rules, cultural norms, routines, habits, technical standards, etc" in the sphere of societal interactions. Besides, (Niosi, 2002, p. 292) argued innovation systems as dynamic due to the "financial flows between government and private organization, human flows between universities, firms, and government laboratories, regulation flows emanating from government agencies towards innovation organizations, and knowledge flows (spillovers) among these institutions".

As knowledge plays a central role within a system for innovation, has been given the most emphasis to the number

of categorizations of knowledge available in the literature as summarized in the Table 1. Theories and principles from a historical background for knowledge were appointed by authors as Le Coadic (1996), Almeida and Kogut (1999), Davenport and Prusak (1999), Drucker (1999); Firestone (2001), Zack (1999), and by thinkers as Confucio, Hegel, Hume, Husserl, Kant, Pythagoras and Socrates.

Knowledge influencing or coming from the innovation theory oriented for knowledge modelling were proposed by Polanyi (1958, 1967, 1974), Vincenti (1984), Wiig and Wood (1995), Storper (1995), Krugman and Obstfeld (1996), Audretsch and Feldman (1996), Niosi (2002) and Lundvall (2000).

In terms of knowledge application on entrepreneurial innovation Karlsson and Manduchi (2001) included categories of scientific (or formal, codified) knowledge referring to the basic scientific principles requiring a formal training to access; also engineering knowledge as equivalent to inventions directly applicable in production; and the entrepreneurial knowledge stemming mainly from learning-by-doing (tacit capacities) and incorporating business concepts, markets, customers and so forth. It has been observed how tacit capacities and formal knowledge have a variable relevance between sectors. For instance, the Information and Communication Technologies (ICT) as science-based industries require more encoded scientific knowledge to foster their absorptive capacity of innovation. One important interaction that contributes to knowledge diffusion between knowledge organizations and the science based industry is by Research & Development (R&D) collaborations.

R&D is the main tool for develops the enterprise's ability to identify, assimilate and explore scientific knowledge of internal and external conditions, that is to say, it is responsible for

absorption capacity and apprenticeship. As the result of (R&D) activities, scientific or formal knowledge included in machineries or production devices, is also called internal codified knowledge. As a result of combination of different information bits in different contents, external codified knowledge emerges during the collective works (projects) of universities, R&D departments of firms and different research centers.

Table 1
Theoretical Perspective on Knowledge-based Innovation

<i>Elements</i>	<i>Knowledge Conceptual approach</i>	<i>Knowledge Applied approach</i>	<i>Knowledge Categorization approach</i>
Period of theory's development		From 1940 to 2000	Late 1990s
Kind of approach	Theories, principles from a historical background	Knowledge influencing or coming from the innovation theory	Knowledge application on entrepreneurial innovation
Theoretical Interpretation	Determination of a concept for knowledge appointed by authors and thinkers	Modelling of knowledge oriented for innovation systems	Tacit knowledge (Operational knowledge), Explicit knowledge (Systemic, Scientific) Technological knowledge Entrepreneurial knowledge
Main references	Confucio, Hegel, Hume, Husserl, Kant, Pythagoras and Socrates; Dahlberg (1995), Le Coadic (1996), Davenport and Prusak (1999), Drucker (1999), Zack (1999) and Firestone (2001)	Polanyi (1958, 1967, 1974), Ryle (1949/1984), Vincenti (1984), Wiig and Wood (1995), Storper (1995), Krugman and Obstfeld (1996), Audretsch and Feldman (1996), Feldman (1994), Niosi (2002) and Lundvall (2000, 2002)	Nonaka and Takeuchi (1995), Nonaka (1991), Fleck (2002) and Karlsson and Manduchi (2001)

Sources: Own elaboration based on theoretical research

Important asset to the entrepreneurial innovation, the technological knowledge stems mainly from formal education, experience and capacities, as well as the mobilization of individuals and institutions. The tacit aspects of knowledge – implicit in activity, also the knowledge not-encoded – are those that cannot be codified, but can only be transmitted via training or gained through personal experience. It appears to have been

introduced by Polanyi (1967, 1974) who argued that “when we acquire a skill, we acquire a corresponding understanding that defies articulation”.

