The Role of Innovation and Technology in Industrial Ecology Systems for the Sustainable Development of Emerging Regions

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Abstract

The excessive growth of industrialization and the enormous movement of economic and physical goods and resources by industrialized countries have created a social imbalance in the poorest regions and a tremendous impact on their environment and on the exhaustion of their natural resources. This situation converges into a dilemma that raises the question: "how to insert technology into the innovation chains to remedy, recycle, reuse and/or redesign industrial processes?" This study proposes a framework for harmoniously articulating the three large sub-systems (the economic, the social, and the environmental) of the natural ecosystem through a systemic model of industrial ecology supported by innovation systems and enabling technologies, capable of maintaining a synergy among all the constituents of the three subsystems, with the intention to arrive at a sustainable holistic development of the regions, mainly for developing countries.

Keywords: Regional holistic development, Sustainable development, Industrial ecology systems, Innovation ecosystems, Developing countries, Sustainable technologies

1. Introduction

Effects of the global industrial economy:

Without better policies and institutions,

social and environmental strains may derail development progress,

leading to higher poverty levels and a decline in the quality of life for everybody

World Bank (2003)

From 1972 to 1995, globalization increased in both industrialized and emerging countries; however, social development and environmental impact have not followed the same trend in developing countries (Rudra, 2002). Additionally, the success of the globalization of the greater part of the industrialized countries has been focused on an excessive economic growth, often at the cost of other countries (Sachs, 2008) that have not yet been able to reconcile complementing their economic growth with social development, much less with regional environmental impact. For these countries the impact of globalization is deteriorating their social tissue and their natural environment.

The growth has not been balanced. This behavior is caused by multiple factors. We believe that a determinant factor is the reductionist approach with which the people responsible for making public policy decisions have resolved the social and economic problems of their regions totally isolated from each other and from their environmental impact (Forrester, 2009). If we add to this situation the distrust in institutions, the high growth of inefficient bureaucratic organizations, uncontrolled population growth, corruption, and the cohesive and inclusive lack of leadership at all levels (Scheel & Pineda, 2011), we end up with regions with eminent social imbalances that are always associated with a great deterioration in the quantity and quality of natural resources, mainly in the world's economically less favored regions.

To simplify the complexity of the situation, we identify three large components of the meta-system of the biosphere, which are the social, the economic and the environmental sub-systems. For some economists, technicians, environmentalists and sociologists, this division in subsystems has generated a controversial dilemma: "Is it possible to maintain equilibrium between the excessive industrial growth and the population's quality of life in a developing region, at the expense of the quantity and the depletion of its finite natural resources, where all sub-systems win?" Furthermore, is technological innovation an effective, viable and durable solution to the dilemma?

For this situation, created in the last century, nobody has immediate or simple answers. Nevertheless, we can establish the role of technology and innovation as strong forces that may allow policy designers to deploy all the constitutive elements, their relationships, the conditions that promote and inhibit them and, with all these parameters, be able to combine the settings needed to make the most adequate decisions (Hargroves & Smith, 2005), aligned to the constituent components of all the agents (individuals, societies, businesses and environment) in long-time horizons and within extensive geographical coverage.

This article presents a proposal for the integration of the industrial cycle with the social development and the ecological footprint by the appropriate use of enabling technologies and innovation systems, articulated to transform the product manufacturing chains into sustainable economically competitive industries, capable of generating and sharing wealth for most of the individuals in a specified region.

To accomplish this objective, the article is organized as follows. First, an industrial growth dilemma is described. In the second section, a conceptual foundation for the study is provided by defining key terms of innovation, industrial ecology and discussing the connection with technology, entrepreneurship, and the systemic approach of regional development. In the third section, the design of a sustainable product cycle is proposed**.** The fourth section contains the study's research design, the methodologies and case studies. Afterwards, the discussion is presented and finally the conclusions are stated.

2. The Dilemma of Industrial Growth

The role of technology has become transcendental since the second half of the 20th century. The current world situation is being rapidly redefined by income growth, climate change, high energy prices, high production and global markets (Von Braun, 2007). John and Pecchenino (1994) established that there has been a direct correlation between economic growth and environmental degradation, due to the disordered growth of communities, their consumption habits and their stressful quality of life. In addition, the World Business Council for Sustainable Development (2011) establishes that "businesses cannot be successful in societies that fail". This statement reinforces the dilemma of the contemporary development of ecological balance against economic and social growth because all cannot grow together due to the isolated optimization of the resources and their divergent impact on each other. Furthermore, Daly (2010) stated: "Sustainable growth on a finite planet is an impossible theorem".

In spite of all these signals, in some advanced economies (like that of the USA) it is possible to observe this reductionist approach applied in most of the public policies oriented towards accelerating economic growth based on the production-consumption model, and exhorting consumer shopping to reduce the fear of an economic recession. In consequence, these economies produce more economic value added, using the economic surpluses to remedy the impact of these decisions on ecological and natural resources.

This situation creates another questions, such as, "Where are the limits to growth?" (Sachs, 2008). What is the limit when the increasing economic returns are not enough to compensate great ecological catastrophes, such as the oil spill in the Gulf of Mexico, the Russian forest fires, or the nuclear accident in Japan? When will the economic efficiency of market forces not be ecologically effective to recover the direct and indirect damages to the environment and/or to the social fabric?

