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Sustainable Economic Development

Green Economy and Green Growth

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Preface

There are at present many attempts to seek effective ways to foster sustainable development on the one hand, and economic growth on the other. Many countries are now pursuing the so-called green growth, often described as the "circular economy" and trying to green their economies. But even though this topic is important, there is a lack of clarity around what green economy policy measures encompass, and how green growth related to sustainable economic development and poverty eradication can take place.

This book addresses this knowledge gap. It illustrates many experiences in designing, implementing and reviewing the costs and benefits of green economy policies. The emerging practices, which this book identified and disseminates, will help to provide some important insights and much-needed clarity regarding the types of green economy policy measures, and the institutional barriers, risks and implementation costs associated with them. The body of knowledge generated by this book will be very useful in offering guidance and in addressing concerns on how to foster the integration of green economic policies and green growth with national economic and social priorities and objectives.

The following elements can be found in many of the chapters of this book:

- principles and practices of green growth
- the implementation of green economy strategies
- the role of ecosystem services
- socio-economic issues
- economic growth and poverty eradication
- aspects of policy and governance

We thank the authors for their willingness to share their knowledge, know-how and experiences, as well as the many peer reviewers, who have helped us to ensure the quality of the manuscripts.

Enjoy your reading!

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Kuala Lumpur, Malaysia — Abul Quasem Al-Amin
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Industrial Symbiosis: An Innovative Tool for Promoting Green Growth

Angela Albu

Abstract

In actual context it is becoming more apparent that economic activities are inconceivably linked with the environment, a fact that is generating the need for a more complex relationship between the economy and ecology. We need to arrive at a reconciliation between the desire for economic and social development on the one hand, and environmental protection on the other. The concepts of industrial ecology and industrial symbiosis are providing viable solutions to economic growth without sacrificing environmental quality. The implementation of industrial symbiosis in the economy represents an innovative method to promote green economy and to create a new culture of economic growth. The chapter will present the concepts of industrial ecology and industrial symbiosis in the context of eco-innovation, the advantages and limitations in their implementation, and some significant case studies with positive results in promoting green growth through industrial symbiosis.

Keywords

Industrial ecology · Industrial symbiosis · Eco-design · Green growth

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1 Introduction

From the first stages of the development of human society, all human activities were developed in the environment and used environmental resources. For a long period of time, the equilibrium between the impact of human actions on the environment and its ability to maintain its natural features was kept. However, the intensification of development, the new industries, products, by-products, pollutants, the huge increase in transportation, demand of resources and many other reasons have led to the deterioration of the environment to the point where it can no longer be restored. Human society has to evolve and the future generations have the same rights as past and actual generations regarding access to a clean environment and to natural resources. This is the starting point for a re-thinking of the whole process of production of goods and the providing the services in society.

Many scientists and scholars contributed to the new concepts used as a basis for the development of a new economy known as the “green economy”, an economy in which all the decisions have two pillars: the economic motivation and the forecasted environmental impact. Bearing in mind this dual manner of thinking, the environmental aspects are not a final problem that needs a solution, but are part of the “whole picture”. The reality shows that it is possible to have economic growth with less impact on the environment or, even better, with a positive environmental impact. According to one of the first scientists in the field of environmental aspects of the anthropogenic activities (Frosch 1992), it is possible to maximise the use of materials, including waste, with notable positive influences on the environment if the design of the product also involves the design of waste, if the waste costs are internalised and if the producers of goods and service providers are totally responsible of their actions.

In the process of re-thinking and re-designing the new economic activities, we don’t have to blame the old processes—they represented big progress, big developments at that moment, the answer to society’s needs. But, in the actual context, these old processes are no longer responding to the economic and ecologic requirements specific to our period. Some of the effects of those processes on the environment could not be forecasted and assessed 50–60 years ago; for example, the ozone hole is the result of releasing into the atmosphere chlorofluorocarbons, substances used as refrigerants due to their ‘beneficial’ properties (nontoxic and nonflammable products). The replacement of nitrogen with chlorofluorocarbons was a big improvement in the refrigeration process, but no assessment was undertaken at the time on the effects of chlorofluorocarbons on the atmospheric ozone.

The interaction between the economy and the environment is complex and we need to have a clear understanding of it. The actions associated with the industrial ecology aim to minimise the negative impact of the processes on the environment, not only “at the end of the pipe”, but especially to create a new manner of thinking, understanding and designing the human activities in accordance with the natural process and natural equilibria. From this point of view, the changes are not only technological but also sociological and behavioural. From a technological point of view, the changes involve the design of industrial processes, products and services from a dual perspective of product competitiveness and environmental concerns. The word industrial is not only addressed to the industry sector, but it involves also agriculture, transportation, production and consumption, all levels of industrialisation from a national economy (Socolow et al. 1994). From a sociological and behavioural point of view, it is about human culture and education, the role of societal institutions, the quality of life, the relationships between people and between people and the environment.

Due to the pollution problems at the present time, very often the environmental requirements are seen as barriers that hinder the development of existing business or future initiatives. The new manner of treating the link between economic activities and their environmental impact can transform the constraints in business opportunities. Table 1 presents some examples.

The classical way of doing business has nothing to do with taking into account the environmental aspects, as the main focus is earning money. Our society is more concerned with ecological and social issues connected with its own activity, but not all companies are acting properly. The big challenge for the new concepts, including industrial ecology, is to demonstrate that eco-economical (ecological and economical) investment and attitude represent an asset for the company, and not a pressure. In this scientific and practical approach, we can use the example of numerous ecosystems which are very effective in recycling resources and can be taken as examples for loop closing in industry (Lifset 1999).

We have to understand that we are still living in a largely non-sustainable system with limited resources, which is not big enough “to swallow” all the pollutants that result from our activities without suffering any changes. Now, we need to find solutions for problems caused by past generations while, at the same time, not to create fresh problems for future generations. The dynamics of the science and research, with their new concepts and knowledge, will allow us to make appropriate decisions for assuring the continuity of economic growth and to have a cleaner environment for future generations.

