SNSIM

Volume 5, Issue 2, 2018

ISSN: 2392 – 9537
ISSN-L: 2392 – 9537

P - ESEM

Procedia Environmental Science, Engineering and Management

22nd International Trade Fair of Material & Energy Recovery and Sustainable Development, ECOMONDO, 6th-9th November, 2018, Rimini, Italy

Selected papers (2)

www.procedia-esem.eu

Procedia
Environmental Science, Engineering and Management

http://www.procedia-esem.eu

P - ESEM

Volume 5, Issue 2, 2018

Procedia
Environmental Science, Engineering and Management

22th International Trade Fair of Material & Energy Recovery and Sustainable Development, ECOMONDO, 6th-9th November, 2018, Rimini, Italy

Selected papers (2)

SNSIM

Procedia
Environmental Science, Engineering and Management
http://www.procedia-esem.eu

Aims and Scope

Procedia Environmental Science, Engineering and Management (P - ESEM) is a journal focusing on publishing papers selected from high quality conference proceedings, with emphasis on relevant topics associated to environmental science and engineering, as well as to specific management issues in the area of environmental protection and monitoring.

P - ESEM facilitates rapid dissemination of knowledge in the interdisciplinary area of environmental science, engineering and management, so conference delegates can publish their papers in a dedicated issue. This journal will cover a wide range of related topics, such as: environmental chemistry; environmental biology; ecology geoscience; environmental physics; treatment processes of drinking water and wastewater; contaminant transport and environmental modeling; remediation technologies and biotechnologies; environmental evaluations, law and management; human health and ecological risk assessment; environmental sampling; pollution prevention; pollution control and monitoring etc.

We aim to carry important efforts based on an integrated approach in publishing papers with strong messages addressed to a broad international audience that advance our understanding of environmental principles. For readers, the journal reports generic, topical and innovative experimental and theoretical research on all environmental problems. The papers accepted for publication in *P – ESEM* are grouped on thematic areas, according to conference topics, and are required to meet certain criteria, in terms of originality and adequacy with journal subject and scope.

Procedia
Environmental Science, Engineering and Management
http://www.procedia-esem.eu

GUEST EDITORS

Fabio Fava, born in 1963, is Full Professor of "Industrial & Environmental Biotechnology" at the School of Engineering of University of Bologna since 2005. He has about 140 papers on medium/high IF peer-reviewed international journals of industrial and environmental biotechnology, sectors in which he coordinated the FP7 projects NAMASTE and BIOCLEAN and participated in other 7 FP7 collaborative projects. He is vice-chairman of the "Environmental Biotechnology" section of the European Federation of Biotechnology (EFB). He is the Italian Representative in the "Working Party on Biotechnology, Nanotechnology and Converging Technologies" at OECD (Organization for Economic Co-operation and Development), Paris, in the "European Strategy for the Adriatic and Ionian Region" (EUSAIR) and in the "Western Mediterranean Initiative" (WEST MED). He is member of the "Expert Group on Biobased Products" (DG GROW, European Commission, EC) and is the Italian Representative in the a) Horizon2020 Programming Committee "European Bioeconomy Challenges: Food Security, Sustainable Agriculture and Forestry, Marine, Maritime and Inland Water Research" (SC2, DG RTD, EC), b) "States Representatives Group" of the "Public Private Partnership BioBased Industry" (BBI JU)(DG RTD, EC) and c) BLUEMED Strategic Board (DG RTD and DG MARE, EC). Finally, he is the scientific coordinator of the International Exhibition on green and circular economy ECOMONDO held yearly in Rimini (Italy).

Grazia Totaro, born in 1976, has a degree in Chemistry (University of Ferrara), a Master's Degree in Science, Technology & Management with a specialization in Environmental Chemistry (University of Ferrara) and a PhD in Materials Engineering (University of Bologna).

She worked at the R&D Centre of Basell Polyolefins in Ferrara for 2 years in the frame of a project addressed to the development of a novel methodology for qualitative and quantitative analysis of additives in polymers. She also worked at ARPA, Regional Agency for Environment in Ferrara, division Water Analysis.

Then she started working at the school of Engineering of the University of Bologna for a Ph.D. in Materials Engineering (2007-2010). After that, she had a scholarship "Spinner 2013" in cooperation with Reagens spa (San Giorgio di Piano) on novel PVC nanocomposites. Now she is post doc fellow at the same school on new polymer-based nanocomposites from renewable sources and inorganic fillers. She also worked at the laboratoire de Chimie et Biochimie Pharmacologique et Toxicologique (Université Réné Descartes) in Paris in 2001 and was visiting professor at the Ecole Nationale Superieure de Chimie (Université Blaise Pascal, Clermont Ferrand, FR) in 2012 and 2015. Dr. Totaro has about 25 scientific papers and several participations at conferences and scientific schools. She collaborates on Ecomondo from 2013.

