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Editorial

Industrial Ecology and Innovation: At What Point Are We? Editorial for the Special Issue "Industrial Ecology and Innovation"

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1. Past, Present and Future in Industrial Ecology Studies

For a long time, starting from the first industrial revolution until the second postwar period, technological progress has been aimed at increasing the technical-economic efficiency of production systems. Joseph Schumpeter (1939) considered technological progress as a fundamental element of the competitive advantage of companies. He also considered innovations as factors of discontinuity and disruption of the equilibrium of the economic system, in the short term, and a key factor of development, in the long term. Innovation, indeed, gives rise in the leading company to a new production function, that is more efficient from the technical and economic point of view.

From the 1980s onwards, the concept of economic feasibility has undergone a slow, but continuous, change: economically feasible production techniques are those aimed at diversifying the offer to quickly adapt it to quantitative and, above all, qualitative changes in demand. The good produced must no longer satisfy generic needs of a mass of consumers (as large as possible), but must respond to the needs, expressed and implicit, of the consumer, as defined by ISO 8402 standard (ISO 1994). Competition has shifted from quantity to quality, which is no longer considered as a characteristic (compliance with technical specifications) but as a value (suitability for use).

Starting from the early 1990s, the introduction of the environmental variable in the strategic and operational choices of companies has radically changed the structure, the organization and rules of governance of these systems, promoting behaviors aimed at pursuing greater sustainability without precluding their competitiveness.

The concept of eco-efficiency, introduced in 1999 by the World Business Council for Sustainable World Business Council for Sustainable Development (1999) to indicate the relationship between the value produced and the corresponding environmental resources used, effectively summarizes such evolutionary step. However, these results are achievable only on condition that companies are committed to a process of redefining production methods, through the implementation of innovations, capable of supporting an economically and environmentally sustainable strategy of growth, that is, the so called "eco-innovations". Eco-innovation can be represented as any form of innovation that aims at significant and demonstrable progress towards the goals of reducing the impact on the environment; improving the resilience of ecosystems to environmental pressures; achieving a more efficient and responsible use of natural resources. Thus, the main purpose is to create added value to the product or service, to minimize the use of natural resources, to reduce the various types of pollution and to optimize processes, producing, precisely, with a greater eco-efficiency. The logical links between the two concepts are obvious: the eco-efficiency expresses the link between the competitiveness of business operations and its sustainability; eco-innovations are the result of the technical-economic and environmental assessments carried out by companies in pursuing this objective (Taddeo et al. 2017).

The macro-typologies of eco-innovation developed in support to a more eco-efficient world of production can differ in the scope and methods of intervention, and in respect of the context in which they are adopted. A first typology, purely technological, includes systems and technologies for controlling and preventing pollution, and cleaner technologies, which have processes or phases of processes as reference framework; in such cases, the intervention mechanism modifies the current state in order to improve performances. A second level includes those innovative solutions that can act on the production output (products and services) in the design phase, for example, through the use of eco-design techniques. A third level includes eco-innovations of an organizational-managerial nature, which act on production models and on the procedures with which the activities that may have direct or indirect effects on the environment are carried out; it is the typical example of the implementation of environmental management systems.

However, almost simultaneously with the concept of eco-efficiency, the first theoretical framework supporting sustainability studies, i.e., that of Industrial Ecology (Lowe and Evans 1995), began to establish. Its origin is usually traced back to the article published by Frosch and Gallopoulos (1989), but its scientific foundations were laid much earlier. The rationale that distinguishes it is the so-called "metaphor of nature", an assumption as simple as it is effective: to try to develop and make anthropic systems work in analogy with biological systems, that is, in perfect harmony and physical balance (in terms of material and energy flows) with the economic/ecological context in which they are located (Jelinski et al. 1992).

The concrete application of this assumption implies a review and evolution of the approaches, methodologies and tools of analysis, from the point of view of design, evaluation of products, processes, production chains, i.e., of the constitutive elements of the production systems and the entities (of the biosphere and of the technosphere) with which they are related. This framework includes other types of innovation, whose scope of reference expands and goes beyond the single product, process or production unit. From this perspective, two other types of eco-innovations can be identified. The fourth level includes "supra-company" solutions, that refers to production supply chains; it is based on the so-called "life cycle" approaches and includes incremental and radical solutions for the design, assessment and reduction of the overall impacts produced in each phase of the useful life of a product (service) or process, from the extraction of raw materials to the end of their life (e.g., life cycle assessment/life cycle design/reverse logistics). Finally, the fifth level refers to production systems, clusters or business networks, in which solutions that can exploit the synergies deriving from the collaborative management of material or energy flows useful for the functioning of the various production units involved (e.g., closed-loop systems, industrial symbiosis solutions), can be implemented.