Table 1 From pressure to business opportunities

Pressures	Business opportunities	Required changes
Stricter environmental legislation	Developing “green” products and services	Designing new products and services
Intensifying of the competition	The development of new markets for ecological products and services	Diversification of the range of products and services
Rising costs	Reduction of the quantity of waste	Intensification of the environmental control, adoption of new technologies
Higher requirements and standards asked by beneficiaries	Using “clean” technologies (eco-technologies)	Adoption of new technologies

2 The Concept of Industrial Ecology

Every industrial activity is connected with hundreds other activities, all of them with different levels of impact on the environment's components. The term of industrial ecology (IE) is an approach that describes the industry–environment interactions—and offers solutions to assess and minimise those impacts. From this general definition, we can understand how difficult and complicated the process of identification of the environmental impacts is, then ranking them according to their level of risk and offering the appropriate solution in order to minimise every impact, taking into account the connections between them.

A broader definition of the industrial concept was given by Graedel and Allenby (2002) in their book *Industrial ecology*:

> Industrial ecology is the means by which humanity can deliberately and rationally approach and maintain sustainability, given continued economic, cultural, and technological evolution. The concept requires that an industrial system be viewed not in isolation from its surrounding systems, but in concert with them. It is a system view in which one seeks to optimize the total material cycle from virgin materials, to finished materials, to component, to product, to obsolete product, and to ultimate disposal. Factors to be optimized include resources, energy, and capital.

The content of industrial ecology was formulated by way of an analogy with a biological system: in this system, energy and materials are consumed or used by the organisms and the wastes resulting from one organism are used or transformed by another one in its own processes. Similarly, the industrial systems must be viewed as part of a larger whole, with connections and interrelations with other systems. This picture is the opposite of the linear approach, based on the concept of unlimited resources and unlimited waste disposed in the environment (Fig. 1).

The linear concept of industrial processes is not a viable one, as the natural resources are not unlimited and the environment is not capable of processing all the wastes and turning them into non-dangerous substances. Analysing the biological system appears to be the logical idea for cyclical evolution inside the components of the system and/or between the components. This description characterised a system with lower consumption of material and energy and lower quantities of waste, which use the products and waste from a component in another one. The similarity of an industrial process with a biological system is not perfect, but has the advantage that it introduces a new manner of analysing and designing for industrial

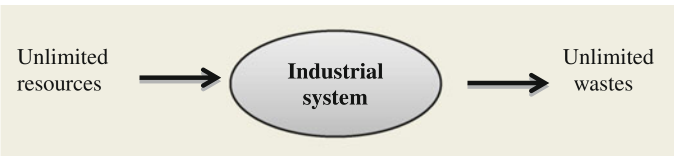

Fig. 1 Description of a linear system. *Source* Own elaboration

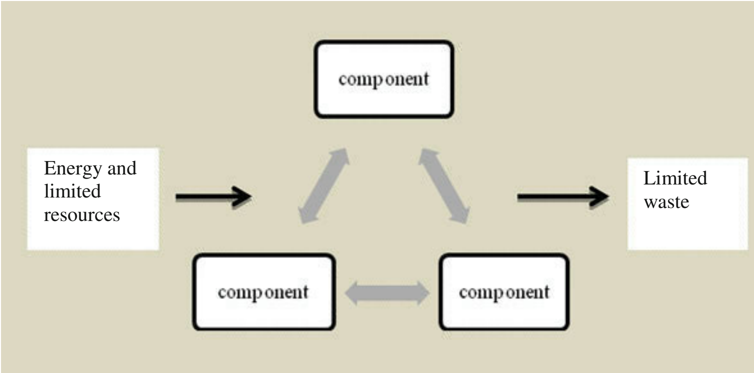

Fig. 2 Quasi-cyclical system. *Source* Adapted after Jelinski et al. (1992)

processes, with the fundamental goal of minimising the consumptions of materials and energy and the emissions of all type of wastes (Fig. 2).

The concept of Industrial ecology can be interpreted very broadly: even the name includes the word 'industrial'. The concept is not limited to the domain of industry, as it includes all the impacts produced by human actions and presence: mining, manufacturing, energy production and utilisation, transportation, construction, agriculture, forestry, services, and waste disposal. The industrial ecology can be oriented toward two different directions of study:

(a) To study individual products and their environmental impacts at different stages of their life cycle. In this approach, taken into consideration as inputs are raw materials, other processed materials or finished products used in the production process, and energy; outputs are considered as, first, the finished product, then the waste and pollutants emitted during the production process and the energy residues (usually as heat and noise). The goal of using industrial ecology is to find the solutions for reusing and recycling wastes and energy residues as much as is possible. For this, it is necessary to elaborate a total material balance (for all material fluxes) and an energy balance and to find innovative ways to use the waste into or out of the system. This approach has both economic and environmental aspects and the difficulty consists in finding the optimum level which satisfies, at the same time, the economic and ecologic requirements.

(b) To study the facilities used in the production process. In this case, we are dealing with more technological aspects because every facility, apparatus, and technical device is analysed from the design point of view and then from its capabilities to fulfill the projected tasks.

An aspect that must be underlined is that the industrial ecology disagrees with the concept of waste. It is a common point with biological systems in that no type of waste is discarded forever; in nature, in some form, all materials are used in different processes and, usually, with great efficiency. In the classical approach, industry is an activity which uses materials and energy to produce goods, the production process being implicitly associated with the emission of wastes and pollutants. After the production process we have to consider also the moment of the end of the life of the product, when it becomes useless and has to be disposed of. In an industrial ecology approach, the production process has to avoid as much as possible the transformation of the raw materials in products without utility and to treat every waste as a source for materials and energy. For this reason, the industrial ecology proposes to use the term residues instead of wastes, defining residues as materials that our economy has not yet learnt to use efficiently. Some authors (Graedel and Allenby 2002) are going further and propose the term *experienced resources* for all the residues and obsolete products in order to gain the attention of specialists, but also society, about the value represented by them.

Industrial ecology is a concept which acts both at microeconomic and macroeconomic levels. It can be applied starting with one single entity and developed at regional/global levels, as shown in Fig. 3.