The dilemma cannot be solved with conventional strategies at the same level it was created (with solutions as business as usual, social protectionism or environmentalist extreme measures) designed to achieve optimal financial efficiency. The best alternative is the harmonious holistic development of the three subsystems, with an open innovation (Chesbrough, 2003) perspective, where technology is used to resemble the natural systems through the redesign of new processes and production chains, and innovation systems integrated in a closed-loop metabolism of industrial nutrients, effective flows and transforming processes; where communities and regions as natural environments can have a sustainable and effective holistic development, keeping in balance all the other sustainability attributes (environmentally: reversible, resilient, and durable; socially: equitable and responsible; and economically: viable and reliable), as shown on Figure 1.

3. Innovation, Technology and Industrial Ecology

The relevance of innovation was first brought to public perception by Schumpeter (1934), who identified innovation as the main driving factor of economic progress for entrepreneurs. Additionally, Solow (1957), through his important empirical studies, reemphasized that innovation and technical progress are among the main drivers for economic growth. Since then, the range of studies of innovation processes and the implementation of ideas has grown, developed, and advanced in response to the changing nature of organizations (Anderson et al., 2004).

Joseph Schumpeter strongly recognized the contradiction between balance and growth (Beinhocker, 2006). Based on this, innovation is considered an internal factor (endogenous) to the economy and not as another theoretical approach that treats innovation as an externality. However, Robert Solow conceived that growth and balance could be compatible concepts (Beinhocker, 2006). Specifically, his argument was that this combination is a dynamic equilibrium or a balanced growth in equilibrium. Therefore, he inserted the technological component to the growth equation in order to obtain a dynamic balanced growth among the other variables (population growth, savings rates, etc.).

Productivity impelled by technology is the key to economic development, as it produces more savings and more investment, with the intention of entering virtuous cycles of increasing returns (Romer, 1991), as well as for demographic growth not solely in terms of population increase.

Economic growth is not only about increasing the amount of production or profits; it is necessary to achieve production embedded into a systemic innovation approach. It needs an inside economic system source of energy linked to the entrepreneurial mechanism represented by an effective "entrepreneur". This special socio-industrial actor breaks with the flow of innovation within markets and causes a creative destruction of the conventional industrial sector cycle of performance.

But how can these concepts are articulated?

In this context, entrepreneurship is seen in revolutionary terms as the ability to bring about something new, whether this is a production method, technological development, product/service, distribution system or even a new organizational form. Moreover, Harding (2004) states that entrepreneurship can create more jobs, contribute to higher economic growth, regeneration and productivity. Additionally, the global entrepreneurship monitor report for 2006 stated that regardless of the level of development and firm size, entrepreneurial behavior remains a crucial engine of innovation and growth for the economy and for individual companies since it implies attention and willingness to take advantage of unexploited opportunities (Harding, 2006).

What all this means is that entrepreneurship is embedded in the language of economics, linking the entrepreneur with wealth creation, economic development, innovation and jobs. In turn, this is translated into enterprise policy promoting and supporting the startup of new ventures and of technological innovation that allows us to understand entrepreneurs from the point of view of the industrial ecology theory that takes into account innovation as a driving motor for regional development.

Recent years have seen the rise of a new theory called Industrial Ecology (IE), dedicated to the goal that the planet should behave in a sustainable way (Graedel, 1996). The use of the word ecology is meant to imply that one should conserve and reuse resources, as is the practice in the biological systems. At the most fundamental level, IE embeds industrial systems as integral parts of natural ecosystems. Consequently, IE is intended to allow for the traditional model of industrial activity--where individual manufacturing processes transform raw materials into products, generating by-product residues and waste-- to be transformed into a more comprehensive model of a regional economy, assembled as an industrial ecosystem, in which the residues of some processes can be used as inputs for others (Frosch & Gallopoulos, 1989; Erkman, S. & Ramaswamy, R., 2003) Additionally, industrial ecosystems can be organized around product or material supply chains as well as in defined geographies (Boons & Baas, 1997).

Therefore, the grand proposal that can be formulated here is how to support industrial ecology systems through the use of appropriate technologies, and insert them into effective innovation chains (from ideas to entrepreneurship) to remedy, recycle, reuse or redesign industrial processes and, with this new design, be able to minimize or eliminate the negative impact that excessive industrialization and social chaos have generated on the environment of the regions, mainly in developing countries, where goods and services are produced, extracted or transformed.

The above proposal is truly important because one major critique of the industrial ecology literature is that it is heavy on speculation and extremely light on empirical evidence (Chertow, 2007). With a review of several industrial ecosystems, it is possible to establish that they are mostly centered in developed countries (which is our target region) (Chertow, 2007; Gibbs & Deutz, 2005; Jacobsen, 2006; Korhonen, 2001; Zhu et al., 2007). Furthermore, the previous studies have relied on qualitative methods to derive mostly theoretical insights but have left aside the practical ones. While previous studies have their merits, their analysis is limited because they were centered on the residue exchanges and flows among firms present inside the region, and the complex phenomena was not conceptualized using an “extended” production chain that admitted viewing the complete environmental impact of the processes chain, and the way that technology can aid in the re-use of residue and in making it resemble more closely to natural ecosystems. Furthermore, this “systemic” approach is in the same line as proposed by Pauli (2010) in his motivating Blue Economy approach.

We believe that enabling technologies and innovation systems continue to be the driving forces of modern sustainable economic development and can insert and transform the huge quantity of waste, toxic contaminants and by-products, wasteland, etc. into redesigned extended cycles of increasing returns of value. In the future, technological innovation’s major impact will be on the transformation of residues created by the industrial metabolism of conventional product chains inserted into the innovation chains of sustainable entrepreneurial networks or innovation clusters. This creates a technological innovation-based ecosystem, the core of regional natural competitive advantages, mainly for developing countries.

