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Article

Industrial Ecology and Environmental Lean Management: Lights and Shadows

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Abstract: Current industrial production is driven by increasing globalization, which has led to a steady increase in production volumes and complexity of products aimed at the pursuit of meeting the needs of customers. In this context, one of the main tools in the management of customer value is Lean Manufacturing or Production, though it is considered primarily as a set of tools to reduce the total cost of the resources needed to achieve such needs. This philosophy has recently been enriched in the literature with case studies that link Lean Management (LM) with the improvement of environmental sustainability. The consequence is an expansion of the Computer Integrated Manufacturing (CIM); indeed, CIM, currently, combining and integrating the key business functions (e.g., business, engineering, manufacturing, and information management) with a view of the life cycle, does not highlight the strategic role of the environmental aspects. In order to deal with the increasingly rapid environmental degradation that is reflected in society, in terms of both economy and quality of life, Industrial Ecology (IE) introduced a new paradigm of principles and instruments of analysis and decision support (e.g., Life Cycle Assessment—LCA, Social Life Cycle Assessment -SLCA, Material Flow Account—MFA, *etc.*) that can be considered as the main basis for integrating the environmental aspects in each strategy, design, production, final product, and end of life management, through the re-engineering of processes and activities towards the development of an eco-industrial system. This paper presents the preliminary observations based on a analysis of both theories (LM-IE) and provides a possible assessment of the key factors relevant to their integration in a "lean environmental management", highlighting both positives (lights) and possible barriers (shadows).

Keywords: lean management; Industrial Ecology; Technology Environmental Innovations (TEIs); Computer Integrated Manufacturing (CIM)

1. Introduction

In March 2010, the European Commission presented its strategy "Europe 2020", and took note that the Western model of economic development has triggered a process of environmental degradation of difficult resolution. Such problem overlaps, both with the problem of limited natural resources, and also with the inequality of resource availability across geographies. Europe 2020 is a decennary strategy aiming at a structural transformation of the European economy in order to overcome the economic crisis and the challenges of the next decade through competitive and sustainable forms [1]. To achieve this, the Europe 2020 Strategy addresses the issue of growth, declining in three main areas [1]:

(1) Smart growth (promotion of knowledge, innovation, education, and digital society);
(2) Sustainable growth (production more efficient in terms of resources and greater competitiveness);
(3) Inclusive growth (more jobs, skills, and combating poverty).

In this way, the Europe 2020 Strategy identifies the eco-industries (also defined environmental industries or companies environmental technology oriented) as the enabled actors in order to do grow wealth and employment without causing serious damage to the environment [1]. For example, the strategy promotes those industries that produce so-called "*enabling technologies*". These kinds of industries allow to greatly increase the performance and ability of the user without increasing the consumption of resources (as in the case of information technology); moreover, this industrial model allows to reach the famous "decoupling" between economic growth and resource use, including the creation of wealth and environmental impacts.

The priority initiatives indicated in Europe 2020, were further underlined by the European Commission in its Communication "Rio+20: Towards the green economy and better governance" [2]. Indeed, the EU highlights the combination of competitiveness and the green economy, outlining the strategic directions (e.g., shifting the aim on R&D, introducing clean technologies, pointing to an industrial policy for green growth as a means to improve competitiveness, creating new jobs working to achieve a low-carbon and efficient use of resources). The increasing attention to environmental aspects, measured along the entire life cycle of a product/process, either by the company or by all possible stakeholders, needs to align the production model to that of environmental management, in order to create a new business model that is green-oriented. The authors, in order to deal the increasingly rapid environmental degradation, in terms of both economy and quality of life, answering to the Europe 2020 strategy, carry out several key factors useful to the re-engineering of processes and activities towards the development of an eco-industrial system.

A possible way is furnished by the Industrial Ecology (IE) theory, that introduced a new paradigm of principles and instruments of analysis and decision support (e.g., LCA, SLCA, MFA, *etc.*); these tools can be considered as the main basis for assessing and integrating the environmental aspects in each strategy, design, production, final product, and end of life management.