Companies play an important role in implementing industrial ecology, firstly because the company is where improvements and innovations take place, where the ideas are put into practice. Secondly, because of the managerial process, more and more organisations are considering the command and control process as inefficient and even counterproductive. Industrial ecology is seen as a flexible and more cooperative tool for managing the process and is focused on accomplishing simultaneously economic and environmental goals (Lifset and Graedel 2002).

According to Fig. 3, the industrial ecology can be implemented in specific, particular ways, depending on the type of activity and the aims of the organisation.

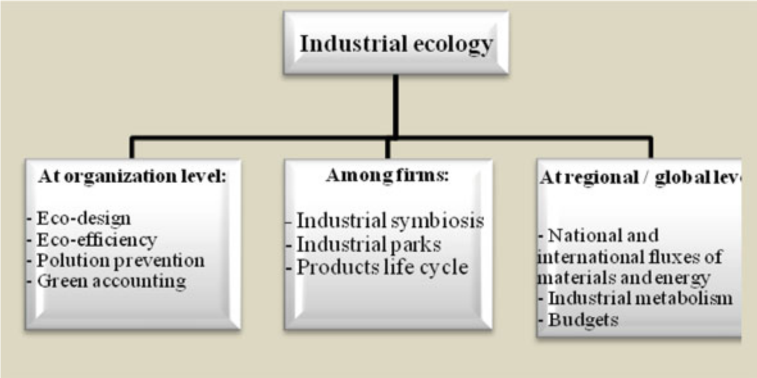

Fig. 3 Spheres of activity for industrial ecology. *Source* Adapted after Lifset (1998)

2.1 Industrial Ecology at Organisation Level

Eco-design is an oriented design in which the final result (product, service, process) must accomplish several environmental requirements. A designer has to understand the relation between the final result of the designing process and the environment and to project a proper set of characteristics. For this, it is necessary to have a database with information regarding the possible or assessed impacts of various processes and products on the environment. For simple products or services, the volume of information handled by the designer is important and it grows significantly for an industrial process. To fulfill the requirements of industrial ecology, during the eco-design process the so-called "life cycle thinking" is used—a reasoning which takes into consideration economic and ecologic aspects related to the designed final result. Given the subject of this chapter, the further discussion will be focused on the ecological aspects. The eco-design must not design "green products" but "environmentally sound product life cycles". It means not to think only of the impacts of the product during its use, but to all the impacts that may occur during its whole life cycle, including the disposal phase. The inputs can be divided in two groups:

- *environmental inputs*: raw materials and energy
- *economic inputs*: other products or semi-finished products, energy, which are outputs from other processes.

Similarly, there are two types of outputs:

- *environmental outputs*: represented by emissions
- *economic outputs*: final products, semi-finished products, energy.

All this information is organised in a MET matrix (M: materials, E: energy, T: toxicity) with three levels, according to the main stages of a product during its life cycle (http://www.pre.nl/ecodesign/ecodesign.htm) (Fig. 4):

The industrial ecology pays great attention to the energy sources, production and consumption. Accordingly, the eco-design process has to evaluate all types of energy involved during the life cycle of the product, taking into consideration several details such as the source of energy, the consumption and possibility to recover energy. Geographical and national aspects can change drastically the final picture of energy involved in the eco-design of a similar product in different

	Materials	Energy	Toxicity
Production	…	…	…
Use	…	…	…
Disposal	…	…	…

Fig. 4 Example of MET matrix

locations. Often in the design process, the energy consumption is underestimated, so the eco-design has to consider this detail.

The eco-design process has the possibility to increase the product life span, which means especially an optimisation of the material consumption and a means for environmental education of the population. Through eco-design, the product is more durable from a technical point of view and, if it is possible, upgradable. Finally, but not without importance, the eco-design is looking to use a minimum quantity of material for products, but not forgetting the quality and use characteristics of the product. This minimisation of the quantity of material is important not only for raw material consumption, but also for energy aspects: less weight means less fuel consumption.

The eco-design for a product is not simple and it becomes more complicated when it is applied to an industrial process. Here, the economic-ecological decision is fundamental for fulfilling the desired economic efficiency and environmental impacts at the same time. The traditional goals for an industrial process are presented in Table 2.

Through the eco-design process developed at the organisational level, there are indirectly fulfilled other requirements associated with industrial ecology, namely eco-efficiency and pollution prevention.

Eco-efficiency is a concept that can be traced back to the 1970s. It was first used in the form of "environmental efficiency" and introduced for the assessment of environmental impacts of the economic activities. Eco-efficiency deals with the use of resources, the volume of products produced and the environmental impacts caused by the production—the conception chain. The World Business Council for Sustainable Development (WBCSD) gave a definition for eco-efficiency: "*Eco-efficiency is reached by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity…*" (United Nations Conference on Trade and Development 2004). The definition emphasises clearly that eco-efficiency is addressing economic activities with their main components: production and consumption.

Table 2 Economic and environmental goals for eco-designing an industrial process

Economic goals	Environmental goals
Accomplish the desired technological results	Prevent pollution
Achieve high precision and high efficiency in the manufacturing process	Reduce risks to the environment
Design the process for high reliability over a long period of time	Perform process design from a life cycle perspective
Design the process to be upgradable and modular (if it is possible)	
Design the process for minimum operating costs	
Make the process safe for the workers	

Source Adapted from Graedel and Allenby (2002)

In the production field, eco-efficiency aims to produce equal or greater outputs with fewer resources and, at the same time, with less pollutants and waste. To achieve this goal, it is necessary to involve technology and innovation; the technology represents the base of the production process, which assures the transformation of raw materials into goods. Eco-efficiency requires technologies that are capable of assuring very high levels of transformation of the raw materials (high yields) with low emissions. These technologies are designed using the eco-design process, targeting economic and ecologic goals (Table 2) adapted to specific requirements of each industry. Innovation is a powerful tool which supports eco-efficiency; through innovation, it is possible to improve the processes, to find new ways for production, to reduce consumptions and emissions, and to find methods of use for waste.