From this perspective, the major challenge for modern industrial and social systems is not only to reduce environmental impact to a viable index, but also to redesign the production chain and the business and social models so that residue and waste can be inserted into an economically viable industrial ecology system, with a perfect synergy between all the production life cycle activities and the sustainable development cycles of the region. This is our approach: To re-design around a sustainable product cycle, aligned to a holistic regional growth.

4. Design of a sustainable product cycle

Economic geographers theorize that regional systems evolve, from locations where co-located firms are unconscious of the greater potential of coordinated actions and simply benefit from economies of scale; to systems where there is dynamic coordination and technological learning to boost regional competitive advantages (Harrison et al., 1996; Porter, 1998). Therefore, there is a need to develop synergies among elements of the three subsystems (economic, social and environmental) in the region, as well as among all stakeholders, producers, suppliers, resources, processes, policy makers, etc. Specifically, these would be synergies that require a “governance system” that not only observes but also manages and executes, holistically and effectively, the relevant flows (matter, information, energy), as well as the resource allocation of the agents, optimizing and balancing the resources, flows and the states of the subsystems. Thus, as regions develop, several parameters characterizing the system increase as well. These parameters include the density of network connections among firms, coordination, innovative capacity and adaptability in the systems (Belussi & Gottardi, 2000).

Following the behavior of the region’s natural environment, a closed loop system must be built with all agents included and connected. To do this, it becomes necessary to change the current paradigm of the isolated efforts of each subsystem into a stabilization of the relational synergies for the creation of “conscious-constructive-capitalist” systems, a true shift from eco-efficient processes to eco-effectiveness (note 1) systems through the redesign not only of the production processes, but also of the business and industrial models with a new paradigm of sustainability based on “products as service” (McDonough & Braungart, 2002).

McDonough and Braungart (2002) describe an approach based on nature, which utilizes science, technology and natural resources in ways that create no negative side effects for the environment. Their approach guides the elimination of pollutants and harmful processes by using all by-products as nutrients of other processes, creating a closed nutrient loop. Using the waste of a process to provide nutrients for another is a challenging concept of redesign for the whole product life chain. In the textile sector, for example, biological nutrients are used, and at the end of their use, natural fibers are ground up and processed into new fabrics or composted, and their nutrients are returned to the ground, thus closing the natural biological loop.

To close the linear industrial chain, it is necessary to redesign a robust regional industrial ecosystem through an innovation system capable of reversing the equation, from an economically viable model designed to patch the environmental and social damages, into a model that can capitalize on the behaviors of non- equilibrium of industrialization processes and turn them into a cycle of increasing returns of economic, social and environmental value in which all systems win. This means transforming toxic (or low value) residue into technical nutrients for other industrial innovation chains, establishing the deployment of the process of transforming ideas into commercial outputs as an integrated flow that presents innovation as a sequential process (Hansen & Birkinshaw, 2007) with higher social and/or economic values.

If this is possible, we can convert the environmental impact indicators (LCA, Ecological Footprint, Resource Intensity, etc.) into indicators of economic value added and social welfare (Senge et al., 2008). In other words, this involves taking advantage of the value of all waste and by-products, generating this entrepreneurship into vibrant "start-ups" with new redesigned processes, capable of manufacturing new products or services that squeeze industrial waste until regions become 0-waste industrial regions (by-products with no more value, as in the case of the 0-waste city of Genève Program).

The new paradigm is predicated on the transformation of "divided" economic, social, and environmental sub-systems into a "systemic" environmental, value-added generation that can be economically viable and socially sharable. Moreover, it seems redundant to add the concept of systemic to sustainability. Perhaps there is not in nature a non-systemic sustainability phenomenon but, as we have observed the different models and approaches (Chertow, 2007; Gibbs & Deutz, 2005; Jacobsen, 2006; Korhonen, 2001; Zhu et al., 2007), we believe that we have to emphasize sustainability as a systemic phenomenon that clearly cannot leave any of the ecosystem components of the biosphere out of the equation.

5. Methodology

Edmondson and McManus (2007) note that quantitative methods are appropriate for mature state theories, while qualitative methods are fit for theories that are emerging (Chertow, 2007). Few researchers provide any evidence beyond a limited number of case studies. For example, the seminal case of the city of Kalundborg (Denmark), where the analysis is focused on the residue exchanges among eleven firms and the role played by the municipality (Gertler & Ehrenfeld, 1996; Jacobsen, 2006). Moreover, Korhonen (2001) analyzed the forest industry in Jyvaskyla (Finland) and realized that the residue exchanges were centered on the creation of energy through wastes because high oil prices triggered the search for alternative energy sources.

The studies above are qualitative. This allows us to establish that the theory is still in an emerging state and that the qualitative method is appropriate. Additionally, it should be noted that the industrial symbiosis studies took placed in developed countries where successful regional practices, such as well-informed systems, exist, and were mainly focused on the type of residue exchange among firms present in the region (Erkman, S. & Ramaswamy, R., 2003). Furthermore, the different national and local contexts influenced the identities and opportunities (Downing, 2005). Consequently, it seems convenient to analyze different regional cases to be able to extract the particular characteristics present in a developing country, with completely different industrial conditions from those of the developed country cases, analyzed by previews researchers.

Based on these experiences, the focus of our approach has been the geographic space of the region because in order to change the traditional paradigm, a complete redesign of the production chain must be reprogrammed and a new culture with systemic orientation must be crafted, all within a target region. In this new model, technology has a remarkable impact on the eco-effectiveness process design. This means that new technological innovations will be applied to the already existing processes, not just to reduce the amount of waste or atmospheric gases, but to close the industrial-environment cycle to remedy the current impact on natural resources until all the elements--products, services, residues, waste, energy and ecological path--become a single closed mega-cycle, capable of creating sustainable industries and 0-waste communities, and of inserting the residues into a regional wealth-creation cycle of ecological entrepreneurship.