In Nonaka (1991, p. 97) the new knowledge always begins with the individual. In order to transform tacit knowledge into explicit or formal requires steps of interaction. As defined (*ibid*) “*socialization* is the step where individuals shares tacit knowledge through observation, imitation and practice; followed by the step of *communication* to translate tacit into explicit knowledge; and the *combination* that means to incorporate the knowledge into a new technology generation”.

Studies on spatial diffusion of knowledge show that spillovers are of economic relevance because of their impact on regional income growth. The effects of spillovers - the unintentional transmission of knowledge to others beyond the intended boundary – can take place between geographically or technologically close firms spatially concentrated in clusters. In this case individuals, firms and institutions possessing specialized knowledge and complementary technological capabilities interact to generate innovation and economic growth. One common mechanism for a diffusion of knowledge is the direct transfer of production technologies, which would necessitate a physical transfer of goods.

In this paper, the telecommunications cluster in Campinas region is analyzed in terms of the technology-based paradigm of industrialization for newly industrialized countries (NICs) such as Brazil. It comprises a description of the major institutional players in the production and transfer of technology, such as universities, research institutions, industry associations and other organizations. This is followed by a discussion on the factors that favor the clustering enabling technology for

environmental sustainability, regional implications, and its growth dynamics and economic development.

2. Clustering, Knowledge Infrastructure and Regional Innovation Systems

Theories on innovation have expanded their focus and complexity, as stated by Niosi, J., Saviotti, P., Bellon, B. and Crow, M. (1993) from an individual firm perspective to the scenario that encompasses the national system of regulations, institutions, the human capital and governmental programs. At national level, the innovation systems perspective on the interactive process play a key role in bringing new products, new processes and new forms of organization into economic use. It is a dynamic interaction between industry, R&D, innovation and productivity centers, university, information gathering and analysis services and financing mechanisms.

At regional level, the innovation systems perspective stresses the effectiveness of the processes of absorption, creation or diffusion of new technologies in a region as determined by the level of participation of institutions involved. The so-called regional innovation system requires an underlying base on human capital, environmental conditions and local markets. Regional conditions imply the accumulation of the technician-scientific knowledge, to the perception of the innovative processes and technology transfer issues. Moreover, regional innovation systems are in direct relation with the social inclusion, employment, and regional development, with a network involving relations between companies and relations between companies and the physical and technological infrastructures.

Overall, the regions present advantageous conditions in function of the proximity between companies, actors and

institutions. A regional agglomeration of competencies depends on the performing and interconnections of actors involved, and also the establishment of collective norms and learning procedures, a process that takes time, even decades, as a learning process in itself. Such dynamic agglomerations have developed spontaneously and as reflected by (Niosi, 2000) “in some cases, governments have set the stage for the synergies to develop spontaneously. In other cases, governments have accelerated unplanned market trends”. This includes policies that address the demand for scientific and technological applications through the development of human resources; the provision of mechanisms to stimulate R&D activities by private firms, alliances and consortia involving public institutions, the constitution of technology information networks, technology transfer mechanisms and liaison agents to promote exchanges of knowledge among firms, research institutions and regions.

The notion of a cluster concept appears to be vague, being still a subject of research suggesting issue analysis and findings from case studies and observations. A cluster term apply for delimitation of the physical space, the diversity and intensity of relations among institutions, the diversity and complementarity of institutions and the target market. Accordingly, Berggren and Laestadius (2003) noted how “clusters defy traditional sector boundaries and therefore cannot be found in conventional industry statistics. Studying clusters thus involves detailed examinations and qualitative assessment of horizontal and vertical linkages”. In Galvão’s definition (2000) “clusters as all kinds of agglomerations of activities geographically concentrated and specialized by sectors – not taking into consideration the size of the production unities, and the nature of the economic activity developed”. Brito (2000) posed “industrial clusters not conceived as a mere spatial agglomeration of the industrial activities, but conceived as a

point of confluence between the local-regional systems of innovations”. In Jacobs and Ard-Pieter’s interpretation (1996) ‘there is not one correct definition of the cluster concept different dimensions are of interest’.