This paper presents the preliminary considerations based on an examination of two accredited theories (also defined strategies and philosophies):

(1) The Lean Management (LM) as a highly competitive production model [3,4];
(2) The Industrial Ecology (IE) as a framework of principles and tools of environmental analysis.

The aim of this paper is to highlight the key factors relevant to their integration in a environmental lean management system, both of positive terms (lights) and possible barrier (shadows).

2. Theory and Methods-Lean Management and Industrial Ecology

The Lean Production (LP) is based on the principles and processes introduced in the Toyota Production System (TPS), and was defined as "doing more with less" [5–7]. Womack, formalizing the principles of this theory, characterizes it as a system of measures and methods that, in a holistic approach, have the potential to reduce the production factors. It follows that the lean production model is reflected in the degree of competitiveness of the entire business system that adopts it. The LP is therefore a strategy or philosophy that promotes the use of practices, such as the *kanban*, a type of scheduling system, the total quality management (TQM) and just-in-time (JIT), to minimize scrap/waste and improve the performance of a company [8,9]. The LP initially broken down into four areas/strategic phases of production: Product development, supply chain, also called Kanban supermarket [10–12], the management of the workshop, and after-sales service. Thanks to a continued and applied research the LP has become a vital model for the entire business system, the Lean Management (LM) [13], emphasizing the expansion of the management production management of the organization in all its activities. In this way, the LM is often seen as a set of tools that compete for the reduction of the overall cost, and at the same time, are intended to improve the quality of manufactured products.

From an operational perspective, the LM is achieved through the adoption of a business model of integrated production or CIM (Computer Integrated Manufacturing), which represents the most complete form of integration between the different areas of a production system in an automated factory (*i.e.*, design, engineering, production, quality control, production planning, and marketing).

The CIM can be considered as a standard for the industry and may be automated through the use of Information Communication Technology (ICT), the LM is performed throughout the business life cycle (from design Computer Aided Design-Computer Aided Engineering-Finite Element Analysis (CAD-CAE-FEA, to the stages of production Computer Aided Manufacturing (CAM), to sales and after-sales service, a unique business model for optimal management of resources, Enterprise Resource Planning (ERP)).

Only recently the scientific literature proposes studies linking the philosophy of the LM with the improvement of environmental sustainability [14–18]. These studies suggest that lean production is more than a set of lean tools to optimize production efficiencies; it is a *modus operandi* and a mindset that must be integrated into production systems, in a systematic way, in order to achieve sustainability [16,17].

Obviously, the goal is to guide the LM towards a green perspective, and involves the crossing of conceptual limits of the same LM. In fact, although certainly the LM ensures better operating results, such as lower inventory through a lean warehouse, higher quality in all business processes, and overall shorter timescale due to a complete synchronization between events, however, it does not internalize the environmental perspective in their principles [6,10].

The above considerations are reflected in the "new inventory paradigm" introduced by Chikan [19], from which one can clearly understand what the relationships to other processes and functions within enterprises geared to profitability are. The paradigm does not focus on environmental issues, but on a number of mediating factors between lean production and financial performance, which is the real driving force in the spread of this theory. The paradigm can be detailed as follows:

(1) Establish a strategic vision: The *Value* must be defined jointly for each product family, along with a cost-based target on the value perceived by the customer;
(2) Identify and establish teams (identify the flow): *Value Stream*, namely the monitoring and identification of responsibility in all activities that are necessary specifications from the design, management of orders and deliveries, launch, production and final delivery to the customer;
(3) Identify the products (slide the flow): *Flow*, rethink specific work practices and tools to eliminate returns, scrap and arrests (of any kind), so that the design, order and production of a specific product may proceed in a continuous manner;
(4) Identify processes: *Pull*, flow only active when pulled to the next step;
(5) Review the layout of the factory: *Perfection*, the complete elimination of muda (waste) so that all the activities cascade contribute to the creation of value;
(6) Select an appropriate strategy *Kanban* (pull-push adaptive approach);
(7) Improve continuously, while maintaining the excellent results.

In combination with the above principles, companies can apply different types of environmental practices to improve their productivity in the use of natural resources, such as energy and materials, and to reduce the related environmental impacts of their activities [4].

