Industrial Symbiosis for Circular Economy: A Possible Scenario in Norway

Angela Daniela La Rosa and Seeram Ramakrishna

Abstract Interaction between industry and environment is crucial for industrial business performance as environmental impacts are constantly increasing pressure on industrial businesses. The creation of eco-industrial parks aims at transforming industrial systems into industrial ecosystems by including some measures like infrastructure and material/energy flows sharing. The introduction of industrial symbiosis scenario in which one firm’s waste becomes another firm’s feedstock represents a further development of eco-industrial parks design. This principle may be extended to cities and, doing so, an integration of socio-economic and ecological systems will be promoted. At the industrial park level, the practice of the circular transformation through waste exchange enhances circular economy. The application of the same principles to cities promotes the circular urban metabolism, where the conversion of natural resources into society occurs with zero-waste production.

Keywords Industrial symbiosis · Industrial ecology · Cleaner production · Eco-design · Eco-industrial parks · Urban metabolism

Learning Objectives

- Business, as usual, is not an option as we are facing an era of environmental and social changes. New economic and industrial scenarios are required dealing with the complexity of socio-ecological systems.
- Is circular economy possible? The creation of industrial symbiosis in industrial parks, in which the by-products produced by the park are consumed by companies in the park, maybe a way to follow.
- The principles of circular economy should be applied to cities, promoting a shift from linear to circular urban metabolism.

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1 Introduction

Industrial symbiosis (IS) is an innovative and unique way of creating networks based on the ability of the partners of working together and exchanging materials, water, and energy streams with the purpose of increasing the resilience and the economic activities while reducing the environmental impact and production costs. The IS concept is in line with the recent Circular Economy (CE) principles referring to the challenges of resource scarcity, negative environmental impact, and economic development to promote a transition from a “Cradle to Grave” approach which means from materials extraction, manufacturing, use, and waste production to a “Cradle to Cradle” approach in a “closed loop,” where the waste produced becomes itself nutrient for the next cycle. The CE concept is of great interest because it is a way for businesses to implement the much-discussed concept of sustainable development [13, 24, 25].

Since the beginning of the industrial revolution, mass production of goods was enabled by new manufacturing methods resulting in products with high availability and low costs. As a consequence, new consumer societies have risen, with increasing emission of pollutants to the environment, solid waste generation, and landfilling.

In addition, the growing world population demands a rising consumption of natural resources. Since planet earth’s resources are limited, the requirements of exponential economic and population growth cannot be met. In this scenario, it is not only the challenge of environmental pollution that is becoming acute but the challenge of global resource scarcity as well.

In line with eco-industrial development, CE is understood as “realization of closed loop material flow in the whole economic system”. In association with the so-called 3R principles (reduction, reuse, and recycling) the core of CE is the circular (closed) flow of materials and the use of raw materials and energy through multiple phases.

Definition

Industrial Symbiosis is an extension of the concept of eco-industrial park in which businesses and infrastructures cooperate with each other through exchanging wastes and sharing physical or non-physical resources, such as materials, water, energy, and information. The mechanism of industrial symbiosis (IS) is that one firm’s waste becomes another firm’s feedstock.

Circular economy is an economic system aimed at eliminating waste and the continual use of resources. Circular systems employ reuse, repair, refurbishment, remanufacturing, and recycling to create a closed-loop system, minimizing the use of resource inputs and the creation of waste. ISO/TC 323 is a new ISO technical committee that intends to develop requirements, frameworks, guidance, and supporting tools related to the implementation of circular economy projects.

Cradle to cradle. The term is a play on the popular corporate phrase “cradle to grave” (from birth to death, or “grave”) implying that after products have reached the end of their useful life, they become either “biological nutrients” or “technical nutrients.” Biological nutrients are materials that can re-enter the environment. Technical nutrients are materials that remain within closed-loop industrial cycles.
Urban metabolism. Urban metabolism is the study of material and energy flows arising from urban socio-economic activities and regional and global biogeochemical processes. The characterization of these flows and the relationships between anthropogenic urban activities and natural processes and cycles defines the behavior of urban production and consumption.