For the production sector, the eco-efficiency concept has the potential to discover a win-win solution for different problems/situations. Improving eco-efficiency entails costs reduction and less environmental impact. We can nominate several instruments used to implement eco-efficiency in the production sector: (a) research, development and innovation, which are the sources of eco-efficient technologies, both for carrying out and their dissemination; (b) Environmental Management Systems (EMS) and environmental standards, which help firms to be more aware of their environmental impact and sustain the control and monitoring processes; (c) economic incentives, which aim to internalise the external costs, like eco-tax or tradable permits (Moll and Gee 1999).

The consumption is viewed in two forms: resource consumption and final consumption (final demand). The resource consumption is integrated into the production sector with all its aspects. The final consumption is linked with the production, but has an opposite trend. While an eco-efficient production means more goods are produced with fewer resources, an eco-efficient consumption promotes the decrease in goods consumption. These two opposite trends can be harmonised, i.e. the production can offer products with higher value which fulfill the requirements for a sustainable consumption. The eco-efficient consumption is based on some simple concepts: extend the life of the products (use phase); repair, reuse the goods (a shift from products to services); education for consumption of more eco-efficient goods and services.

The instruments used for implementing the eco-efficient consumption are: (a) information instruments such as eco-label, Fair Trade label, FSC label, environmental statement, awareness campaigns for the environment and eco-efficient consumption; (b) economic incentives and programmes to stimulate eco-efficient consumption and behaviour.

Implementation of the eco-efficiency concept is not easy due to several barriers: financial problems, which do not allow the replacement of old technologies and production systems, inappropriate public policies, low public awareness, lack of education.

Adopting eco-efficiency means one must not only understand the concept and introduce improvements, but also find appropriate methods to measure the results. Therefor, there were proposed *eco-efficiency indicators* to assess the different aspects of economic and ecologic efficiency of the production and consumption processes. This means they are useful also for the assessment of the industrial ecology progress at organisational level. Without appropriate measuring methods, the concepts of eco-efficiency and green growth would remain at a declarative stage. According to the United Nations Economic and Social Commission for Asia and the Pacific (2009), the eco-efficiency indicators are useful both at organisational and national level for:

- measurement of eco-efficiency for an organisation or for a sector of economy;
- identification trends in eco-efficiency at both levels mentioned above;
- comparison of the eco-efficiency of different organisations in the same area of activity or different countries;
- as support for decisions and policies in economic and environmental fields.

The basic principle of the elaboration of eco-efficiency indicators is a determination of the ratio between the value of the product or service and its environmental impact.

$$Eco-efficiency = \frac{Value\ of\ a\ product}{Environmental\ impact\ of\ a\ product}$$

There are two ways to enhance the eco-efficiency: to raise the value of the product (for example, improving the quality) or to reduce its environmental impact. The concept of eco-efficiency leads to the identification and utilisation of a large number of eco-efficiency indicators, which can be divided into two groups (Table 3).

The reverse ratio—environmental impact reported to the value of the product, called eco-intensity—is used for assessing the environmental impact of economic activities (Ehrenfeld 2005). Generally, eco-intensity is used to measure the welfare and expresses how much "nature" is necessary to produce a certain level of welfare (Klein et al. 1999).

Table 3 Eco-efficiency indicators for organisation level

Scope indicators	Subject indicators
Indicators for assessing the eco-efficiency at micro and macro level	Indicators for resource-use intensity: water, energy, material and land use intensity
Sector-specific indicators: industry, agriculture, transport, services	Indicators for environmental impact intensity: refers to emissions and waste

Source Adapted from United Nations Economic and Social Commission for Asia and the Pacific (2009)

Eco-efficiency and eco-intensity represent basic elements for decision-making in the process of adoption of industrial ecology. The industrial ecology itself considers eco-efficiency as one of its main features, and focuses on the minimisation of the environmental impact of the product.

The concept of eco-efficiency and the set of indicators can be used for integrated analysis and assessment of industrial ecology, e.g. to assess the efficiency of changes introduced by industrial ecology to a production process.

Pollution prevention (*P2*) is an approach which deals with the protection of the environment and more efficient use of the resources. Both aspects are connected directly with industrial ecology, especially at the level of an organisation. The main concept of pollution prevention is the reduction or elimination of the pollutants and waste at their sources. It is obvious that less wastes and emissions will cause fewer problems and will lead to less action needed for the management of pollution of the environment. Pollution prevention is a participative approach; it involves not only emission control, but it aims to collaborate with other areas like eco-design for achieving its goals—a cleaner environment and a better use of the resources. Pollution prevention can have different aspects: re-designing the products to have less emissions, pollutants and waste during their entire life cycle (extraction, production, use and final disposal), better practices in the production processes to avoid/minimise leaks and fugitive releases, actions for the reduction of energy consumption or new production processes with better environmental performances. The concept of pollution prevention addresses mainly to the industry, but all other areas can contribute with their efforts: transportation (through minimisation of air emission and optimisation of the routes), agriculture (using fewer quantities of fertilisers and other chemicals), offices (with a better use of paper and printing cartridges), and every household and every person.

Pollution prevention is a medium and long-term approach with significant environmental, economic and social benefits; however, these benefits differ from one country to another, with many different variables. According to United States Environmental Protection Agency (1998), the main factors that will determine the success of pollution prevention actions are presented in Table 4.

It was mentioned previously that industrial ecology disagrees with the concept of waste; it means that the pollution prevention process is integrated in industrial ecology and represents a particular method for adopting industrial ecology concepts

Table 4 Success factors for pollution prevention

Availability of resources	Technical, financial, scientific and engineering resources available to develop and implement pollution prevention
Stage of development	Includes the specific degrees and forms of pollution for each area, the capabilities and the willingness of the responsible parties, or society in general, to solve the environmental problems
Cultural and educational issues	The cultural acceptance of the environmental aspects by the population and the ecologic education and behaviour

Source The author with information from United States Environmental Protection Agency (1998) in an organisation. The reduction of waste and pollutants represents the main goal, both for pollution prevention and for industrial ecology, and there has been a great deal of effort made in this direction at firm level (Salhofer et al. 2008). Industrial ecology is focused on source reduction, which prevents the generation of wastes and environmental releases and conserves natural resources. This is in perfect accordance with EU policies, which are promoting mainly the prevention of waste production, i.e. a complex of measures taken before a product, substance or material has become waste (Albu and Chasovschi 2014). The pollution prevention approach involves several methods to reduce waste at the source (Phipps 1995):

- material substitution—the replacement of hazardous material in a product composition with other materials that are less toxic and with equal performances;
- improvements in process efficiency—improving or designing new production systems and making them more effective in terms of production yields and resource conservation;
- preventive maintenance—refers to a set of activities that prevent equipment malfunctions and environmental emissions;
- in-process recycling—can be applied to some industries and means the reusing of some materials back into the process before they become waste (waste is not generated). These materials include scraps (low-quality final products that don't fulfill the qualitative requirements), metal pieces, some products in food industry or pulp and paper industry;
- inventory control—a management issue and deals with the reduction of product losses due to over-stocking and product expiration.