The report "Lean and Green", presented by Zokaei *et al.* [20], and the studies carried out by Glavic and Lukman [21] and Lozano [22] provide an overview of some of these practices (e.g., the use of cleaner forms of production, the introduction of models production-oriented eco-efficiency). For Cagno *et al.* [23], cleaner production is an initiative of environmental protection that the company puts in place with a view to prevention. This initiative is designed to minimize the amount of waste and emissions (negative output), while maximizing production (positive output).

Using the definition given by González del Río [24], clean technology can be assimilated to changes in production processes that reduce the amount of waste and pollution generated in the production process or during the entire life cycle of the product.

This approach directs the company towards a greater focus on the analysis and measurement of the flows of materials and energy produced by the relationship between the company itself and the reference area or crossing. In addition, the management, in a pro-active way, adopts strategies to reduce these flows in their industrial processes, using both the improvements in the management (for example, the integration of the quality management system with the environment management system-TQEM). Another strategy is the introduction of technological advances applied to production (introduction of the Environmental Technology Innovations (TEIs)), in order to develop an eco-friendly company policy (e.g., the sustainable issue are the waste reduction, the improvement in the integrated management of the water cycle, the reduction of greenhouse gas emissions and losses of warmth, the attention to other impacts, such as acoustic, *etc.*).

Korhone [25] rationalizes the above principles in seven critical success factors, which are necessary to achieve eco-efficiency in production:

(1) The reduction in the intensity of the material (de-materialization);
(2) The reduction in energy intensity (de-energized);
(3) The reduction of dispersion of toxic substances;
(4) The improvement the recyclability of materials introduced into the production process;
(5) The substitution of input materials with other resources more environmentally sustainable;
(6) The reduction in the degree of persistence of the pollutants;
(7) The value increasing of the intangible component of each product.

These success factors are combined with the need to incorporate eco-efficiency already in the vision and business strategy, along with a growing availability of cleaner technology, which transforms the green market in the new field on which to compete. In contrast, the process of industrialization, compared with an ever-increasing demand following the enlargement of markets, is linked to the follow main factors of environmental impact:

(1) The high level of air pollution caused by combustion processes;
(2) The pollution of water bodies, determined by discharges of process waste to which are added the discharges of household;
(3) The production and accumulation of waste, increasingly complex, and difficult to recycle;
(4) The production of new materials, chemical products, such as plastics and synthetic products are not biodegradable.

In this way, another important role is played by the community of all stakeholders, which have to be involved in the decision process in order to build a shared knowledge and a collective consciousness changing its behaviors [26].

As a result of the foregoing, the world of scientific research and technological innovation, has set the goal of finding the appropriate solutions, creating new technologies applied to production cycles, making it possible to prevent and/or reduce pollution and to reduce, to minimal amount, the substances emitted (output) and the natural resources used (input).

At the same time, the increased level of awareness on the environmental risks has spread an ever-increasing attention on environmental aspects along the whole life cycle of a product/process; in this sense, it has reinforced the need to assess and share information, such as [27]:

(1) The environmental damage caused by the technological processes implemented and processed products;
(2) The actions necessary for modernization or modification of the technological process;
(3) The results of the comparative analysis for the definition of alternative technologies that lead to the production of the same product or a product change, reducing environmental impacts.

In response to these pressures from the legislature, the marketplace and the community, and the local, national, and international levels that, among the various theories have assumed a significant role in the Industrial Ecology (IE). The central concept and characterizing for the IE is an industrial system that should not be considered isolated from its surrounding systems, but in a position of continuous exchange. The IE deals with the systematic study of patterns of industry in relation to the natural and social systems involved, and it is designed to optimize such trade in terms of sustainability [28,29].

Tibbs [30] and Ayres and Ayres [15] summarize the concept of industrial ecology and translate it into an "industrial ecosystem", stressing the importance of thinking about how the characteristics of the natural ecosystem can be translated into an industrial ecosystem. The introduction of the concept of time-scale completes this concept, which in the anthropic system (techno-sphere) is relevant and not unlimited, allowing the analysis of the interactions that take place between all parties (competitive interactions and/or cooperation). Focusing on the principles of industrial ecology, they could be considered as the main support for the introduction of environmental considerations in all activities, from strategy to design, to production, to the realization of the product throughout the life cycle, through the king-engineering of processes and activities in an eco-industrial system.