Industrial Ecology certainly deserves credit for having created a new field of studies, which has progressively developed, perfected and integrated approaches, methods and tools to support a paradigmatic transition, towards a more sustainable development. Indeed, concepts such as "green economy" and even more "circular economy", born in less academic and more political-government contexts than that of Industrial Ecology, have led to the large-scale diffusion of the aforementioned eco-innovations, by enabling the actors involved (companies, associations, central and local governments, consumers) to include them in their choices of production, use and consumption of goods and services, choices of which, for the first time in decades, it is possible to see the concrete effects.

In the near future, the role of innovations will be precisely supporting the growth of the anthropic *ecosystems* (industrial, urban, agricultural), in their process of sustainable transformation, keeping in balance all the sustainability attributes: circular, resilient, and durable from the environmental point of view; equitable and responsible, from the social perspective; and viable and reliable, from the economic stand.

The Special Issue of *Administrative Sciences* entitled "Industrial Ecology and Innovation" was able to collect meaningful contributions that demonstrate both how the scientific community is attentive and ready to meet the current challenges of an increasingly sustainable, circular and eco-efficient growth and the need to integrate different tools and approaches to achieve this common result. In this perspective, Industrial Ecology represents the privileged research field thanks to its interdisciplinary approach and holistic vision.

The Special Issue received 17 submissions from December 2018 to December 2019. Among them, 9 contributions have been accepted to be published (acceptance rate above 50%), after the one-blind peer review process. Published manuscripts were considered having scientific soundness and originality, but, especially, leading to the advancement of knowledge in the proposed research field.

2. Articles in the Special Issue

Through the contribution of Foschi and Bonoli (2019) "*The Commitment of Packaging Industry in the Framework of the European Strategy for Plastics in a Circular Economy*", the massive and strategic work done by the European Commission in order to regulate production and consumption patterns on plastic carrier bags and packaging, was investigated. These efforts allow to facilitate the achievement of the specific targets provided by the Directive on the reduction of the impact of certain plastic products on the environment (commonly known as the Directive on Single-Use-Plastics), putting plastics at the center of the debate, as recognized, by the European Union, a source of growing concern for the environment and climate, but also a key material able to push the transition towards a more sustainable and circular models of production and consumption. In this study, the closed-loop system implemented by an Italian packaging company has been described. It is based on an internal post-consumer bottle recycling process to produce high quality food grave of recycled polyethylene terephthalate (PET). While the recycling plant works on bottles sorting and washing, other departments of the group are devoted to grind, extrude and thermoform the recycled PET to produce secondary plastic materials for punnets and trays manufacturing. The case study analyzed shows as synergistic and collaborative solutions are able to produce relevant results in terms of economic growth, value created and environmental issues.

In their article entitled "*Life Cycle Assessment of Honey: Considering the Pollination Service*", Arzoumanidis et al. (2019) aim at exploring the economic value of pollination phase as a potential basis for managing multifunctionality in Life Cycle Assessment (LCA) modelling. In the field of Industrial Ecology, LCA is widely recognized as one of the most robust methodologies for the assessment of the environmental impacts of a product (or service) along its entire life cycle and for the improvement of its environmental performance. In this article, the authors carried out a case study on the honey food industry and addressed the multifunctionality of the system by performing economic allocation between the pollination service and the main product (honey). They found, for this case study, that the production phase is the most impactful, followed by the distribution, whilst the most affected environmental impact category is represented by natural land transformation, followed by marine ecotoxicity, freshwater eutrophication and human toxicity.

The article written by Imasiku et al. (2019) "*Unraveling Green Information Technology Systems as a Global Greenhouse Gas Emission Game-Changer*", lies in the field of technology, analyzing its strategic role in supporting the efficient management of environmental emissions and impacts while supporting an ecological sustainable development. In particular, the authors aim at unraveling the Green Information Technology System (Green ITS) as a potential tool to combat Greenhouse Gases (GHGs) emissions by analyzing the different elements of Information and Communication Technology (ICT). They use a twofold research methodology of measuring and monitoring GHGs emissions with the implementation of a lean six sigma approach useful to reduce any other categories of environmental waste (as carbon emissions). In their conclusions, the authors emphasize the need to exploit the technological skills, also through the use of software based on artificial intelligence, to monitor environmental emissions and to use a more aggressive approach of adopting renewable resources, with a particular focus on the potential of some lean production techniques, such as lean six sigma, in reducing waste, transforming companies into eco-efficient ones.

In the article *"A Call to Integrate Economic, Social and Environmental Motives into Guidance for Business Support for the Transition to a Circular Economy"*, Velenturf et al. (2019) point out the need to integrate social and environmental issues in supporting the transition process towards circular economy. They recognized how current measures, also those put in field by the European Commission, limit the role of companies and the motivation of business managers mainly to economic reasons. This finding underlines the multidimensional nature of circular economy phenomenon that, in a sustainable development perspective, is called to answer to environmental, social and economic issues. The authors come to this conclusion observing the behavior of small and medium-size enterprises in their engagement in EU founded projects for regional development in the field of resource efficiency and environmental protection. They conclude highlighting the need to provide a more inclusive support guidance to be able to realize the full potential of circular economy opportunities.

