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Symbiosis between industrial systems, utilities and public service facilities for boosting energy and resource efficiency

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Abstract

Industrial symbiosis represents a great opportunity for boosting energy efficiency, shifting the focus from a single industry to cluster of firms. Collaboration and synergistic possibilities offered by geographic proximity lead to great competitive advantages involving waste and resources flows. Energy clustering can provide relevant benefits hardly achievable without cooperation, mutually improving the energy efficiency of industries and of other activities in the neighbourhoods, e.g. hospital, schools. In the present work, several synergies currently applied have been mapped in a district of Brescia, moreover the introduction of foreseeable new synergies have been identified and evaluated aiming at reducing the local energy utilization and environmental impact, considering industrial facilities, utilities and public service facilities as an holistic system.

Keywords: industrial symbiosis; energy efficiency; synergies; sustainable production; resource flows

1. Introduction

Climate change and sustainability issues concerning the industrial development have recently increased the scientific focus on Industrial Ecology (i.e. industrial resource consumption, resource efficiency and by-product management approaches), looking at natural ecosystems as models for industrial activity. Specifically, Industrial

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Symbiosis (IS) refers to business-to-business relationships that mimic symbiotic interactions between organisms, where surplus resources generated by an industrial process are captured and redirected as ‘new’ input into other processes providing mutual benefits instead of being thrown away. Among the industrial ecology research area, IS represents a great opportunity to optimize the efficiency and the utilization of the resources and, at the same time, to improve environmental, economic and social performances leading to huge competitive advantages [1–3]. This is mainly due to the fact that the global benefits introduced with the industrial symbiosis network are greater than the sum of the single benefits that the actors could individually generate [4]. Moreover, a broader vision of industrial symbiosis considering an increasing collaboration between private companies and regional or national authorities, through public-private partnerships, allows to gain greater benefits also for public organizations: (1) improved performance of the public service facilities; (2) reduced and stabilized cost for providing services such as heat, cooling and electricity to public service facilities (e.g. hospitals, offices and schools) leading to greater cost-efficiency and (3) reduced environmental impact.

The main principles of industrial symbiosis include ensuring economic and environmental advantages for the involved companies and society, and ensuring the least distance between companies that are implementing the by-product exchange in order to exploit the synergistic potentials offered by geographic proximity [1, 5, 6]. As the nature makes a complete and continuous recycle of every material, IS also addresses high focus on closed-loop solutions and circular economies for which everything is recycled or re-used and nothing destroyed, i.e. no waste and pollution are produced. Actually, three types of symbiotic transactions can occur: (i) using waste as raw material input for other actors (by-product exchanges), (ii) sharing infrastructures, utilities or access to services (such as energy or waste treatment), and (iii) cooperating on issues of common interest such as emergency planning, training or sustainability planning [7]. Evolving from the traditional single firm perspective to the holistic system approach leads to catch energy efficiency opportunities at an aggregated level and to achieve optimizations otherwise not realisable. These greater benefits are possible thanks to the fact that the aggregation provides higher economies of scale, reduced installation costs, higher production efficiency of large scale installations, accessibility to more efficiency techniques, reduced raw material purchasing costs, revenues from by-product exchanges, reduced waste management costs, reduced maintenance costs, reduced taxes related to greenhouse gas emissions and access to subsidies. Industrial symbiosis represents a significant opportunity especially in boundaries characterized by industrial districts (ID), since clusters of firms present heterogeneous service requirements and geographical proximity, leading to a greater scope of interventions. In Italy, for example, there are several companies that have realized programs of synergies and internal collaboration: e.g. [8] presents the case of the ID of Manzano (Udine), known also as “the triangle of the chair”, which constitutes one of the major reality of the regional economy.