To achieve these goals, it is necessary to understand the factors influenced a sustainable society; these are the scarcity of resources, the need for materials and the growth of energy consumption, the approach to the de-materialization and substitutability for sustainable development. In this sense, there are three major transitions [31,32]:

(1) The transition from fossil fuels to renewable energy sources;
(2) The transition from linear flows of an economy closed-loop material that gives economic value to the new secondary raw materials, with a view to re-use and recycling;
(3) The transition from the exploitation of nature and biodiversity to its protection.

The IE is a paradigm for environmental management principles and makes use of tools for environmental analysis and the definitions of compatible choices. It can then be finalized by the interpretation of the transformation of the industrial system connected to the load capacity of the territorial system in which it is rooted. In this sense, the IE has been regarded as a broad holistic framework to guide the transformation of the industrial system towards a model of sustainable production.

The profound change that is involved in the management of production from a linear model into a closed-loop model closely resembles the cyclical flows of ecosystems, drawing on the biological concept of ecology, which is the branch of biology that deals with the study of relationships that occur between organisms and the physical environment that hosts them [15].

Therefore, the IE seeks to structure the industrial models in a substantially closed loop, to benefit both economically and environmentally, not focusing on individual industrial processes, but proposing a new sustainable economy, based on a clear understanding of the interaction between the world of production and environmental system.

For sighting this result you need to avoid that the analyses are partial and simplistic, ignoring important variables and, above all, leading to unintended consequences.

The IE, in fact, addresses the entire lifecycle of a product-process, focusing on the use of resources and materials in relation to the analysis of energy flows, and through modeling systems, investigates the impact-relations environment, using a multidisciplinary and interdisciplinary approach, which aims to suggest options and more sustainable choices.

The IE uses a set of tools oriented to the product, e.g., the analysis of the life cycle (LCA), which seeks to ensure that, in the examination of an industrial process or product, all its interactions and impacts on the environment are fully accounted, from the extraction of raw materials, the processes of production, use and disposal of the product; this tool has been further specialized with the assessment of costs throughout the life cycle (LCC) and the evaluation of social aspects (SLCA), which are also particularly important in the industrial process in terms of human resource management [33].

Together with the LCA, there are a number of other tools oriented to the study of relationships between environmental systems (e.g., enterprise/manufacturing district and geographical areas of production and sales). Among these services, one may include the analysis of the flow of materials (MFA), which adopts a macroscopic approach, the analysis of the flow of a substance (SFA) with a microscopic approach, tools based on input-output tables that use statistical data and are most suitable for studying environmental reports at national/international regulations (e.g., physical input-output table (PIOT), and the ecological network analysis (ENA)).

For the analysis of the flows of materials and energy the first law of thermodynamics on the conservation of matter is applied, allowing a consistent and comprehensive collection of input and output flows, and stocks within the study area, *i.e.*, the system under observation [34].

The analysis of the flows of materials and energy can be used at both the global and local scales. Globally, this analysis of flows can help determine the extent to which human activities are influencing/impacting the natural systems of the Earth (e.g., hydrological cycle, the carbon cycle, and the nitrogen cycle). At the local level or enterprise level, these instruments introduce research methods that calculate the mass balances of industrial processes, the results of which can be used to ensure that all resources are fully valued in a sustainable manner.

The IE also introduces tools that are particularly suited to the realization of environmental information that is clear and easily understandable, and especially consumer-oriented. For example, the concept of ecological footprint has been developed by Ayres [35] in response to the debate on the concept of "carrying capacity". The carrying capacity is defined as "the population of a given species that can be sustained indefinitely in a given habitat without permanently damaging the ecosystem on which it depends" [36].