2 Some Examples of IS

The earliest example of industrial ecology was the symbiosis of industries at Kalundborg, Denmark [8]. Since then, the industrial symbiosis had successfully transformed existing industrial parks [29, 30] such as the National Industrial Symbiosis Program (NISP) in the UK, the regional synergies in the Australian mineral industries, and the Circular Economy program in Chinese industrial parks [17, 4, 11]. Other notable examples included the symbiotic alliance of Kymi pulp and paper mill and its allied industries in Kouvola, Finland [20], the waste management companies of Chamusca, Portugal [9], and the Tianjin Economic-Technological Development Area (TEDA) in China [26]. Boons et al. [5] formulated a conceptual framework demonstrating the dynamics of industrial symbiosis. The assessments mostly were qualitative and descriptive in nature. How did one quantify the benefits and impacts of industrial symbiosis and compare pros and cons across the industrial parks that took different forms and shapes? Several approaches had been employed to quantify the advantages of industrial symbiosis [31], [21], [10, 28]. Mattila et al. [23] compared process, hybrid, and input-output life cycle assessment (LCA) approaches in quantifying the environmental impacts of a forest industrial symbiosis in Kymenlaakso, Finland. The methods, however, did not cover entirely the impacts of industrial symbiosis in industrial parks as resource inputs from both natural and anthropogenic activities needed to be included.

Example

An early case study was a Swiss regional IS assessment (water, energy, metals, e.g., iron, copper, aluminum, wood, plastics, food, and building material are accounted) described by Massard and Erkman, in 2007. By-products exchanges create the IS. Together with utility sharing opportunities for supply and treatment, these elements grouped together to create resource synergies. By-product exchanges may be prohibited by national or local legislation intended to protect our environment. The legislation revealed that the Swiss laws on waste do not hinder by-product exchanges, in contrast with the EU policy.

By setting up very restrictive environmental laws, Swiss policy tends to charge the companies for the real costs of supply, effluent, and waste treatment [22]. Therefore, the companies themselves are often searching for alternative outlets for their by-products in order to reduce their costs. Implementing a new industrial park will change the local by-product exchange pattern and result in structural change, therefore, a macro-level decision support approach is necessary. Figure 1 highlights some key indicative points.
Fig. 1 An example of IS. The resources synergies include by-product exchanges and utility sharing

2.1 Weak Points of IS

The symbiotic relationship is a type of resource interdependence, which mainly involves the physical exchange of materials, energy, water, and by-products [7]. The mechanism of IS is that one firm’s waste becomes another firm’s feedstock; therefore, firms involved in IS relationships become resource interdependent. This type of interdependence may also extend from the operational level to the strategic one when a company uses wastes from the other company to generate new products for the market [1].

As firms become more and more embedded in the network of IS relationships, the degree of interdependence also rises and the need for coordination becomes high. In this regard, companies face interorganizational challenges and several inter-firm activities need to be planned to carry out the IS relationship [3, 15]. First, companies should agree on the quantity of waste that will be exchanged and the delivery time. Planning the right amount of waste that will be delivered to the right customer at the right time can be harder compared to similar activities in traditional businesses since waste is not produced upon demand but emerges as a secondary output of main production activities.

Furthermore, some wastes might require a treatment process before being used as inputs, removing impurities or contaminants from the waste, which can be operated by a third firm.

Such a practice increases the complexity of the IS relationship, which needs additional coordination. Accordingly, when inter-firm relationships require greater
coordination, transaction costs increase [12]. Rather than to exchange waste with another company, waste producers might use wastes within their boundaries (e.g., by using a waste produced by a given production process as input for other production processes or simply selling wastes on the market, when a waste market exists) [27]. In such a case, there is no interdependence between firms within the system and the need for coordination is thus low, thus resulting in low transaction costs for the company. However, in order to use a given waste internally, companies need to operate production processes able to receive that waste as input.

The governance of the IS system is also characterized by centralization of control, i.e., the extent to which a central actor manages the entire system of relationships. A high centralization of control regards IS systems managed by a central actor who has disproportionate authority over which companies become part of the system, where and how symbiotic interactions take place.

3 A Possible Scenario in Norway

Scenario

The forest industry is very important in many areas of the country and profitable forestry industry is of great importance for settlement, employment, and sustainable business development within a specific region. The main tree species by volume and economic importance are spruce, pine, and birch, and analyses show that a significant amount of forest resources can be exploited in a sustainable and climate-friendly manner. The best practice would be to establish an industrial area in a strategic geographical location, covering a short distance between forests (the ecosystem) a city (the people), and the industries (the economy).

The following step would be to implement symbiosis and reduce the energy flows, by promoting waste/by-product exchanges between all the actors. Some possible ways are

1. Adopting and improving technologies that save resources and enhance waste reuse and recycling. Selecting materials that have lower embodied energy and reducing adverse environmental impacts material consumptions and productions. Technology innovations would be imperative in achieving goals.
2. Optimizing energy structure and promoting cascade utilization of energy would further improve energy efficiency and reduce emissions.
3. Restoring local ecosystem for sustainable developments of the industrial park. The ecosystem in which the industrial park was located being a fundamental life-support system not only provided essential services and resources but also was a resource base and a carrier for economic activities.