The concept of industrial symbiosis has been firstly introduced by Chertow in 2000, [1]. Afterwards, the term has become widely used and has gradually developed into a research domain of the industrial ecology. Reference [9] presents a recent bibliometric and network analysis describing the evolution of industrial symbiosis research. It illustrates that in the first period (1997–2005), the research was mainly about the concept of IS, the assessment of eco-industrial park projects, and the establishment of networks for waste treatment and recycling; while, in the second period (2006–2012), different research approaches and theories enriched the field, evolving from practice-oriented research toward coherent theory building. However, most of the works are still focused on specific case application such as the analyses of the district of Kalundborg in Denmark [10] and the National Industrial Symbiosis Program (NISP) in the UK [11]. Other relevant case studies include: [7] which conceptualizes the relationship between agglomerated economies and industrial symbiosis, finding that many negative environmental externalities can be reduced while increasing production efficiency in four industrial regions of Puerto Rico; [12] proposes an optimization model and a case study to evaluate the economic benefits of industrial symbiosis in the forest industry; [13] aims to develop a conceptual framework to embrace integration and identifies opportunities for companies to jointly work, considering the case of a large UK distributor; [14] presents the results of a research project which studies the potential of synergies in the Taranto industrial district; [15] analyses the existing opportunities for small and medium sized enterprises grouped in industrial areas or parks for systemic eco-innovation in the region of Cantabria; [16] studies the physical flows of materials and energy in a local forest industry in Finland using a systems approach; [17] demonstrates the benefits introduced through “green practices” in the aluminium supply chain management, proposing a model that evaluates economic and environmental effects of substituting the traditional supply strategy through solid ingots with the supply in molten state. From the best knowledge of the authors, industrial symbiosis is becoming more and more analysed by the research community, however it is still focused on specific case applications and the involvement of public service facilities is not deeply investigated yet. The aim of the present work was to analyze and evaluate current and potential synergies of creating an industrial symbiosis network in a specific Italian district, considering the geographical area of Brescia. The study is focused on the development of solutions for the reduction of the energy utilization (both electrical and thermal), considering the opportunities introduced through synergies involving industrial system and public service facilities (public-private partnerships) enabled by geographical proximity. Since sources of energy losses considered as a waste for a given company could be a valuable resource for another one, both production activities and service plants are considered and the effects of energy waste reduction, renewable energy sources production and energy recovery are analyzed. The purpose is, thus, to identify and implement an industrial use of techniques and technologies for production, use and recovery of energy from a "saving" viewpoint. The paper is structured as follow: in Section 2 the methodology used is defined; in Section 3 the considered district in the province of Brescia is characterized and an analysis of the current resource efficiency is performed; in Section 4 potential synergies generated through the creation of an Industrial Symbiosis Network are identified and evaluated; finally, in Section 5 the concluding remarks are presented.

2. Methodology

The methodology used for the evaluation of potential industrial synergies is based on the approaches proposed in [7] and [16]. The first step of the method adopted consists in the definition of the goal and scope of the study: i.e. clear descriptions of functional units, system boundaries, by-products and impact categories. After that, auxiliary materials consumptions, resources flow, by-products generation and waste are mapped and quantified for each actor since they represent a priority in identifying potential environmental synergies.

3. Productive district of Brescia

3.1. Scope and goals

The productive district of Brescia under analysis is characterized by a huge number of companies which allows the secondary sector to be the most developed one. Currently, the different firms do not cooperate except for limited transactions of resources flows and thus a great potential for increased efficiency is not valorised yet. The focus of the present study is on raw materials (e.g. fuels, biochar), waste materials (e.g. black slag, wood waste) and energy (both electrical and thermal) flows among several companies and the main goal consists in the reduction of the overall energy consumption which results in reduced system cost and CO_2 emissions.