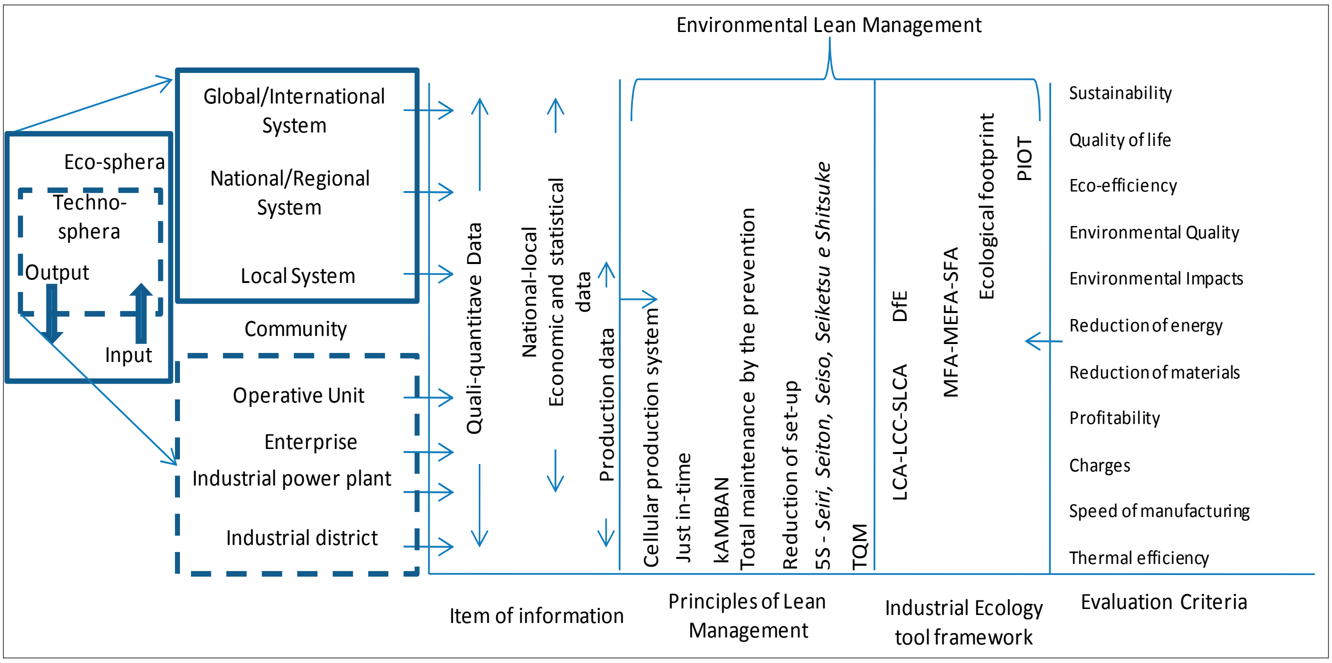
Thus, the ecological footprint expresses the theoretical area (in a single indicator that is "global hectare") used by man to produce biological resources it consumes and to absorb the waste it generates (including CO_2 resulting from its use of energy) [37].

Finally, again, based on the LCA, it is appropriate to highlight the Design for Environment (also called eco-design), which is a widely used approach for the improvement of environmental performance. The Design for Environment integrates environmental considerations throughout the life cycle of the product from the earliest stages of product design [38].

What has been said up to now shows the intrinsic connections between the LM and IE approaches. Based on the previous discussion of both theories, it is possible to identify a set of common evaluation criteria, which use the same data to measure the relationship between the company (techno-sphere) and the environment (eco-sphere).

The full integration of the two theories could represent the real success factor by single operating unit up to complex industrial system (e.g., District), observing such phenomena from the local to global/international level (Figure 1).

Figure 1. Selection of LM principles and IE tool, on the basis of common evaluation criteria and the same data types in order to support an environmental lean management model.



In this context, a lean company, although not necessarily green-oriented (rather generally, companies must make trade-offs among multiple objectives that are not fully compatible), has time for conversion and response to new market trends, including environmental, quicker and, therefore, is particularly ready to adopt a model of environmental lean management.