Clusters develop over time, and they are composed by enterprises to cooperate mutually or to develop integration complex systems, with solidarity and valuation of the collective effort. The reliance inter-organizational is based on the identity between the parts, in terms of thought, values and interests, once the cooperation allows the enterprises to have a higher degree of specialization. Wiig and Wood (1995) stressed the presence of mutual trust and collective tacit knowledge in a region to stimulate innovative activities, however ‘each cluster in a region has its own norms’ that ‘facilitates the exchange of knowledge’.

As important factor, cluster-based economic development refers to a broader microeconomic strategy, essentially territorially-rooted, arising from the articulation of competition and collaboration between public and private sectors at diverse spatial levels. It is also including all elements affecting the context for productivity and innovation in individual firms and creating an institutional focus on competitiveness beyond the life cycle of specific administrations.

3. The Emerging Telecommunications Cluster of Campinas, Brazil

An industry based definition of the Information and Communication Technologies (ICT) sector was first agreed upon at the 1998 meeting of the Organization for Economic Co-operation and Development (OECD) member countries. The principles underlying the definition were for services and

manufacturing industries. It means the products of a candidate industry must be intended to fulfill the function of information processing and communication including transmission and display or must use electronic processing to detect, measure and/or record physical phenomena or to control a physical process. For services industries, the products of a candidate industry must be intended to enable the function of information processing and communication by electronic means. Such definitions were based on the International Standard Classification of activities (ISIC Rev. 3) as a first step towards obtaining some initial measurements of ICT sector core indicators.

ICT sector plays an important role, notably by contributing to rapid technological progress and productivity growth. Firms use ICTs to organize transnational networks in response to international competition and the increasing demand for strategic interaction. In an economy based on creating, evaluating and trading knowledge, ICT sectors determine the productivity level. As a traditional supply-side approach, the performance of the ICT sector is analyzed in terms of employment, production of goods and services and creation of value added. Secondly, due to the pervasive nature of their products produced by the ICT sector is of significant importance for the performance of the remaining sectors of the economy (the use of computers for production and administrative purpose, e-commerce, etc).

Brazil occupies an outstanding position among the newly industrialized countries (NICs) mainly for its large and diversified manufacturing sector, for the country's gross domestic product (GDP) of approximately US\$717 billion, ranking among the world's ten leading economies. The industrial economy became concentrated particularly in São

Paulo State, the highest concentration of national manufacturing employment and responsible for approximately half of Brazilian GDP. The structure of the Campinas high-technology cluster [1] is related to the urban infrastructure and also to its location within São Paulo's area of influence. Though locally-created companies have multiplied in Campinas, some large technology-based firms originate from São Paulo and other regions have moved to Campinas to take advantage of technological opportunities and other perceived benefits of that location. The firms are distributed among six fields of activity: telecommunications equipment, electrical machinery and equipment, computers and office equipment, scientific instruments, information, engineering and scientific services, and software.

The build-up of the cluster was based on a strong scientific infrastructure at the state-owned University of Campinas (UNICAMP) founded in the mid-1960s. It was also built-up due to the gradual set up of subsidiaries of Multinational Companies (MNCs) in the 1980s and the interactive process between the government Telebrás Research and Development Center (CPqD), university system and local firms. A science-based support structure has been conducive to the growth of the Campinas telecom cluster of over 40 firms, producing telecom equipment and components. A survey carried out in the mid-1990s, in high-tech small and medium sized telecom firms in Campinas, São Paulo, found that 50% of them were created by former CPqD engineers (Quandt, 1997). The importance of the high-tech cluster in Campinas extends increasingly to the regional economy and to advanced technology development objectives, networks have been established in terms of productivity and competitiveness.

The UNICAMP, a State University with roughly 20,000 students is consistently ranked among the top universities in the country, it boasts the largest number of patents at national level; it also builds a strong scientific base by attracting leading Brazilian and international scientists and by concentrating massive government investments in state-of-the-art research laboratories. In the region, also the Catholic University of Campinas founded in 1946 offers ten graduate degrees among its 32 degree-oriented programs, and has developed an interdependent relationship with local industries.