It should be remembered that large firms usually have a corporate environmental protection program dictated top-down, which creates problems in the implementation of environmental measures (Schick et al., 2002). In addition, in a firm practices, different levels of ecological awareness, and activity can be observed. Most organizations still practice a defensive strategy in which they comply with legal obligations and try not to attract special attention from local residents, environmental activists or the general public (Belz & Strannegard, 1997). Therefore, it is necessary to observe the region as a "whole", with all the components of the innovation chain articulated, to achieve a holistic regional development.

The method selected to answer the research question was to use two different qualitative case studies as this approach facilitates the exploration of a phenomena within its context, using a variety of data sources (Baxter & Jack, 2008). This creates the possibility of revealing and understanding multiple facets of the phenomenon, and is a common practice (Yin, 2003) when covering contextual conditions is necessary or the boundaries are not clear between the phenomenon and the context.

First Case

Let us analyze a very simple application case of the above mentioned approach: how to transform a highly polluting product into a nutrient for another chain of high social value, with a low environmental impact. We selected this case because it allows us to actively choose the most productive sample to answer the research question (Marshall, 1996). We analyzed how a plastic (PET) bottle can be re-evaluated under three different value schemes. The first is to become more efficient by utilizing new reuse process technologies that are designed for the production of zero waste and reinsertion of the bottle in the same industrial chain, with the drawback that the bottle remains a bottle with the same pollution content. The second is to develop a new recycling process for the production of plastic bottles that generates fewer residues of CO_2 and other contaminants, and less consumption of H_2O. The third is to create a network of start-ups that can insert the bottles (with their intrinsic value) into another industrial sector. To do this, a value-mobilization procedure (Scheel, 2011) is used to insert a residue (i.e., bottle as a nutrient) into another production line (i.e., social housing construction), resulting in the assembly of a new innovation cluster.

Specifically, the mobility would consist of inserting the residue (product of the consumption-production chain), i.e. PET bottles, into another production line, like home construction industry, generating a new more valuable product development chain, with a higher social / lower environmental impact, as depicted in Figure 4.

In this case, the best option is the insertion of the waste into a more valuable (socially, in this case) industry closing the eco-social cycle more effectively. Furthermore, the industrialization of the collection of thousands of bottles, the reduction of the ecological footprint of transporting them, the preparation and insertion of them into the construction process, the scaling of the process to build hundreds of houses, with high insulated protection that is economically viable, environmentally non-polluting, and with great impact in terms of social welfare (especially in arid areas of developing countries) requires sophisticated logistics, clean technologies, efficient industrial processes, etc. (Scheel & Galeano, 2012). This can be described as an industrial ecology manufacturing closed-cycle system.

This is the core of the proposed framework (the SWIT (note 2) Model: Sustainable Wealth creation based on Innovation systems and enabling Technologies), designed to close the industrial cycle by taking into account properties of the residues value as nutrients for other product chains, as well as energy and waste materials and remediation costs, as part of a unique sustainable extended chain cycle (Scheel, 2011).

It must be mentioned that a backward glance at the definitions of industrial metabolism, synergies, symbiosis and all the mechanisms used to transform and manage residues and energy resources reveals that the missing link is how to transform these products or sub-products into some kind of valuable wealth. Unless we provide a model capable of transforming recyclable products and waste into new emerging enterprises (capable of transforming inputs into a socio-environmental-economic value added mechanism, articulated by innovation clusters), developing countries will be unable to create and share wealth within a sustainable increasing returns cycle. We need an entrepreneurial mind-set (economic, ecological and social) focused on the beginning of the eco-innovation chain, capable of producing or transforming residual by-products into valuable products with 0-wastes industries and a minimum impact on regional natural resources.

Second Case

To close the cycle of industrial sectors, first we must define the boundaries of the region in which the industrial ecology system will be enclosed. In doing so, it is necessary to involve the proper regional ecosystem with all the synergies required to articulate an efficient process of transformation and an innovation governance of all the required agents. Based on dozens of experiences delivered by the author, we have elaborated a comprehensive framework that deploys all the relationships, flows and processes required for the industrial metabolism and industrial ecology system to be effectively implemented.

We selected the current case because it allows us to answer the research question (Marshall, 1996). We chose the tortilla industry because it is a large, socially important one, that constitutes the basic food chain of millions of inhabitants in Mexico (and many other countries), and in the production process it has a great impact on the country's CO_2 footprint. In the production of corn (the basic ingredient of the tortilla), there are three main stages that must be analyzed. These are the harvesting process, the production of the dough, and the production of the tortilla for the end consumer. Specifically, we selected the production of the tortilla dough base. In this case, the dough is prepared by the multinational GRUMA Corporation (Mexican Stock Market, 2011).

In the following case, the tortilla industry chain is briefly illustrated. We show an excerpt of the extended value system (EVS) chain with all the players needed to transform resources (materials, processes, information, energy) into high-value products. Here we can see how the production manufacturing chain is merged with other complementary chains, resulting in the assembly of an Industrial Ecosystem Value Map with the following components:

- Resources (matter, energy, information)
- Transformation processes
- Product manufacturing chain
- Energy required for the transformation processes chain
- Residues/waste generation chain
- Residues / waste transformation processes chain
- Remediation costs chain

To quantify the use of energy in the dough production, an average of the energy consumption by diverse machines (cocedores and cooking piles) used in this process was determined. Specifically, the case of CO_2 is critical because the amount produced is significant and can be calculated using a financial statement reported by GRUMA. The company sells 1,114,000 tons of tortilla dough a year, requiring daily 3,052,054.79 kg of dough, which generates 494.73 tons of CO_2 daily, at a remediation cost of 24, 241.8 US dollars.