3. Results

Environmental lean management fully integrates with the green-oriented LM model, combining the basic principles of LM (*i.e.*, the five basic principles [39]) with those green principles (e.g., better use of natural resources and the reduction environmental impact [4]) in order to create a unique integrated model.

The environmental model of LM introduces the environmental variable along all processes, imposing eco-efficiency in production and use of resources, materials, and energy, and also introducing the goals of reducing environmental impacts, and of sharing the environmental information for environmental awareness spread along the flow/value chain.

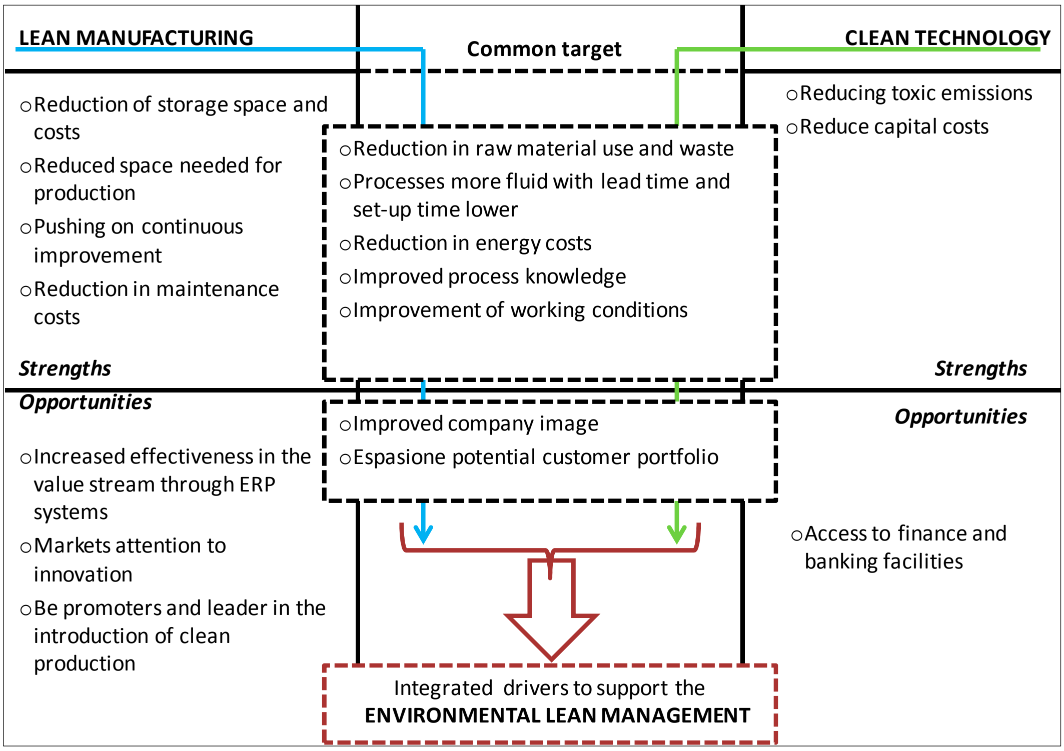
From integration of LM and CT strengths and opportunities, is possible to carry out the common targets' need to push the launch of the Environmental lean management system (Figure 2).

The environmental model of lean management is focused on overcoming the traditional forms of savings, which include reduction of overproduction, waiting time, transport optimization, adequacy in the answers to the problems, sizing inventory flow management, and reduction of defects [40].

This idea is reflected, for example, in the study by Moreira *et al.* [4], which explores other forms of loss in value (environmental impacts, energy consumption, material consumption, and emissions) to demonstrate that environmental liabilities are hidden inside of classic lean manufacturing.

From what has been stated in the previous paragraph, it is possible declare that a lean environment acts as a catalyst to facilitate environmental sustainability.

Figure 2. Synthesis of the main strengths and opportunities of LM and CT, in order to support the environmental lean management model.



Combining the LM aims [40] with the needs of sustainability that society asks [41], is possible to identify the vision of the environmental model of LM, that is to realize an efficient production system, effective and sustainable, within the social and economic aspects connected to the environmental and territorial conditions, from a long value chain perspective (from local community to global market).