Pollution prevention is now generally accepted as part of sustainable development and its principles and methods are applied in all fields of activity. The results are goods that are improving with every positive experience gained by the organisations. However, it is necessary to identify also the barriers and restrictions of pollution prevention. One of these can be the organisational culture and norms; if the business leaders are not convinced with the importance of environmental issues, they will not make decisions to support the pollution prevention process and other actions in this direction. Very often, the better ideas for improvements are originating from the workers that are dealing every day with different problems. Breaking down hierarchical barriers and offering the possibility to communicate and to offer their opinion is fundamental to the success of the pollution prevention process.

Costs can also represent a restriction to the successful implementation of pollution prevention actions. The final goal is, of course, the improvement of the environmental performance of the organisation; but, besides this goal, pollution prevention is a means of saving money. For a manager, it is important to understand that, first, there are necessary investments for the reduction of emissions, for the improvement of energy efficiency, replacing hazardous materials, re-designing the products and for other actions in the frame of pollution prevention. For SMMs enterprises in particular, these costs can be more than the organisation can afford. This will not stop the development of the industrial ecology approach at the organisation level or pollution prevention actions; it is only a problem of priorities and resource allocation. The authorities have the task of adopting legislation and financial measures which support the economic entities in their efforts for a sustainable development.

Green accounting, or environmental accounting, has developed as a tool for assessing the environmental performance of organisations, together with a set of eco-efficiency indicators. As environmental preoccupation has risen during the last few years, a new type of accounting has developed to assess environment-related economic activities. According to Huiguan et al. (2014), green accounting studies and discloses artificial assets, natural assets and conversions between these assets. Environmental accounting is viewed in two different ways: (i) in a simplistic approach, green accounting plays a role of "book noting" like general accounting; (ii) in a larger approach, according to which environmental accounting has a managerial role, to confirm, distribute and analyse material flows and related cash flows through the use of the environmental accounting management system. For sustainable development, the latter description of green accounting is the most suitable because it offers a broad picture of the connections between the activities developed in an organisation and its impacts on the environment, all in financial terms.

Green accounting operates with the notion of environmental costs; they are defined as 'additional expenditure caused by enterprises' attempt to reduce negative effect of producing activities on environment' (Wei and Jinglu 2015). This definition shows that all the activities involved in the company's efforts to improve its environmental performance are resulting in extra costs. This is only the formal part of the green accounting, because there are also non-formal aspects, which are not always measurable, regarding the benefits (financial and non-financial) brought by the environmental improvements. The environmental costs fall into the following categories, as presented in Table 5.

For industrial ecology, green accounting represents a very useful tool for the assessment and improvement of the results at organisation level. Green accounting takes into consideration the environmental costs and calculates the following (Patrut et al. 2008):

Table 5 Classification of environmental costs

Criterion	Description of costs
Implications of environmental costs	*Environmental costs in narrow sense*—include organisation costs for recovery and improvement of environmental conditions
	Environmental costs in broad sense—include the costs for natural resources consumed and the environmental pollution costs
Level of occurrence	*Internal costs*
	External costs

Source The author with information from Wei and Jinglu (2015)

- conventional calculations with the aim to obtain a detailed report about environmental protection costs and pollutants costs;
- calculation of costs connected with losses;
- cash flow accounting, based on all environmental costs.

Green accounting represents a useful tool for the management of decision making. With information provided by green accounting, the manager sees confirmation of environmental costs, can control these costs and is able to make decisions with positive economic and environmental impacts.

2.2 Industrial Ecology Among Firms

The second level where industrial ecology is utilised is among organisations which have the possibility to cooperate for mutual advantages. The concept of industrial ecology itself emphasises the necessity of collaboration between different entities to reduce the environmental impact and to improve the resource use, which means interaction and interdependence. Because the industrial symbiosis is treated separately in this chapter, here we will focus only on industrial parks and products life cycle as manifestations of industrial ecology among firms.

Industrial parks are modern patterns of organisation within the economic environment, where the proximity of different organisations creates the prerequisites of business development. If the operating of an industrial park is aimed at environmental improvement, it uses the term eco-industrial park to emphasise this aspect. The eco-industrial parks are the most visible form of industrial ecology; several companies are located near one another and have the opportunity to change fluxes of materials and energy. The eco-industrial parks are designed from the beginning to search for the best possibilities for collaboration regarding the environmental impacts associated with business. This collaboration includes energy management, water resources and waste water management, material resources and wastes resulting from technological processes. The principles that underlie the operation of an eco-industrial park respect the concept and the goals of industrial ecology (http://makinglewes.org/2014/02/25/eco-industrial-parks-and-industrial-ecology/):

- industrial processes from the eco-industrial park are connected systematically to reduce consumption of raw materials, energy and water;
- in an eco-industrial park, the largest proportion of wastes (or all wastes, if it possible) become raw materials for different activities located in the same eco-industrial park;
- co-location of organisations together in the same space allow the reduction of transport activities, transport costs and logistic simplification;
- best practices and expertise can be shared among the organisation situated in an eco-industrial park.

The eco-industrial parks are very good examples of business integration: here are integrated the principles of industrial ecology with principles of pollution prevention as well as sustainable development and eco-design. The co-located firms are acting symbiotically, the overall result being more than the results obtained, but of each organisation separately. Although the discussion about eco-industrial parks is focused on the environmental benefits, all the scholars involved in this area recognise the economic benefits for all the companies situated in the park. According to Tudor et al. (2007), the main economic benefits fall in two categories, as presented in Fig. 5.