Given the high environmental and remedial costs, there is a need to search for other solutions. Here technology plays a fundamental role because by analyzing possibilities in other industries, it becomes feasible to transform carbon dioxide (CO_2) emissions into carbonate products that can be used by the paper, pharmaceuticals and fast-moving consumer goods industries.

According to Vanderheiden (1987), production of a two- micron ball of precipitated calcium carbonate (PCC) requires 25 grams of CO_2, 100 gr. of aqueous slurry of calcium hydroxide and 1 gr. of dissolved polyphosphate. Furthermore, it should be noted that PCC is a product in high demand because it is used in the three industries mentioned above (plastics, paper and pharmaceutical (note 3) sectors). Therefore, we are assuming that all of the daily CO_2 generated by GRUMA can be turned into PCC. Consequently, it becomes possible to produce 19,789,200 two- micron balls of PCC daily. Based on this information, the daily total production of PCC has a cost of: (Table 1)

Once the conditions for the capture and transformation of the CO_2 have been created, the production line must be inserted into other industrial chains capable of feeding and transforming the PCC into new valuable products with additional increasing economic returns. This sounds good; however, this CO_2 is not concentrated in a single location, which makes transportation (usually using highly pollutant vehicles) a relevant issue of the transformation chain, adding enormous costs to the remediation and to the total cost of production of the end products.

Thus, new regional start-ups must be created with high ecological value, able to collect thousands of tons of CO_2 and reduce the ecological footprint of transport, and prepare and insert them into the plastic, paper or pharmaceutical industries. This would bring important social welfare benefits, especially in poor areas of developing countries. Briefly, these are some of the additional benefits of this new regional ecosystem approach.

6. Discussion

The above example shows how it is possible to generate an exceptional EVA from by-products whenever technology and innovation processes are included in the sustainable regional development framework. However, a step forward can be taken by trying to reduce toxic residues and waste generated by the production chain, and concentrate on the redesign of the main product (i.e. the tortilla) without taking out too much of its flavor, texture, etc. and create a substitute product (i.e. pita bread) that is accepted by millions, this would skirt part of the high remediation costs of the conventional industry. The question that arises here is whether the processes, the products and the business models can be redesigned for this gigantic industry.

For instance, a product redesign could be one in which the process of recycling the residues might be shifted from the customer to the manufacturer. This would be possible when the manufacturer intervenes with the recycling or reuse services by including the technology costs for converting the products into nutrients for other industrial chains regionally located. This can change the way new business and industrial models would be designed.

Both of the previous examples are key to the modern R3 processes (reuse, recycle, revalue), which help the sustainability cycle by diminishing environmental impact and, at the same time, can produce a positive effect not only on economic value but also lead to social benefits. However, for the product as service to be effective, all the regional industrial stakeholders must participate, not just two or three firms or organizations, because regional competitiveness can force some companies to play unfairly if not all industrial participants in the region's extended value chain take part in a win-win framework for everyone. This means a holistic development of the region's entire industrial ecosystem, a new paradigm for regional competitiveness, a rare practice found in developing countries.

When the above cases are used as samples of best practices, most businessmen, ecologists, sociologists and policy makers bring to the table a lack of systemic awareness on the part of all stakeholders. Specifically, the role of technology and the new business models need a systemic governance of all the innovation chain participants: from the ideas and concepts generation, to research, patenting, product design, transfer, production line, scaling, residues metabolism, etc. A robust network of specialized agents must be created to support this approach.

These valuable networks must attract all the necessary and sufficient resources and drivers capable of mobilizing value in a "systemic way", as part of a regional innovation (Cooke, 2001; Scheel, 2011) ecosystem cluster with the proper management to articulate all activities. These activities include the industrial intelligence mechanisms (technological trends, prospective scenarios, industrial metabolism, industrial symbiosis, geo-referenced information, etc.), the specialization of firms and regions, the industrial clustering strategies and public policies, the resource allocation management mechanisms, the enabling technologies; as well as the holistic governance of the interests of all the stakeholders in the regional ecosystem.

In consequence, the use of science, technology and innovation must be planned as a whole and as a "holistic strategy" for the development of a regional ecosystem. The new framework breaks with the conventional regional development paths. It is not "doing business as usual" (Senge et al., 2008); rather, it is the construction of eco-systemic spaces where the concept of sustainability is overriding and a detonator, with the ability to redesign regions through industrial ecology systems able to include and interrelate all resources, flows, energy and transformation processes as a systems dynamics model of increasing value returns of social benefits and economic profits for all members of a region, through a new entrepreneurial program.

In summary, this is the key to the science, technology and innovation plan for wealth creation. First the creation of the ecosystem spaces (industrial ecosystem innovation clusters), and then the dynamics between the production (life cycle) chains and their ecological (residual/waste) impact chains (residues, waste, energy and ecological paths), linked to the value opportunities within the region, as well as all the process technologies required for the metabolisms, synergies and the resource/residues mobility. And finally, the insertion of all of them into an entrepreneurial program of "closed chain of valuable increasing returns" with an effective and sustainable governance and resource allocation management to provoke in selected regions, a sustainable balance of social well-being, environmental recovery and economic growth.