A schematic and simplified concept of symbiosis for the suggested scenario is drawn in Fig. 2.

The industrial symbiosis should consist primarily of infrastructure sharing and waste/by-products exchanges that lead to resource conservations. Industrial symbiosis reduces waste transportation and disposal.
Three possible scenarios are considered, and the effects are summarized in Table 1:

- **Scenario 1**: the absence of industrial symbiosis.

  The scenario assumes a park with more than two companies that manufacture products generating, e.g. heat, paper/cardboard, plastics, biomass waste. It is assumed that all these by-products are discarded outside the park.

- **Scenario 2**: the presence of partial industrial symbiosis.

  The scenario assumes an amount of inbound by-product in the park, and an amount of outbound by-product discarded outside the park.

- **Scenario 3**: perfect symbiosis.

  The scenario assumes a situation in which all the by-products produced by the park are consumed by companies in the park (a case of perfect symbiosis).

### 4 Contribution of the IS in the Sustainability of the Waste Management

The industrial symbiosis scenario includes the establishment of an anaerobic digester that will be able to treat the organic waste derived from crop cultivation and other
| By-products/Wastes     | Without IS                                                                 | With IS                                                                 | Action                                                                 | Effects                                                                 |
|-----------------------|---------------------------------------------------------------------------|-------------------------------------------------------------------------|------------------------------------------------------------------------|--------------------------------------------------------------------------|
| Heat                  | Heat released in the ecosystems. Wasted by-product                         | Heat collected and provided to the Skjerven area                        | Benefits                                                               | – Resources recovery                                                      |
|                       | Pollution. GWP                                                             | Benefits                                                                | – Avoided pollution                                                     |                                                                          |
| Biomass               | Food waste and biomass waste collected from the municipality, the forest and the agro-industrial area | Biomass collected and treated in the local anaerobic digester Production of biogas | Benefits                                                               | – Public transport. Bus using methane from the municipal biogas plant   |
|                       | Economic costs Money required for treatment in specific service            | Benefits                                                                | – Biomass recovery. Wastes transformed into methane for public bus      |                                                                          |
| Plastics              | Waste collected from municipal wastes and from the industrial area. Packaging wasted | Plastic wastes treated in the recycling plant located in the Skjerven industrial park | Benefits                                                               | – Money saving                                                           |
|                       | Economic costs Money required for treatment in specific service            | Benefits                                                                | – New packaging produced by recycled plastic packaging                  |                                                                          |
| Infrastructure sharing| Use of private services and facilities                                     | Use of shared facilities and services                                   | Economic saving from                                                   | – Shared solid and liquid waste management                               |
|                       | Economic costs Environmental burden.                                      |                                                                        | – Shared training in new regulations and technologies                   |                                                                          |
|                       |                                                                            |                                                                        | – Shared emergency management services                                  |                                                                          |
|                       |                                                                            |                                                                        | – Transportation services                                               |                                                                          |
|                       |                                                                            |                                                                        | – Others                                                                |                                                                          |

This process will contribute to bridge the gap between cities and industries by making a significant contribution to sustainable cities.
5 Future Trends

The study of the resource consumption and environmental pressure of urban areas in a systemic way falls within the scope of Urban Metabolism (UM). This field of research has become increasingly important in the last two decades, developing applications for Sustainability Indicators, Greenhouse Gas Accounting, Policy Analysis, Design and Material Flow Accounting. Kennedy et al. [18] and Zhang [32] provide reviews of the history, methodology, and applications of Urban Metabolism.

Urban metabolism is a multidisciplinary research domain focused on providing important insights into the behavior of cities for the purpose of advancing effective proposals for a more humane and ecologically responsible future. Material recycling should be a focus of urban policymaking and development due to its high potential to significantly reduce cities dependence on external and non-renewable resources. The principles of the industrial ecology approach are to be applied to the urban metabolism concept, in which it is seen as the conversion of nature into society. Girardet [14] coined and drew the difference between a ‘circular’ and ‘linear’ metabolism. In a circular cycle, there is nearly no waste and almost everything is reused.

Cities have a key role in the battle for sustainability. Cities are places of political contention [2, 16]. Cities represent the possibility to develop new regulatory structures and spaces of governance [6]. Furthermore, the social economy within each locality creates a dense fabric of relationships that allow local citizens to work together in identifying and acting on local problems or in taking local initiatives [19].
6 Conclusions

The approach of creating industrial symbiosis in industrial parks encounters the vision of an economy in loops (or circular economy) with a focus on job creation, economic competitiveness, resource savings, and waste prevention. This intends to promote a transition from a “Cradle to Grave” approach which means from materials extraction, manufacture use and waste production to a “Cradle to Cradle” approach in a “closed loop,” where the wastes produced become itself nutrient for the next cycle. The closed-loop model can be extended to cities and to the urban metabolism with the intention of reaching the sustainable development goals (SDGs 2030) by interconnecting social-ecological and economic complex systems.