The Research and Development Center (CPqD), located in Campinas and the largest applications laboratory in Latin America, was formally established in 1976 to reduce the Brazil's dependence on foreign technologies. Until that time, foreign equipment had been adapted to local networks, and implementation of specific requirements involved high costs to operators. Approximately 1,200 people work in CPqD; some of them are employees of private companies or universities engaged in temporary projects. Indeed, the strengthening of telecommunications equipment established in Brazil was a necessary condition; however it was not sufficient for the development of a larger part of R&D activity locally. In this regard, the CPqD created much needed innovative capacity within local industry, building stronger links between Brazilian firms and their MNCs partners rather than simply operating as commodity suppliers (Mani, 2004). Campinas' long tradition in hosting MNCs subsidiaries (Nortel Networks, Ericsson, Siemens, Lucent Technologies, Daitan Labs, IBM, etc), assures a strong environment for sourcing top performing experts.

Campinas has several other research institutions and organizations that have had some impact on technology transfers

to industry. Other important local initiatives comprise two companies set up as joint partnerships involving the public and private sectors. Codetec was created in 1976 by UNICAMP, the Ministry of Commerce and Industry and several private companies, conceived to conduct R&D, to adapt existing technologies, to provide technology support services and to foster start-up technology based firms. A recent institution is the Synchrotron Light Laboratory (LNLS) funded by the Brazilian Ministry of Science and Technology (MCT), offering conditions to perform research at an internationally competitive level, as a multi disciplinary laboratory, open to researchers from local and outside institutions.

As a legal frame, the “IT Incentives Law” no. 10176, approved in January 2001 by the MCT, was an extension which included alterations to Law no. 8248, in effect since 1991. The IT Law was designed to stimulate the development of national research and development projects and to reduce the importation of information technology goods and services. On December 30, 2004, the Federal Government issued further necessary legislation to the IT Law, which was modified as Law no. 11077/2004.

The IT Incentives Law has provided tax-exemptions on Industrialized Products (IPI) and Reduction of Income Tax (IR). It adds two core elements to Brazil’s production system: it cuts the local manufacturing cost through partial exemption of the IPI tax on information related goods; it requires beneficiary companies to allocate stipulated annual investments to R&D, consisting of 5% of their net revenues brought in through IT goods and services. In turn, this 5% is distributed for in-house applications (2.7%), and the remaining 2.3% must be allocated to research or education centers or institutes (1%), part of which must compulsorily be spent in the Northeast, Amazon or Mid-

West regions (0.8%) and part of which must be deposited into the Scientific and Technological Development National Fund – FNDCT (0.5%).

4. ICT Cluster and Sustainability

ICT for sustainability has been a theme of study, speculation and debate, and there is an untapped potential for adding intelligence to ICT components, products, and services to address economic and environmental challenges. Authors such as Berkhout and Hertin (2001) indicated “large and growing efforts that have been made to understand the emergence of ICT as a ‘general purpose’ technology and to analyze their impacts on the economy and society”. Madden and WeiBrod (2008) pointed out ICT as a sector able to reduce the environmental footprint, a key player in creating a low carbon economy, since it is deemed to be the primary focus where the ICT can be mobilized to make the most substantial contribution.

As the sector is both energy-intensive user and a potential foundation of the economy’s efficiency, the ICT might face an absolute increase in emissions that will have a significant bearing on expectations in that it should commit to absolute reductions. As reflected by Forge (2007) it is clear how ICT’s impacts on our economy have developed to the point of complete dependence for which we are paying a penalty, principally in terms of their externalities in energy usage. Similarly, Ryan (2004) seems ICT having touched almost every area of the economy, just reaching a critical point where reactive change is giving way to the dynamics of innovation, exploiting new technological and organizational potentialities.

Ideally, such critical point might mean where ICT can provide the desired functions of dematerialization with considerably less

materials usage, by decreasing materials flows in the economy. In fact, Luukkanen (2005) suggested structural changes in the economy, most notably dematerialization, as essential for advancing sustainability; or as proposed by Hughes and Johnston (2005), dematerialization creates opportunities for decoupling economic growth from the use of limited resources, increasing material productivity.