7. Conclusions

The chaotic growth of industrialization and the tremendous mobility of physical and economic resources throughout the world have created a social imbalance in the poorest regions and an impact on natural resources and the environment, impossible to reverse. The complexity of the situation has been attacked from multiple perspectives. Economists focus on the macroeconomic development of the regions, sociologists and policy makers, on models for reducing poverty or improving the quality of life in marginalized areas, while environmentalists try to protect the environment at all costs (Sachs, 2008). However, when an attempt is made to evaluate the results of these isolated efforts, one discovers that in the long run all these schemes are useless if they are tackled in an isolated manner, disarticulated one from another.

To return to the initial argument derived from the question: "how to insert technology into the innovation chains to remedy, recycle, reuse or redesign industrial processes", the complex phenomena of sustainable wealth creation cannot be solved with reductionists' tools of efficiency and local optimization. It is important to develop new holistic solutions which include, together with the product life cycle and production cost evaluation, a residue and energy transformation chain that considers all external costs of remediation and recovery of natural resources. Some cases were presented in which industrialization of waste and residue transformation using new technological innovations have become economically viable and ecologically favorable.

New forms of redesigning products to be eco-effective were presented, as the concept of product as service, allowing for the reduction of the environmental impact and, at the same time, creating a positive effect, not only on economic value but also on social benefits. For these models technology and innovation ecosystems are of great utility in developing new business models because unless we transform recyclable products and waste into new emerging enterprises (EVA producers), developing countries will be unable to create and share wealth within a sustainable "regional" increasing returns cycle. This requires an eco-entrepreneurial mind-set (economic, ecological and social tri-part approach) focused on the beginning of the eco-innovation chain to produce valuable products with 0-waste regional industries and a minimum impact on natural resources.

To manage this industrial ecology system, a new sustainable wealth creation model (SWIT), has been proposed, capable of generating the proper articulation of all stakeholders of the three sub-systems into an industrial ecology cluster of people, enterprises, industries and regions, all collaborating in a unique ecosystem space across boundaries, with the sole purpose of generating sustainable wealth for the region. With this new model in mind, the dilemma can be managed with a regional holistic development focus, in which a synergy between all components of the three subsystems must be maintained to achieve a win-win situation for all regional stakeholders.

Through this systemic approach, all components of the industrial ecology system [regional natural resources -energy and transportation, food and water, and material waste and toxicity (see Senge, 2008)-, regional conditions, processes technologies, social equality programs, ecological footprint, etc.] are interconnected with the industrial chains inside a region, forming high value entrepreneurial chains.

Based on the industrial metabolisms of the products / residues chains, the proposed model uses enabling technologies and innovation systems to articulate the synergies of the components, toward a truly "holistic ecosystemic development", maintaining the interactions among the sub-systems, as well as the sustainability attributes of: reversibility, resilience and durability of the environmental system; equitability and responsibility of the social development; and viability and reliability of the economic growth, all toward a single goal, achieve a sustainable wealth creation, mainly for regions of developing countries.

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Notes

Note 1. McDonough and Braungart (2002) state that the concept of eco-effectiveness leads to human industry that is regenerative rather than depletive. It involves the design of things that celebrate interdependence with other living systems. From an industrial-design perspective, it means products that work within cradle-to-cradle life cycles rather than cradle-to-grave ones.

Note 2. The SWIT model is based on the already developed model named WIT that can be found in Scheel (2011)

Note 3. CO_2 can be used in several different industries, as the multi-billion dollar global market for PCC has a growing projection.
http://ecopreneurist.com/2008/10/13/carbon-sciences-transforming-co2-into-useful-technology/

Table 1. Daily costs of total production of PCC by GRUMA

Raw Materials	Amount	Costs
CO_2	494.73 tons	16 961.4 €
Aqueous slurry of calcium hydroxide	1978.92 tons	326 522 euros
Dissolved polyphosphate	19.78 tons	19 285.5 euros
Labor costs	30 workers	Depends on the basic labor fee established by each country

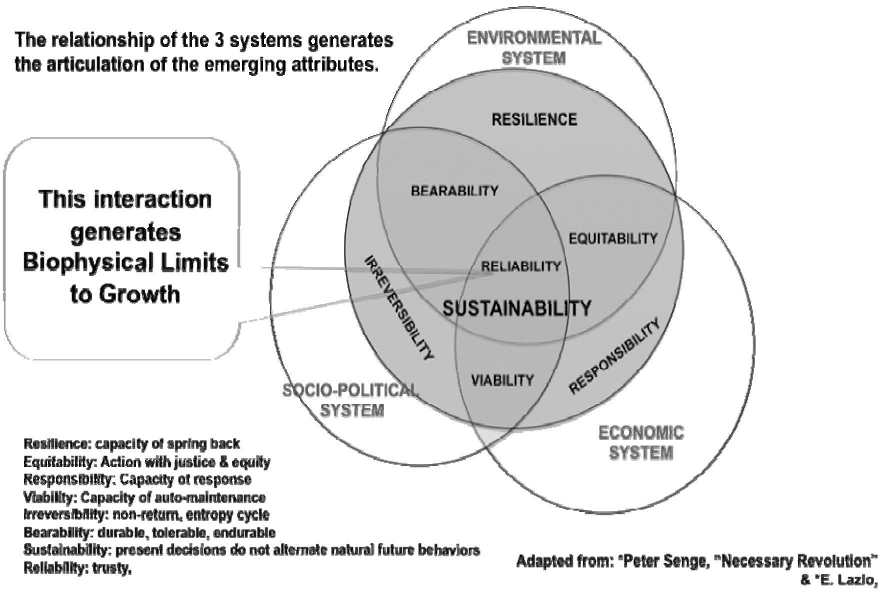

Figure 1. Relationship of sustainable attributes among the three sub-systems. Adapted from P. Senge et al. (2008), and E. Lazlo (2008)