In this perspective, the IE provides, through its principles, and its analysis and decision support tools, an effective response to transit from one model to that of environmental lean management.

In fact, the IE, in terms of support for the environmental assessment, applied to the entire corporate system allows:

(1) An overall assessment of the environmental risks arising from technological process and finished products;
(2) The quantitative analysis of environmental burdens related to the flows of materials and energy used in the process, as well as the flow of output products (In-put = output + stock);
(3) The evaluation of the recovery of secondary raw materials derived from waste and recycling processes that should be taken into account;
(4) The measurement of the consumption of all the raw materials and the use of recovered energy in the process;

(5) An identification of any other industrial waste streams secondary (solid, liquid, and gaseous fuels) to be taken into account (hidden flows);
(6) An identification of any flows of co-products harmful to the environment.

Then, IE could be considered as a paradigm of tools that environmental lean management adopts to maximize resource productivity and close the cycle of movement of resources within the techno-sphere, preserving the limited natural resources and minimizing the amount of production waste and related emissions.

This model can be used as a basis for determining the prospects and the direction of change necessary for a sustainable society, increasing the productivity of resources through the recirculation of what, before, was "lost" or "released" to the ecosphere.

A company that intends to reconvert according to a model of environmental lean management must start from the identification of the main sources of waste, and proceed with the elimination of the arising inefficiencies, and, then, develop more sustainable products, addressing green markets.

With the introduction of IE in the *modus operandi* of the LM, it is possible to define a new set of objectives that integrate environmental aspects within the financial-productive concerns:

(1) Reduce material and energy use for a product, including services in the course of his life;
(2) Reduce emissions, dispersion and the creation of toxic substances during his lifetime;
(3) Increase the amount of recyclable materials;
(4) Maximize sustainable use of renewable resources;
(5) Minimize the intensity of service for products and services;
(6) Extending the useful life of a product;
(7) Assess and minimize the environmental impact during the life of the product;
(8) Have a "functional economy" is a way to replace the products with services;
(9) Use "reverse logistics", which means that all efforts are used in order to reuse products and materials;
(10) Increase the efficiency of a product during use.

The final result is that both theories-philosophies have a strategic function and totally present, if one (IE) is applied in the other (LM).

4. Discussions of Positive Aspects and Possible Barriers

The correlation between LM and IE, for the study of new business models, leans green-oriented, points to a number of involved factors. The most important pressures for companies of a certain size, are the standards and rules set by customers (particularly international customers) that require environmental safeguards, in the perspectives of both cost savings and increased profits for shareholders; moreover, the increasing of communication and sharing of policies and performance, in terms of action and responsible environmental protection, with all the stakeholders-community, represents another relevant matter.

Instead, for SMEs, the most important drivers are represented by the target of cost savings. In addition, for such companies, environmental sustainability remains a consequence dictated by the legal obligations that continue to play a decisive role (mandatory system under "command and control").

Availability and accessibility to technology are two other key factors. However, an ever-increasing level of technological development is not proportional and uniform access to it. Limitations on physical-geographical, political-regulated, financial, and historical barriers are also slowing down in the field of technological innovation, the introduction of cleaner technology.

The three dimensions of sustainability (3P-society (people), environment (planet), economics (profit)), should, therefore, be extended by a fourth: The technological dimension [42–44]. The European Commission, in this sense, plays an important role as a catalyst for the development of European Technology Platforms (ETP) that promote the TEIs. In doing so, they gather key stakeholders operating in sectors with a high content of technology, innovation, and research, and sectors for which competitiveness and innovation, economic development and social development, depend on technological advances implemented in the medium and long term.

ETPs represent a model of technological governance, in which the legislature is a partner of the voluntary initiative of a European industrial system, with "bottom up" and "technology driven" approaches.

The ETP also try to overcome some of the main obstacles to the development of a lean green-oriented model from the point of view of industrial operators, namely the high costs of implementation of TEIs and the lack of tradition/skills.