The analysis of the economic aspects summarised below in Fig. 5 shows that the companies involved in eco-industrial parks have a competitive advantage resulting from a better use of the resources, a minimisation of energy consumption, a better use of land and an added value to their products or services. Besides these very important aspects, the eco-industrial parks involve some indirect, but equally important, benefits: the collaboration between organisations lead to innovation, eco-innovation and knowledge sharing. Taking into consideration the EU policy to support the innovation, technology transfer and continuous development, we can conclude that eco-industrial parks are effective patterns of organisation, capable of fulfilling the specific requirements of sustainable development.

The industrial ecology and its application, the eco-industrial parks, are innovative concepts with positive results confirming the possibility of developing "cleaner business" and economic efficiency. However, we cannot underestimate the limitations put in front of the development of eco-industrial parks, of which three are considered as being major: (i) The system is considered fragile because it strongly depends on the organisations being located in the park; if one of them leaves or closes the activity, the entire chain is affected; (ii) The mechanism of results control, and evaluation for an eco-industrial park, is complex and complicated; it is possible to experience a lack of clear understanding as to what an eco-industrial park is exactly, the best way to manage such a system, what parameters are used for evaluating the efficiency of the eco-industrial park; (iii) The types of activities and wastes categories will determine the possibility of establishing an eco-industrial

Economic benefits of eco-industrial parks	
Benefits of sustainable production processes - Exchange fluxes of raw materials, energy and water - Joint use of utilities - Collective gathering and management of wastes - Combining transport of goods and people	**Benefits for the location** - More intensive use of space - Efficient use of public utilities - Joint commercial firm facilities - High-quality and efficient public transport

Fig. 5 Two categories of economic benefits of eco-industrial parks. *Source* The author with information from Tudor et al. (2007)

park and its efficiency. The reality shows that there will always be wastes that are impossible to recycle/recover; plus, even with every effort made, it isn't possible to create appropriate links between companies according to industrial ecology principles.

As a final remark, we can affirm that eco-industrial parks play a significant role in achieving sustainable development, both for organisations and organisation networks. If the specific factors are taken into consideration, it is possible to design and to manage a successful eco-industrial park.

Products life-cycle is a concept that has a major impact on resource consumption, pollution prevention and, generally, on sustainable development. The life cycle assessment (LCA) of products aims to conserve non-renewable resources and ecological systems, to minimise the magnitude of pollution and to promote appropriate methods for pollution prevention, to maximise the recycling of materials and wastes and to develop and use cleaner technologies. LCA liaises between companies and links them in a common effort toward a development based on eco-economic decisions. For each organisation, as well as for a group of organisations, there are several opportunities to reduce waste output and to optimise the consumption of resources. All these opportunities can be analysed from different perspectives with the final goal—to produce goods with minimum impact on the environment. Figure 6 represents a simplified diagram for a product's life cycle, which shows the fluxes and the connections between different stages during the life of the product.

In the frame of industrial ecology, the role of an LCA is to explain the materials and energy fluxes associated with a product manufacturer, use and disposal, the emissions released during the entire life of the product and how it is possible to

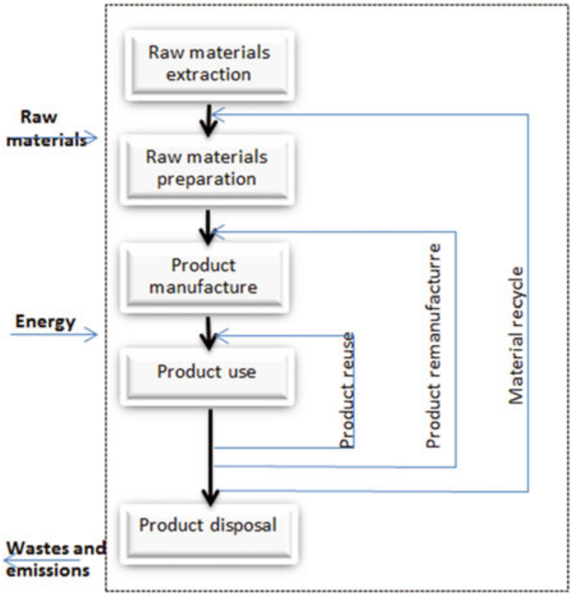

Fig. 6 Main stages from a product life cycle. *Source* Adapted from http://www.utexas.edu/research/ceer/esm282/dfe/LCAoverview.PDF

minimise all of these negative impacts. We can say that LCA is analysing the environmental impact from the product's perspective. Besides this role, the LCA represents a very important tool for comparing and improving the products. The method reveals the energy and material fluxes associated with each phase during the product life, which enables us to act where it is necessary to minimise any negative effects.

2.3 Industrial Ecology at Regional/Global Level

The third level of action for industrial ecology is the macro-level, which involves the study of materials and energy fluxes between regions or countries, environmental policies and financial support promoted by the governments. The concept of industrial ecology is consistent with sustainable development and offers solutions to the current major problems of mankind: generalised pollution, depletion of non-renewable resources, and population growth accompanied by increasing consumption. Being a new concept, industrial ecology needs innovation at institutional and managerial levels and to be able to promote appropriate measures for the creation of a competitive environment. At the same time, in order for it to contribute to pollution reduction and optimisation of resource consumption, it needs an innovative approach. This is why the success of the application of industrial ecology depends on the policies and economic measures promoted by authorities. Taxation policy may help or, to the contrary, act against utilisation of industrial ecology as support for sustainable development. For example, if the taxation policy favours import-export activities, this approach will hamper the interest and the diffusion of industrial ecology among organisations. Access to the production resources (raw materials and energy) will determine firms' orientation toward recycling, reuse, re-design, eco-design or other tolls specific to sustainable development and industrial ecology.