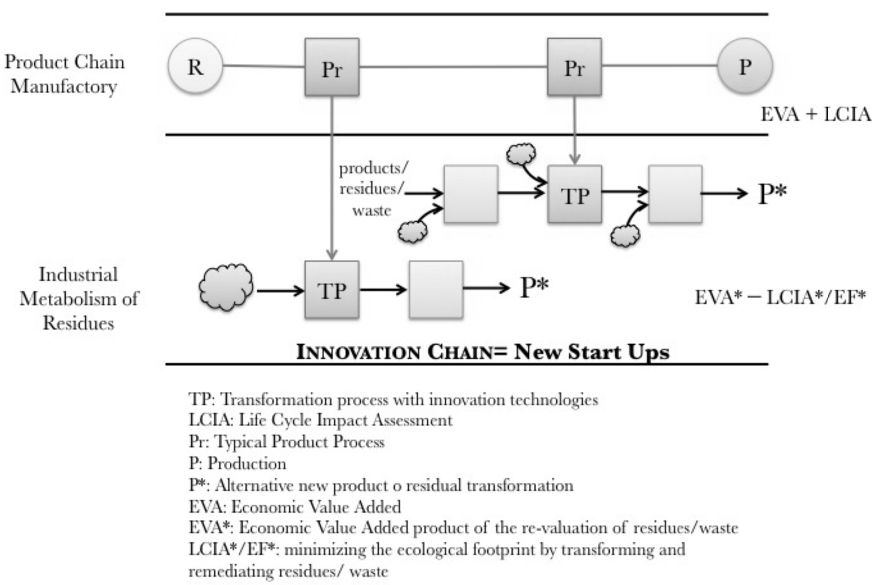

Figure 2. How Product Chain Manufacturing generates a new Residual Chain adding value from the transformation of residues and from the reduction of the Life Cycle Impact. The innovation chain transforms the input residue by-products into new enterprises through an effective entrepreneurial cluster.

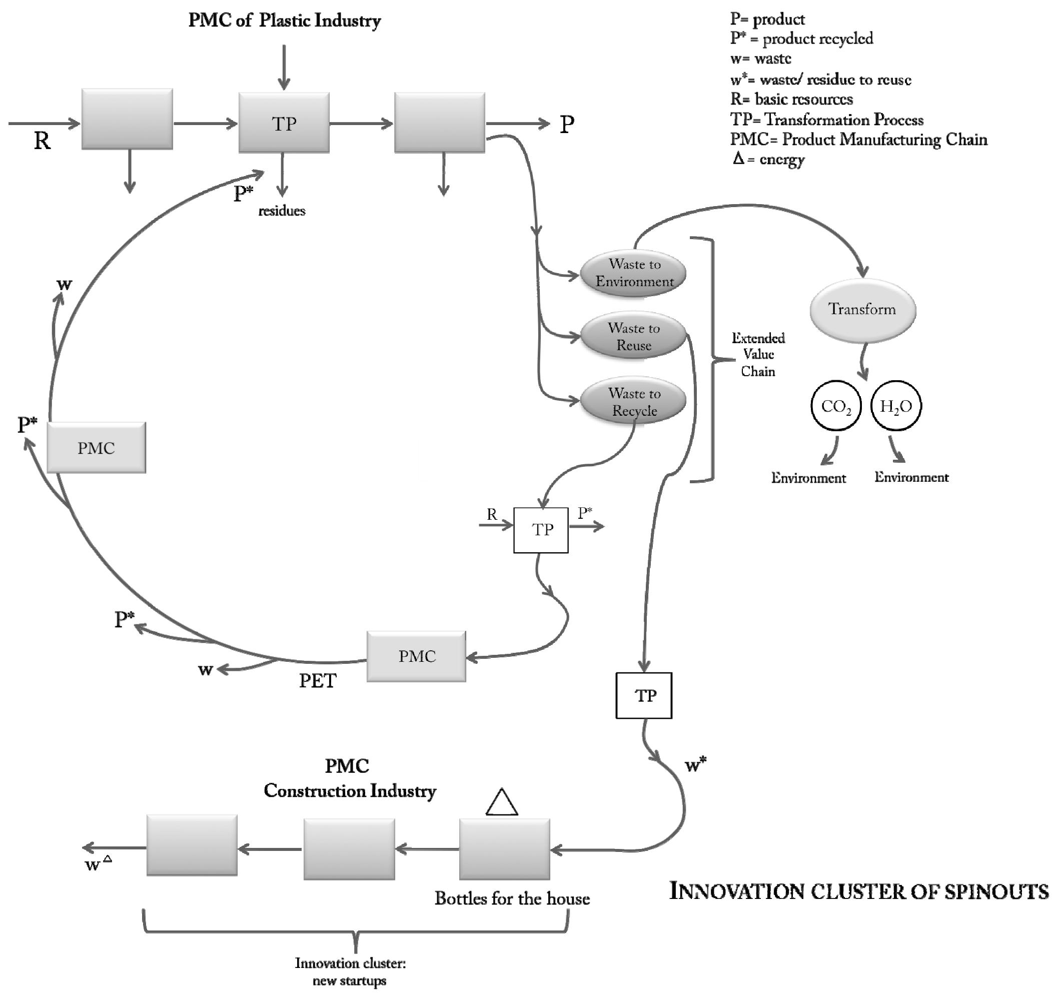

Figure 3. Result of the Transformation Process. Value Opportunities Synergies Map (resources, residues, waste, extended value chain with new technologies and innovation chains).