Questions

1. How the creation of industrial symbiosis brings benefits to industrial parks?
2. Is industrial symbiosis easy to plan and carry out?

Answers

1. It depends on the specific cases, but in general industrial symbiosis allows resources conservation due to waste recycling and reuse, avoided pollution and economic savings from.
2. Industrial symbiosis is a relationship that requires a certain degree of interdependence among the companies. In this regard, companies face interorganizational challenges and several inter-firm activities need to be well planned to carry out the IS relationship.

Suggested Reading

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**Professor Seeram Ramakrishna FREng, Everest Chair** (https://www.eng.nus.edu.sg/me/staff/ramakrishna-seeram/), is among the top three impactful authors at the National University of Singapore, NUS (https://academic.microsoft.com/institution/165932596). NUS is ranked among the top five best global universities for engineering in the world (https://www.usnews.com/education/best-global-universities/engineering). He is the Chair of Circular Economy Taskforce. He is a member of Enterprise Singapore’s and ISO’s Committees on ISO/TC323 Circular Economy and WG3 on Circularity. He also the Chair of Sustainable Manufacturing TC at the Institution of Engineers Singapore and a member of standards committee of Singapore Manufacturing Federation (http://www.smfederation.org.sg). He is an advisor to the Ministry of Sustainability & Environment—National Environmental Agency’s CESS events, (https://www.cleanenvirosummit.sg/programme/speakers/professor-seeram-ramakrishna; https://bit.ly/catalyst2019video; https://youtube.com/watch?v=ptSh_1Bg1lg). European Commission Director-General for Environment, Excellency Daniel Calleja Crespo, said, “Professor Seeram Ramakrishna should be praised for his personal engagement leading the reflections...
on how to develop a more sustainable future for all’, in his foreword for the Springer Nature book on Circular Economy (ISBN: 978-981-15-8509-8). He is a member of UNESCO’s Global Independent Expert Group on Universities and the 2030 Agenda (EGU2030). He is the Editor-in-Chief of the Springer NATURE Journal Materials Circular Economy—Sustainability (https://www.springer.com/journal/42824). He is an Associate Editor of eScience journal (http://www.keaipublishing.com/en/journals/escience/editorial-board/). He is an opinion contributor to the Springer Nature Sustainability Community (https://sustainabilitycommunity.springernature.com/users/98825-seeram-ramakrishna/posts/looking-through-covid-19-lens-for-a-sustainable-new-modern-society). He teaches ME6501 Materials and Sustainability course (https://www.europeanbusinessreview.com/circular-economy-sustainability-and-business-opportunities/). He also mentors Integrated Sustainable Design ISD5102 project students. Microsoft Academic ranked him among the top 25 authors out of three million materials researchers worldwide based on H-index (https://academic.microsoft.com/authors/192562407). He is named among the World’s Most Influential Minds (Thomson Reuters) and World’s Highly Cited Researchers (Clarivate Analytics). Listed among the top three scientists of the world as per the Stanford University researcher study on career-long impact of researchers or c-score (https://drive.google.com/file/d/1bUIrvurVVBxSl9eFZRSHFf7tt30-5U/view). He is an Impact Speaker at the University of Toronto, Canada Low Carbon Renewable Materials Center (https://www.lcrmc.com/). He is a judge for the Mohammed Bin Rashid Initiative for the Global Prosperity (https://www.facebook.com/Make4Prosperity/videos/innovation-inclusive-trade/479503539339143/). He advises technology companies with sustainability vision such as TRIA (www.triabio24.com), CeEntek (https://ceentek.com/), Green Li-Ion (www.Greenli-ion.com) and InfraPrime (https://www.infra-prime.com/visibility-leadership). He is a Vice-President of Asian Polymer Association (https://www.asianpolymer.org/committee.html). He is a Founding Member of Plastics Recycling Association of Singapore (PRAS). His senior academic leadership roles include University Vice-President (Research Strategy), Dean of Faculty of Engineering; Director of NUS Enterprise and Founding Chairman of Solar Energy Institute of Singapore (http://www.seris.nus.edu.sg/). He is an elected Fellow of UK Royal Academy of Engineering (FREng), Singapore Academy of Engineering and Indian National Academy of Engineering. He received PhD from the University of Cambridge, UK, and The TGMP from the Harvard University, USA.