Another aspect controlled by the authorities, which affects companies' decisions for adopting industrial ecology, is the government system of regulations (Jelinski et al. 1992). This system can make reuse/recycling so complicated and expensive that firms will be discouraged and will not take into consideration the environmental aspects in the decision-making process. Conversely, the regulations can promote the environmental initiatives and collaborations between organisations with better economic and ecologic benefits. The price system represents another macro-economic element which will impact the adoption and diffusion of industrial ecology; if the price includes the externalities associated with its environmental performance, the company will pay more attention to the possibilities to reduce its negative impact, using all types of methods and tools, including industrial ecology.

Related to the issue of the national/global extent of industrial ecology, it is necessary to bring into the discussion the relation between industrial ecology and the standard of living of consumers and level of education. The standard of living can encourage two types of behaviours: a long-term use of the products or a short-term use, followed by early disposal of the products. A medium level of education, including environmental issues, can guide the population through a sustainable behaviour in all stages of a person—whether as an employee or as a customer.

At a regional/global level, industrial ecology is part of the process of globalisation; we are witnesses not only to the pollution generalisation, but also the joint efforts of emissions reduction, for a correct management of the resources, for restoration of polluted sites or for the adoption among companies of a responsible attitude. At regional level, industrial ecology provides guidelines for the improvement of environmental performance by promoting a 'win-win' collaboration, eco-efficiency, reducing consumption and cost saving.

We can affirm that implementation of industrial ecology will lead to local, regional and national development; new business and new jobs can be created, organisations can save money and improve their economic efficiency, while ensuring a minimal environmental impact. Besides these aspects, industrial ecology has an educative potential. The employees (which are also citizens) become more careful with environmental aspects in their jobs and in society, which represents added value for the communities.

Unfortunately, industrial ecology is moving slowly in terms of application and results; even for the organisations that are using this tool, the results came after long periods of efforts and sometimes failures. This situation is not normal considering the good results obtained with industrial ecology. The main problem is represented by the behaviour of the organisations: if not all, or almost all, organisations act according to the principles of industrial ecology, it is hard to improve economic and ecological efficiency at the global/national levels and to see notable positive environmental effects (Ehrenfeld 2006).

Industrial ecology brings a new, innovative manner of thinking and decision-making for managers. In the traditional economic thinking, the competitive advantage was obtained with low-cost inputs; now, the competitive advantage is not only about lowering the costs, but finding innovative ways to increase product values, have a lower environmental impact, gain money from waste, to use less energy and many others.

Industrial ecology brings many benefits, as presented briefly previously, but we have to be conscious of its limits. According to Esty and Porter (1998), there are two aspects when considering the limits of industrial ecology:

(a) The situation when costs exceed benefits. There are many cases when using eco-design, recycling, reusing, recovering and other processes connected with industrial ecology are too expensive and do not represent a viable strategy for the organisation. For this reason, many scholars are suggesting that industrial ecology should focus on the substantial zone that overlaps the competitive strategy for the organisation; in this way, more managers will be attracted to industrial ecology in their business.
(b) Imperfect environmental regulations. In our current regulation there exists the permission to emit different substances to specified levels of concentrations. In these circumstances, the organisations will not make any efforts to find

solutions for these pollutants as long as the emissions are under the legal limit. If the company is still interested in using industrial ecology in order to avoid pollution when its emissions are below the required limits, it will face pollution costs that their competitors don't have. The social benefits resulting from applying industrial ecology do not outweigh the costs.

We can conclude that industrial ecology can promote innovation and help managers find opportunities both inside and outside the organisation to add value to their products. However, industrial ecology cannot, by itself, be an independent tool for all the problems within a company.

3 Industrial Symbiosis—Or How We Can Close the Loop

Natural symbiosis occurs between at least two organisms that are changing materials or energy for mutual benefit. This was the model for the so-called 'industrial symbiosis', an innovative process included in industrial ecology, which focuses on the inter-changes among firms for by-products, energy, materials, and water for mutual benefit. The key to industrial symbiosis is the location—the entities which are changing fluxes have to be settled in the same location or at a short distance one from the other. Being part of industrial ecology, industrial symbiosis is oriented through the fluxes which can have negative effects on the environment, e.g. residual energy, emissions, by-products, water vapours, wastes, and others. In practice, industrial symbiosis seeks to 'close the loop', giving new life to the materials and products at their end of life moment, or recover the energy for optimum consumption of the resources. Sometimes, the loop can be closed inside the company if it is able to reintegrate the by-products and residual energy; however, more often, the cycle includes other entities more appropriate for the use of residual fluxes.

As part of industrial ecology, industrial symbiosis proposes another meaning for the wastes: it is not a useless, polluting and expensive element for a company, but a new form of resource that can be re-integrated in the economic cycle. This approach encourages economic entities to look beyond traditional markets for business, without affecting the environment (Albu 2011).

The process of industrial symbiosis has some very important strong points, both from an economic and ecological point of view. First, industrial symbiosis is based on the collective efforts and actions; working together in synergy, entities can obtain better results than the sum of individual benefits that could be achieved by acting alone. Second, industrial symbiosis encourages firms to look for options and ways for re-using and recycling their own by-products, wastes and residual energy with an overall goal—to reduce material and energy costs. This will involve a sustainable consumption of the resources and have less environmental impact. Third, industrial symbiosis will lead to social benefits for communities because the process involves not only the companies, but also institutions, universities, research centres, and NGOs. All these participants are striving for common interests which offer the possibility to find appropriate solutions for the community and strengthen the relation between them. The main benefits of industrial symbiosis are:

Exchange fluxes of materials and energy—co-products, waste or residues of a company may have practical uses (replacement of raw materials and fuels) in production processes or providing the services of another company.

Common infrastructure—the companies are using and managing in common the usual industrial infrastructure (water, energy, water vapours, sewerage) for the optimisation of the consumption.

Common utilisation of the services—the entities involved in industrial symbiosis can use common services such as firefighting, transportation and catering, for a better use of resources and to cut costs.

Costs minimisation—the industrial symbiosis allows a reduction of costs for supplying, production and waste management.

New jobs, cleaner environment, better relation between participants.

Industrial symbiosis can appear natural (such as the classical example of Kalundborg), or be created; a modern management and decision-making process can have as a strategy identification of the intern and extern cycles from which it is possible to use the residual fluxes.