To further emphasize the role of life cycle-based approaches in the Industrial Ecology research field, Rimano et al. (2019) propose the article entitled "*Life Cycle Approaches for the Environmental Impact Assessment of Organizations: Defining the State of the Art*", in which, through a systematic literature analysis, the state of the art and the current application developments of those approaches have been defined. In particular, the analysis focused on the Organizational Life Cycle Assessment (O-LCA) and the Organization Environmental Footprint (OEF), which currently represent the main life cycle-based methodologies designed to evaluate the environmental performance of organizations. The research conducted revealed how, despite the very recent development of the two methodologies, both the organizations and the scientific community recognize their relevant role and, in the case of organizations, their adoption allows to increase their awareness of the impacts that they generate and committed to their reduction, being able to identify the main hotspots and having all the necessary information to support decision-making.

Lütje and Wohlgemuth (2020a, 2020b) have published two articles in the Special Issue, both focused on the theme of Industrial Symbiosis (IS) which, as described above, represents one of the most powerful tools for achieving the objectives of a sustainable and circular growth.

In the first article entitled *"Tracking Sustainability Targets with Quantitative Indicator Systems for Performance Measurement of Industrial Symbiosis in Industrial Parks"* (Lütje and Wohlgemuth 2020a), the authors face one of the questions still open in the field of Industrial Ecology represented by the need to measure and monitor the actions undertaken in IS projects, which are characterized by high degree of complexity, precisely because they depend on the interaction of numerous factors (technical, economic, social, regulatory, etc.) that come into play. In this study, a quantitative indicator system to measure and track the IS sustainability performance in industrial parks over time, is proposed. The indicators have been based on a system matrix, which covers all the three dimensions of sustainability (environmental, social, and economic) and will be embedded in an overarching IT-supported IS tool. As for the contribution of Imasiku et al. (2019), also in this case a prominent role is recognized to IT tools in supporting and driving the dynamics of IS development and, more generally, in supporting a sustainable ecological development.

In their second article entitled *"Requirements Engineering for an Industrial Symbiosis Tool for Industrial Parks Covering System Analysis, Transformation Simulation and Goal Setting"*, Lütje and Wohlgemuth (2020b) propose a systematized Requirements Engineering (RE) scheme in order to elaborate an initial basic framework for a holistic IT-supported IS tool for the evolution of IS in industrial parks. Two are the main results of this study: the extension of the perspective to future visions/scenarios and goal setting for elaborating target-oriented transformation pathways and, the inclusion of supporting simulation and modelling techniques.

The two articles presented are part of a large project conducted by the authors investigating the technology-enabled environment for IS system analysis, transformation simulation and goal-setting to enable and facilitate the implementation of IS solutions in industrial parks.

The article "*Sustainability Performance Indicators and Non-Financial Information Reporting. Evidence from the Italian Case*" written by Raucci and Tarquinio (2020), focuses on sustainability performance indicators widely recognized as useful tools in evaluating and communicating measurable aspects of environmental, economic, and social company's performance. In particular, the analysis conducted examined the effect of the introduction of EU Directive 2014/95/EU on non-financial information in Italy. Through the methodology of content analysis, the authors analyzed 31 companies carrying out a survey in the year 2012 (before the entry into force of the Directive) and in the year 2017 (after the entry into force of the Directive) to understand the rate of adoption and the use of such indicators by companies. They noticed a drastic reduction of the number of sustainability performance indicators reported in 2017. This result could be justified by the transition process that characterized companies and made them more cautious and selective with respect to the sustainability information they wanted to communicate. Although controversial in some ways, the obtained results are useful for both policymakers and companies in order to define strategies for improving and extending the disclosure of less disclosed indicators in the first case, and for identifying usable benchmarks to compare their approach to the disclosure of non-financial indicators with those of other competitors operating in the same or different industries.

As for the contribution of Foschi and Bonoli (2019), in their article *"From Trash to Cash: How Blockchain and Multi-Sensor-Driven Artificial Intelligence can transform Circular Economy of Plastic Waste?"* Chidepatil et al. (2020) focus on the eco-efficient management of plastic materials, as it represents one of the major challenges for environmental policies worldwide. In particular, in this study, the authors present an ongoing work related to the development of tools using blockchain and multi-sensor-driven artificial intelligence systems to segregate plastics based on the three different recognized categories (recyclable, non-recyclable, and complex or unknown) and improve the reliability of information about recycled plastics. The obtained results show the relevant role that technology can play in supporting the process towards a more efficient and circular economy and the need for different tools that can operate at different levels and integrate with each other to reach the main objective.

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