3.2. Companies

The different companies considered in the present analysis are the following:

- One of the largest Italian multi-utility company, leader in the energy, environment, heat and networks sectors;
- 5 steelmakers which are leading manufacturers in the production of a wide variety of steel products, mainly for application in the oil & gas, petrochemical, power generation, aerospace, automotive, mechanical and naval industries: e.g. steel for reinforced concrete, continuous casting billets, hot rolled wire rod, bars in coils, alloy steel bars for special applications, large special steel ingots and forged bars. The steel making process of every company is characterized by the operation of an electric arc furnace (EAF) and a ladle furnace (LF) for secondary metallurgy;
- One of the most advanced cement producer in the world, with a strong focus on innovative and sustainable construction materials;
- One company focused on the treatment of solid waste and biomass, which is skilled for wood's pyrolysis;
- One company specialized in the production of wood chips from wasted wood;
- One company responsible for the treatment of the car fluff using a latest generation technology type without combustion and in total absence of oxygen to generate raw materials, such as coal;
- A company leader in the field of road asphalting, road embankments, excavations and earthmoving;
- The world leader in the production of caviar obtained from sturgeons bred.

3.3. Material waste and energy analysis

In the present sub-section, a material waste analysis is performed starting from the companies defined above. The main material waste identified in the analyzed district are defined in Table 1. Currently, almost all the waste produced is disposed in landfill site; only a limited share of them is recycled and reused: for example, the metallic fraction of black slag, dry sludge, dust and sintered mill scales are recycled in the same steelmaking process, after specific treatments and the excess heat of one steelmaker is recovered to produce electricity and heat for the city of Brescia and to heat the water of fish tanks to produce caviar.

Table 1. Main material waste produced within the company district analysed.

Waste type	Origin
Biomass	Municipality
Black slag	Steelmakers
Car fluff	Steelmakers
Dust	Cement producer and steelmakers
Mill scales, refractory and other coating materials	Steelmakers
Municipal solid waste	Municipality
Pallet and wasted wood	Woodchip producer
Sludge	Various companies

An analysis of the energy flows within the district were also performed: a great amount of heat loss was identified within the steelmakers and the cement producer that would represents a large potential for a sustainable recycling.

4. Industrial symbiosis network in Brescia

This section evaluates the opportunity to create an industrial symbiosis network among the previously defined companies of the selected district of Brescia analysing the huge potentials in terms of environmental and economic benefits. The district analyzed is particularly favourable for establishing energy synergies thanks to the presence of a waste to energy plant and of a large district heating network and in some parts, also of a district cooling network. In Table 2, a SWOT analysis of IS in the considered district is proposed.

Table 2. SWOT analysis.

Strengths	Weaknesses
S1. Exploiting of waste to energy plant and of district heating network	W1. Uncertainties in coordination mechanisms
S2. Existence of specialized companies on technologies in the area	W2. Financial and technical barriers in implementing IS
S3. Presence of a huge amount of industries and public service facilities in a strict area (geographic proximity)	W3. Needs for new investments
Opportunities	**Threats**
O1. Improved energy efficiency and sustainability	T1. Multiple decision makers who may potentially have varying and conflicting interests
O2. Reduced GHG emissions, reliance on fossil fuels and system costs	T2. Potential risks and vulnerabilities that may result from the interdependence and interaction of network participants