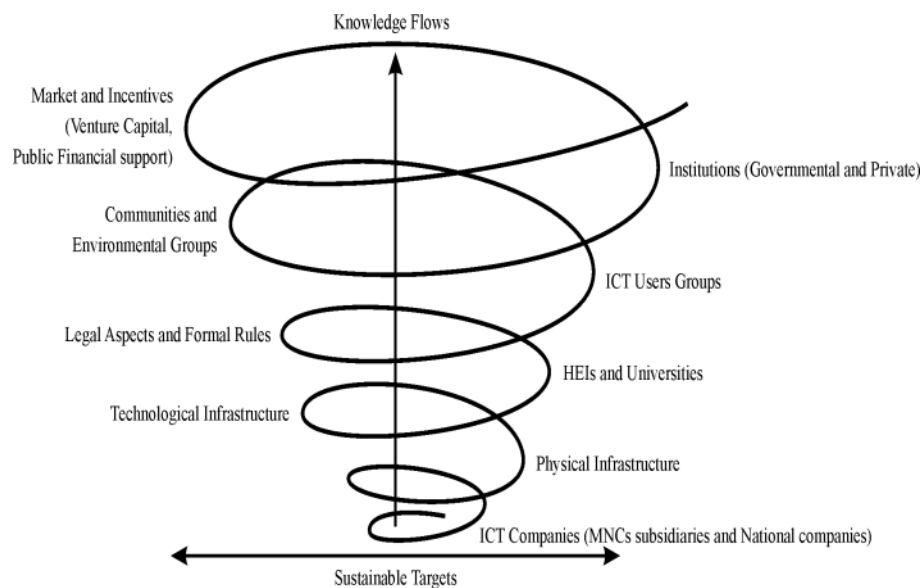
Therefore, ICT Cluster-based sustainability is concerned with the dematerialization creating opportunities for decoupling economic growth from the use of limited resources, increasing equilibrium between the economy and the environment. It implies areas of knowledge and skills as basis for sustainability, which brings R&D for energy-efficient and environment outputs closely together. Three sets of capabilities dynamically interact as critical elements of such a strategy:

- empowering community awareness, collective intelligence and action;
- sustainable targets based on natural capital and ecosystems, and insights into the technological, economic and socio-cultural principles that underpin sustainability;
- cooperation with Higher Research Institutes (HEIs) and universities to provide expertise knowledge by contract R&D or by the transfer of technological or scientific solutions.

A structure for ICT cluster-based sustainability is suggested schematically in the Figure 01, comprising linkages between the networks of knowledge, institutions, and areas of infrastructure. In terms of Sustainable Targets, particular attention has been paid to ICT across their operations, effects and impacts on the natural environment. Edler and Lundberg (2004) illustrated the ICT life-cycle phases, noting that product manufacturing (especially of electronics in user terminals) accounts for about

22% of the impact on the environment. The operational phase, which is the most critical phase, includes actual equipment operation and operator office activities. During this phase, equipment operation and office activities account for about 78% of the total impact on the environment. The operation of telecommunications equipment accounts for about 60%. In order to pursue efficiency across their operations, each element in the product chain is regularly assessed to identify potential energy savings – during production, distribution and supply, as well as in installation and operation – requiring a multi-stakeholder structure.

Figure 1
ICT cluster, knowledge flows and sustainability: an illustrative scheme



Sources: adapted from Ryan (2004). Own elaboration based on integrated works (HEIs Higher Research Institutes; MNCs Multinational companies; ICTs Information and Communications Technologies)

By placing emphasis on the “redesign” stage of products, services and operations within the entire lifecycle (of the product), ICT companies make real strides towards sustainable targets. The Design-for-Environment (DfE) strategies play an important role in this concern by incorporating environmental considerations through every phase of the product (energy saving, reduced use of harmful chemicals and

increased use of used parts and recycled material, etc), or by offering new criteria for evaluating design, such as choices for production techniques, finishing technologies, and packaging methods. As the entire product life-cycle is a process, which stimulates partnerships between suppliers, distributors and recyclers, the DfE facilitates systematic evaluation of an ICT product lifecycle, from supplier management during component manufacturing, through end-of-life solutions. For an ICT company, energy use is a pivotal factor in determining its environmental profile. By applying life-cycle technique, companies are in a position to make a contribution to structural change, using minimal energy to maximum effect for ICT users groups.