Note: Adapted from Senge et al. (2008), who has an excellent explanation of this cycle.

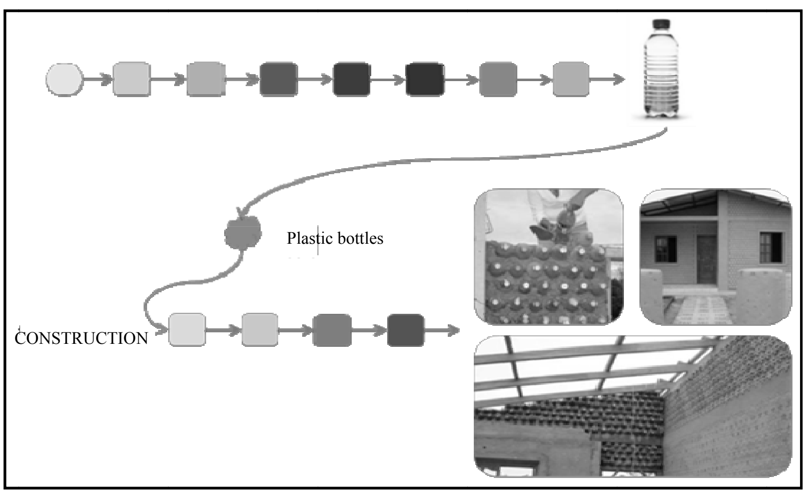

Figure 4. An up-cycling case: How to transform a product from a manufacturing chain into a cycle of social impact

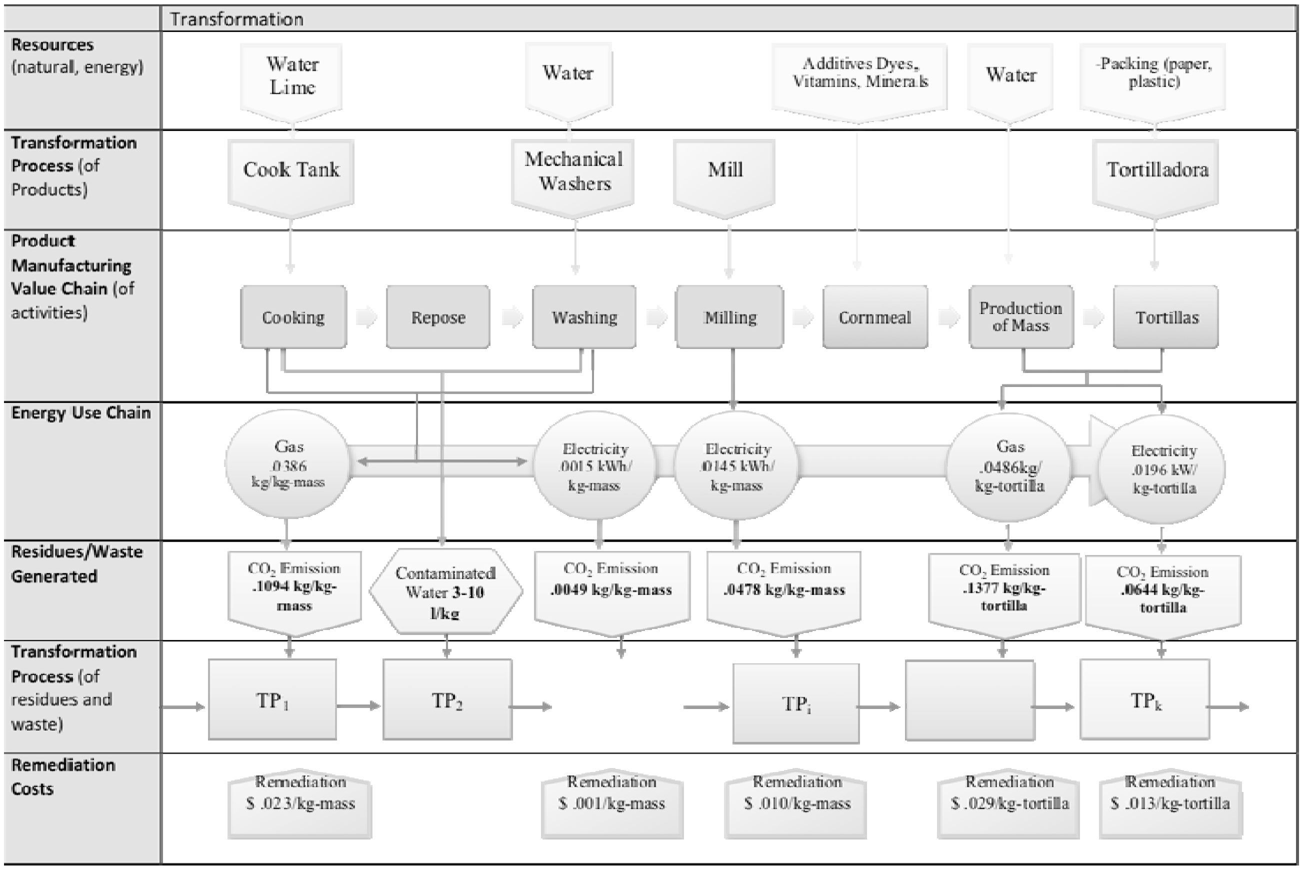

Figure 5. Excerpt of the Industrial Ecosystem Value Map of the tortilla industry. (see Scheel, C. & Hinojosa, J. 2010)