After the analyses performed, several potential industrial symbiosis synergies have been identified among the different actors. Firstly, to avoid or at least reduce energy losses, the companies that produce surplus energy (electrical or thermal) could sell it to the multi-utility for satisfying the public service facilities or to other members of the networks that need it. For example, the heat from the cooling of the dangerous fumes produced by the steelmaking process and which contains harmful dust can be reused to provide thermal and/or electric energy to other users instead of being released into the air. The excess heat can be supplied through a direct inlet into the district heating network, while for conversion into electric energy an investment in technology is needed: the excess heat will be no longer discharged into the environment but it will end in the turbine of an Organic Rankine Cycle (ORC) containing silicone oil that traps pollutants. Thanks to this synergy there will be a saving of carbon dioxide and a reduction of fossil fuel consumption used by the municipality to power the district heating and to satisfy the electricity demand. Another synergy that can be created from the excess heat of steelmakers is to release it to the caviar producer through a heat exchanger in to heat the water, contributing to the reduction of indirect emissions of carbon dioxide due to the fossil fuels consumptions avoided. Globally, it has been observed that, with the synergies identified a great amount of energy (electrical and thermal) can be exchanged from the companies to the multi-utility which, in its turn, sells to the municipality. Steelmakers provide most of the energy exchanged among the network (almost the 75 %), since their process produces a relevant quantity of heat. In addition, the steel producers can take advantage of the geographical proximity to replace the traditional supply strategy through solid ingots with the supply in a warm state obtaining great costs saving and reduced environmental impact. Regarding raw materials, the main flows identified leading to a reduced amount of traditional fossil fuels are: excess sludge, waste wood and car fluff flows from the manufacturers to companies that implement products treatments (e.g. pyrolysis) converting waste into fuels and by-products and sent them to the steelmakers, to the cement producer and to the multi-utility in different forms [18]. From the sludge and the waste wood it is possible to produce fuels through drying, gasification and pyrolysis techniques rather than dispose them in landfills [19]. The pallets are deprived of the metal and shredded, in this way, the woodchips producer can make use of the metal-free wood residues for sustainable building and for the generation of electrical energy in biomass power stations. Steel and cement plants can exploit the combustion of biochar produced by the wood waste treatment as an energy source. In addition, energy-intensive companies can use also the energy produced burning the coal resulting from car fluff treatment instead of using traditional fossil fuels. The chemical process for the treatment of the car fluff, generated by the demolition of cars, allows to obtain liquid and gaseous hydrocarbons through the chemical bonds' rearrangement of the initial macromolecules and of the soot. These products are refined by distillation and separated for different and various uses to which they may be intended: for example, the liquid fractions can be used in the field of hydrocarbons while the solid fractions in the steel industry supporting the melting phase. The process is characterized by the presence of a service fluid which makes possible the optimization of the heat exchange for the distribution of heat in the reaction system and the continuous working of the installations. The latest generation technologies allow to treat waste with a high calorific value and to avoid some environmental problems, such as the emission of highly polluting compounds. An additional flow selected in the present study is the reuse of black slag, i.e. residue of steelmaking processes generated during the melting of iron scrap. From every tonne of pig iron and steel are generated about 0.2 tonnes of waste. The production process and the control of the black slag from steel has been highly improved leading to the generation of a by-product, instead of waste, with physical and mechanical properties improved with respect to valuable inert materials such as basalt and porphyry normally used for road funds. Hence, they result useful in civil engineering works, construction of roads, concrete and bituminous mixtures. Instead of being regarded as special waste to be disposed of, black slag can be recycled and reused, becoming a safe investment in ecological, energy and economic issues: recycling steelmakers' waste, it is possible to heavily reduce disposal, transport and storage costs, which represent a relevant share of the total costs, and the environmental impact for the extraction of natural material. In Fig. 1, the potential flows across the different actors are shown.

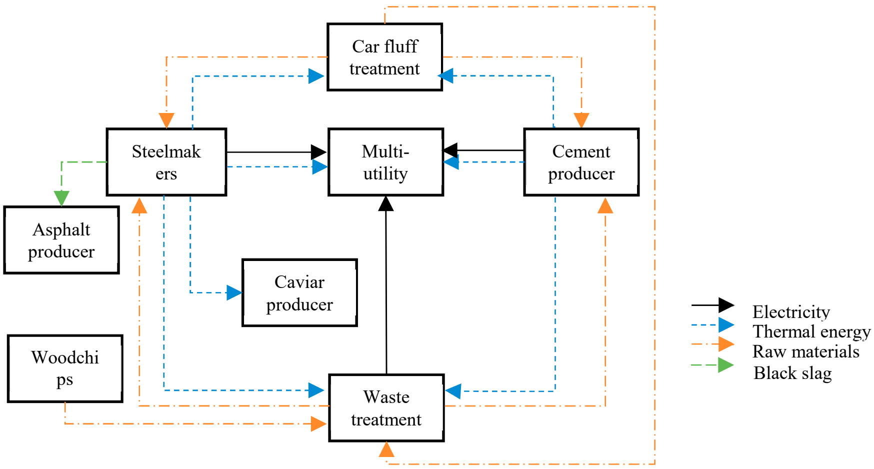

Fig. 1. Energy (electrical and thermal), raw materials and black slag flows potentials in the industrial symbiosis network.