In this sense, the ETP represent a positive boost thanks to the mobilization of significant human and financial resources and can help ensure investment in research and development to improve the competitiveness of European companies and bring benefits to European citizens. Another significant aspect, not related to the company size, is represented by the objectives posed by the highly diffused Total Quality Management models. These are an ideal base for expansion and integration with other management models (e.g., environmental, social and ethical, safety, *etc*.), supporting a culture of environmental protection, through shared responsibility between the high direction (top-down) and all the parts inside and outside the company (bottom-up), and a culture of training extended to the entire lifecycle of the product, from the supplier to the end customer (life cycle management).

From an operational perspective, the literature shows that most of the efforts are focused, for instance, on product design and on the introduction of technology on single production step, but not along the entire supply chain; this strategy acts is more oriented on the management of end-life, rather than on an integrated production system. In this sense, the biggest problem is the mentality of the producers, who believe that the main role of industrial systems is to transform inputs into outputs, cost-effectively, using technologies and efficient processes, but does not consider it essential that sustainability can play a key role in competitiveness.

This can also be attributed to the lack of widespread knowledge about the forces and mechanisms that support the implementation of practices for sustainable production are only also connected to a non-adequate notice of the improvements achieved by some green-oriented producers.

With regard to instruments introduced by the IE, there are strong resistances due to, e.g., the need for an investment in terms of money (external advice or preparation of a team within the company), or in terms of time and commitment to the collection of data, which are often not easily accessible and do not have adequate strength. For example, in the case of LCA, Udo de Haes [45] emphasizes the significant role to assess the complex interaction between a product and the environment, from cradle to cradle (as closed circle) and provide in-depth information on environmental impacts. LCA can be useful for manufacturing companies because it can demonstrate that the activities, processes, and materials used contribute to the production of large environmental impacts; these results can then serve as targets for improvement for green-oriented businesses.

However, as with other instruments, for the complexity of LCA studies can be particularly difficult for the entrepreneurs [46]. We have tried to overcome this negative aspect, which often prevents the application of a full LCA, through the application of a simplified version that also integrates into the paradigm the key features of lean management. Several other rigorous methodologies have been introduced to simplify LCA, supporting the adoption and dissemination [47].

Once all the difficulties that are typically associated with the application of IE are overcome, the analysis may prove its full ability to capture all environmental aspects. For example the DfE clearly points out the environmental impacts of a product that can be reduced more effectively, through the integration of environmental aspects in the early stages of the process (design) [48,49]. Environmental lean management can be a way to address the barriers and turn them into positive factors of competitiveness. In fact, this philosophy-strategy, if widely adopted, could represent a road map to guide long-term scientific and technological research, according to the needs of the industry, and to promote the application of technologies with a valid commercial return; environmental lean management can be considered an interdisciplinary model on which the industry may be interfaced with the research community and public authorities and regulators, in order to extend the dialog aimed at developing more effective and consistent standards and regulations, even in terms of promotion and development of adequate funding.

5. Conclusions

Improving the environmental performance in the manufacturing sector means decoupling economic performance from the environmental load of human activities. Environmental lean management represents a new frontier in terms of production efficiently, and is effectively able to reduce inputs of natural resources, materials and energy, or waste or pollutant outputs, while maintaining the assets of the techno-sphere separate from those of the ecosphere, in order to avoid environmental degradation.

The proposed integration could represent a best solution to achieve the sustainability. Current research in the areas of technologies for the production and management company systemic apparatus are increasingly linked to the productivity of resources, especially energy efficiency, and environmental assessment. Despite the growth in research on sustainable production, as well as efforts in the industrial sector, it is still difficult to find information on how to improve manufacturing operations and the cash flows of resources from the point of view of the producer [50].

The theme, still strongly present, meets a great deal of resistance among entrepreneurs, but it is a springboard for a future in the short term, in which the environmental variable has a weight comparable to or greater than the financial condition.

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Author Contributions

These authors contributed fully and equally to this work. Giuseppe Ioppolo contributed to research design and coordinated with Luigi Ciraolo on the research project. Stefano Cucurachi analyzed the sources and literature. Roberta Salomone and Giuseppe Saija supervised the research project and carried out a detailed revision. All authors wrote the body of the paper and read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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