Approaching things from an ecological perspective, a big problem worldwide is the over-exploitation of natural resources. Current models of production and consumption lead to negative environmental effects which, most often, have an inequitable global impact. Industrial symbiosis focuses on increasing the eco-efficiency of production and consumption processes, leading to better economic performance of firms taking part in symbiotic activity.

Industrial symbiosis is closely linked with economic efficiency; it uses familiar practices such as recycling, reuse, remanufacturing and energy recovery, which obviously determine a better use of materials and energy—a better economic performance. However, it is not the only aspect connected with economic efficiency; industrial symbiosis creates a link between firms which contributes to an increasing performance for all the partners. One firm, analysed alone both from economic and ecologic points of view, can have an unsatisfactory result. The connection with other partners will contribute to the improvement of its performances with mutual benefits for everybody.

This kind of relation between companies is often called a 'cascade link' for illustrating the involvement of several entities in the symbiotic process (Ehrenfeld and Gertler 1997). The cascading use of materials in industrial symbiosis means the utilisation of by-products resulting from one process as feedstock for another process. This creates economic and ecological advantages due to the replacement of the raw materials with by-products and to the reduction of the emissions in the environment. The cascading use of energy is more complex because it involves not only companies, but also other institutions. The residual energy of liquids, steam or gases is used in industrial processes or as a source for heating and hot water for populations and institutions. The group of firms that participate in the symbiotic process, including all the links between them, form an industrial ecosystem. This structure resembles a cluster which has many elements in common.

The administrative organisation of an industrial ecosystem often takes the form of an eco-industrial park—a location that hosts different economic entities with links between them, which develop collaborative strategies such as: waste-to-feed exchanges, cascading use of energy, common logistics and shipping and receiving facilities, green technology purchasing, green building system, shared sewerage and treating water facilities and local education and resource centres.

Because the companies and other entities that participate in the industrial symbiosis process have to be located near to one another, this collaborative approach addresses especially local and regional economies. Closing the loop at local level gives the opportunity to involve several production and service provider companies with benefits for the community. The implementation of industrial symbiosis is part of industrial ecology; however, in a more practical approach, there are many examples of projects implemented or in the implementation stage that deal with this modern approach. By analysing the goals of these projects or actions and the fluxes between participants, Chertow (2000) proposes a taxonomy of industrial symbiosis types:

Type 1: Characterised by one single material circuit—the waste flux. This situation is not exactly an industrial symbiosis because waste fluxes exist also in traditional business. There are entities which collect certain types of wastes for processing, reusing or selling. Even local authorities, with their waste management programmes, are part of the chain, but the waste flux is only one-way, oriented to the disposal at the end of the life cycle.

Type 2: The industrial symbiosis established inside a company. The situation is possible for large entities formed by several parts which can change fluxes of materials and energy between them. Outside, the company will exit only the materials and energy that cannot be recycled/recovered at the internal level. Significant results can be achieved if the company uses eco-design for its products, the life cycle assessment, the cradle-to-grave approach or the cradle-to-cradle approach.

Type 3: Industrial symbiosis among firms collocated in a defined area (possibly an eco-industrial park). This is the model of an industrial symbiosis projected for this special purpose—to create from the beginning appropriate links among firms in order to maximise the use of by-products and residual energy.

Type 4: Industrial symbiosis among firms which are not collocated. This model characterises the situation where firms exist in a certain area; they act according to their strategies, but they realise it is possible to establish connections and change material and energy fluxes for their mutual benefit. For sure, the location contributes to the development of business relations between firms, but industrial symbiosis opens opportunities for new business. The proximity of the companies reduces transport costs and enhances the collaboration.

Type 5: The model of industrial symbiosis developed on a broader region. At first sight, this model seems complicated and risky. Some costs become higher due to the distances among firms and the fluxes scheme can become very complicated. However, Type 5 industrial symbiosis gains value through the number of economic entities involved and through the contribution to the local/regional development. Of course, the fluxes of material and energy have to be optimised, reaching the best partner for a certain by-product, waste or energy. Regarding the contribution of the local/regional community, the Type 5 model of industrial symbiosis can involve SMMs, NGOs, local farmers, and small family businesses in the process of closing the loop. This will be materialised in new businesses and the development of existing ones, new jobs, better lifestyle conditions, cleaner environment, more confidence and collaboration among firms and with the local community.

A very good tool that helps the initiation of an industrial symbiosis is the materials and energy map. For the entities involved in the industrial symbiosis, or those that want to participate, it is necessary to draw a map with all materials and energy fluxes. From the map, it is possible to identify the partner and the proper flux for each partner.

Similar to industrial ecology, industrial symbiosis is not an attractive alternative for a large number of managers. According to Ehrenfeld and Gertler (1997), there were identified several reasons for not adopting industrial symbiosis:

- the process is interesting only if the company has big fluxes of energy, wastes or by-products. Otherwise, changing the usual patterns, managerial changes and possible supplementary expenses are serious reasons for managers not to adopt industrial symbiosis;
- the fact that the firms don't know, and are not conscious of, the savings that can be obtained by changing materials and energy. The situation can be improved with accounting tools like ante calculation, cost comparing, managerial accounting and others that can prove the benefits of industrial symbiosis;
- regulatory context and local/regional/national policies can support or break the initiatives for adopting industrial symbiosis. In the states where the decision bodies and policy makers have a constant dialogue with the economic sector, companies are stimulated to find innovative ways of improving their environmental performance, while being profitable at the same time. Denmark, where such a symbiotic system was developed for the first time at Kalundborg, has such a consultative system of regulation.

The current vision of closing the loop using industrial symbiosis is an innovative one and it is gaining more and more followers in all economic branches. The new currents of industrial ecology and industrial symbiosis changed the way of thinking not only for scholars, but for managers, too. The waste has had a long history during which it were ignored and abandoned (Erkman 1997). Now, it is difficult to change this vision and to see wastes as sources of materials, energy and money, but the large number of eco-industrial parks and projects in the industrial symbiosis field proves that the new concepts are correct. Actually, we are witnessing a cultural change that involves the production chain, the business management and decision-making process, the authorities' attitude and the behaviour of every member of a community.