Implementing the industrial symbiosis for the selected companies in the province of Brescia, it is possible to incur into great amount of overall cost savings which allows to overcome the huge initial investment's costs. The creation of the synergies defined above has a positive impacts on both environmental and economic performance of the overall system: i.e. a reduction of costs and CO_2 emissions with respect to the "AS-IS" scenario (100 %–100 %) occurs. The industrial symbiosis results convenient almost for every individual actor, except for the asphalt producer which incurs in an increased cost. The actors characterized by greater savings are the steelmakers and the multi-utility, since they are the one characterized by great energy (electrical and thermal) flows, which present higher costs. From the environmental point of view, the synergies between the various companies allow a relevant total reduction in carbon dioxide emissions. This overall reduction is mainly due to the increased use of energy from renewable sources and of recycled material, instead of exploiting fossil fuels extracted from the ground, and the higher reduction is undertaken by the multi-utility. The waste to energy synergies can be enhanced through the installation of energy storage systems: for instance, for electrical energy storage, lithium-ion batteries represent one of the most promising technology [20]. These different eco-efficiency impacts for the companies in the network as individuality pose a relevant focus on profit sharing and benefits' redistribution mechanisms as a mean to encourage all the companies to establish the proposed synergies. For instance, financial collaboration and joint financing of investment among the partners represents one relevant opportunity [21].

5. Conclusions

In recent years, the focus on Industrial Symbiosis has been strengthen since it represents the most concrete example of the concept of industrial ecology, which aims is to optimize resources use and to reduce the quantity of waste generated in a "closed loop". Industrial symbiosis engages traditionally separate industries and public service facilities in cooperative approaches to manage the totality of flows, shifting the focus from the single industry to a holistic point of view which considers clusters of firms, to improve the overall environmental and economic performances. Three types of symbiotic transactions can occur: (i) utilizing waste as inputs of other companies (by-product exchanges), (ii) sharing utilities or access to services, and (iii) cooperating on issues of common interest. These different transactions allow to achieve higher energy efficiency at an aggregated level, to perform optimizations otherwise not achievable and to approach the 3R principle for the waste management (reduce, reuse and recycle). The main principles of industrial symbiosis include ensuring economic and environmental advantages for the involved companies and society, and ensuring the least distance between companies that are implementing the by-product exchange (geographic proximity). The existence of industrial districts (ID) increases the benefits generated and the scope of the interventions since these groups of customer firms present heterogeneous service requirements and geographical proximity; thus, in the Italian background, it represents a significant potential.

The present work aims at studying and improving solutions for the reduction of energy utilization and environmental impact, considering both the production activities and the service plants and analysing the effects of energy waste reduction, renewable energy sources production and energy recovery. The purpose was, thus, to identify and evaluate an industrial use of techniques and technologies for production, use and recovery of energy from a "saving" viewpoint considering the life cycle approach. It has been proposed an industrial symbiosis network in the province of Brescia, considering companies belonging to different sectors, the municipality and public service facilities. From the analyses conduct it has been shown how the synergies in the specific cases allow to incur in relevant costs savings and to highly reduce the CO_2 emissions. Further developments of the present work consist in a deeper evaluation of the benefits introduced through the identified synergies, an analysis of the main barriers to implement IS and industrial collaborations, and the identification of alternative profit sharing mechanisms so as to encourage all members to participate to the IS network.

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