A 'crossover' from 'environment policy' to 'innovation' is a condition to build the design innovation capacity within ICT industry driven to continuous improvement in the (life-cycle) environmental impacts of products and services. Furthermore, a legal or a merger of environmental policy and technology policy and better co-ordination among are fundamental requisites to combine entire technological system (product, production chain and associated infrastructure and institutional structure) with skilled labor and infrastructure entails to achieve breakthrough innovations taking into account environmental aspects.

Indications on market-based policy incentives refer to a cost-benefit perspective such: taxes and subsidies to send the right price signals on resources (e.g. on carbon based energy); standards for performance (energy); take-back (extended producer responsibility) requirements for particular product categories, requiring producers to collect, treat, recycle and recover materials and components for near-to-zero waste (for example in waste electronic equipment).

Environmental groups, in digital society, can provide information about the role of ICT in enabling a low carbon economy can potentially empower consumers to make green purchasing decisions with regard to efficiency technology adoption. Consistent with that, ICT have changed the way businesses interact with their consumers and also supported the emergence of green consumerism – it is easier online to track down sustainable products that are not widely available (Madden and Weissbrod, 2008).

5. Conclusions

Campinas agglomeration arises from a substantial pool of knowledge workers and such knowledge-intensive industrial cluster for sustainability (and particularly for the environmental dimension of sustainability) is a complex matter and a terrain for reflection at a widely view.

Through a number of potentialities and uncertainties on information and communications technologies, an analysis of Campinas cluster for environmental sustainability implies the process of adapting of the following sets of capabilities:

- empowering community collective intelligence and action to make organizational and social behaviors more sustainable, there has to be awareness at the outset when introducing new ways of working (i.e. tele-working, videoconferencing); streamlining supply chain (i.e. smart logistics); generating and distributing energy efficiently (i.e. smart power grid); living efficiently (intelligent residential buildings); operating smartly (intelligent industrial buildings); and designing well informed policies (dynamic interaction between ICT, economic system, and sustainability). Individuals and organizations should be supplied with sufficient information to take

environmentally aware decisions when acquiring new technologies; also to replace the mode of consumption from product ownership to services through dematerialization, i.e. buy digital alternatives instead of physical products;

- Sustainable targets refer to the effects through skilful, sensitive design to eliminate negative environmental impacts, and to stress efficiency; resiliency; patterns, processes associated with ICT product lifecycle. ICT Design-for-Environment is a strategic approach for sustaining economic and societal development in the Campinas region. Moreover, the development of technologies adopting de-carbonization strategy in manufacturing processes; reducing carbon and other emissions; and using environmental standards defined at national level and internationally;
- Cooperation strengthening with Higher Research Institutes (HEIs) and universities, since the high-technology agglomeration of Campinas shows an existent relationship between production capacity, technological capabilities and the potential to attract R&D. The cluster specialization in telecommunications combines endogenous efforts by the region's institutions with equally significant initiatives from extra-regional sources such as governmental interventions as well national and MNCs number of large multinational corporations. Subsidiaries of MNCs play an important role regarding technology diffusion in Campinas, however we do not know much on their real impact, which are influenced by some factors such as subsidiary R&D management, costs of local technical and scientific networking, links between companies and research institutes or universities, and time consuming.

The IT Law has been crucial for the increase in technological efforts of the multinational branches, encouraging investments in R&D and partnership with local universities and research centers. Since its implementation, the law has stimulated those MNCs in the Campinas cluster to develop significant activities into technological chains.

This paper aims to be a contribution to the existent demand on studies to analyze environmental constraints and economical opportunities in high-technology clusters such as Campinas agglomeration. Nonetheless, being an essential and strategic component of the economic development, ICT must be treated as sustainability factor, with new criteria in the design of energy efficient and technological systems.

Nonetheless, being an essential and strategic component of the economic development, ICT must be treated as sustainability factor, with new criteria and measures in the end-use energy efficiency and in the design of socio and technological systems.

Note: [1] There are many large-scale industries in Campinas and surrounding cities, with concentration of subsidiaries of the world's largest multinational corporations, such as Mercedes-Benz, Bosch, Hewlett-Packard, Texas Instruments, General Electric, Merck, Pirelli, Singer and Clark, Honda, Toyota, Rhodia, Dupont, Procter & Gamble and Compaq.

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