(http://en.ecomondo.com/)

SNSIM

Procedia
Environmental Science, Engineering and Management
http://www.procedia-esem.eu

Procedia Environmental Science, Engineering and Management **5** (2018) (2) 61-122

22th International Trade Fair of Material & Energy Recovery and Sustainable Development, ECOMONDO, 6th-9th November, 2018, Rimini, Italy

CONTENTS

Procedia
Environmental Science,
Engineering and Management
http://www.procedia-esem.eu

Procedia Environmental Science, Engineering and Management **5** (2018) (2) 61-72

22th International Trade Fair of Material & Energy Recovery and Sustainable Development, ECOMONDO, 6th-9th November, 2018, Rimini, Italy

THE SUPPLY CHAIN IMPLICATIONS OF INDUSTRIAL SYMBIOSIS*

Luca Fraccascia[1,2], Devrim Murat Yazan[1]**

[1] "University of Twente", Faculty of Behavioral, Management, and Social Sciences, epartment of Industrial Engineering and Business Information Systems, 5 Drienerlolaan, Enschede 7522 NB, The Netherlands
[2] "Sapienza University of Rome", Faculty of Information Engineering, Informatics, and Statistics, Department of Computer, Control, and Management Engineering, 25 via Ariosto, Roma 00185, Italy

Abstract

This paper proposes an enterprise input-output model to assess the impacts created by industrial symbiosis (IS) on traditional supply chains for production inputs, triggered by resource use change. The model is capable of measuring a variety of sustainability indicators such as resource and waste savings, total energy use reduction, employment creation, reduction in greenhouse gas emissions. Furthermore, the model can be used to analyze IS exchanges from a dynamic perspective, since it is able to take into account dynamic scenarios in wastes production and inputs requirement. A numerical example is presented to show how the model works. This example shows how the impacts of IS strongly depend on the combined effects of upstream supply chains topology, waste treatment processes, and waste-input substitution rate.

Keywords: circular economy, industrial symbiosis input-output, sustainability, supply chains

1. Introduction

Industrial symbiosis (IS) is a subfield of industrial ecology that engages separate industries in a collective approach to competitive advantage, involving physical exchanges of materials, energy, and services (Chertow, 2000). In particular, companies can replace production inputs with wastes generated by other companies. Through IS, the amount of wastes disposed of in landfills and the amount of production inputs purchased from conventional suppliers can be reduced. Furthermore, by adopting the IS practice, companies

* Selection and peer-review under responsibility of the ECOMONDO

** Corresponding author: e-mail: l.fraccascia@utwente.nl can achieve economic benefits from reducing their waste disposal costs and input purchasing cost while creating environmental and social benefits for the collectivity simultaneously (e.g., Jacobsen, 2006). For this reason, the IS practice is expected to play a major role for the transition towards circular economy (e.g., Lüdeke-Freund et al., 2018; Saavedra et al., 2018).

Although IS takes place between production processes of several companies, it creates induced impacts on their traditional supply chains, triggered by resource use change. Hence, IS may be responsible for creating indirect impacts from the environmental, economic, and employment perspective. However, so far the literature focused on assessing the direct effects of IS, i.e., the physical and monetary flows generated between the production processes exchanging wastes and the new jobs created by the symbiotic exchanges (e.g., Bain et al., 2010; Sendra et al., 2007), while less attention has been devoted to analyze the above-mentioned indirect effects. The assessment of such effects is fundamental to fully understand the overall impact of IS on productive systems. Furthermore, the models so far proposed to quantify the effects are not dynamic, i.e., they are able to analyze the effect of the IS relationship only in a specific scenario, defined *a priori*. However, since companies are involved in a dynamic business environment, the effectiveness of the above-mentioned models might be limited.

In order to fill both these gaps, we design a Dynamic Enterprise Input-Output (EIO) model (Grubbstrom and Tang, 2000) for analyzing the changes in physical flows of resources in the upstream supply chains of companies involved in IS synergies. The proposed model is able to analyze IS exchanges from a dynamic perspective, since it is able to take into account changes in waste production and input requirement. A numerical example is used to show how the model works.

The paper is organized as follows: Section 2 presents the EIO model, Section 3 shows the numerical example, and Section 4 is devoted to discussion and conclusions.

2. The enterprise Input-Output model

This section is divided into three subsections. Section 2.1 presents the dynamic EIO model for IS relationships, which allows to take into account all the flows of waste and resources directly created by the symbiotic practice. In Section 2.2, a generic upstream supply chain is modeled according to the EIO approach. Finally, Section 2.3 models the effects of IS on the upstream supply chains of the waste treatment company and of the company using wastes to replace production inputs.

2.1. Dynamic EIO model for IS relationships

According to the EIO approach, companies are modeled as black boxes transforming inputs purchased from their suppliers into one main product, which is used by other companies as intermediate product or is sold on the market. As a result of this transformation, companies produce wastes, which need to be disposed of. Both inputs requirement and wastes production are driven by the amount of main output produced and the production technology.

Let us consider two firms, A and B, and let us suppose that one waste generated by A can replace one input required by B. In this regard, let $w_A(t)$ and $r_B(t)$ be the amount of waste produced by A and the amount of input required by B at the generic time *t*, respectively. They can be computed as Eqs. (1-2):

$$w_A(t) = W_A \cdot x_A(t) \tag{1}$$

$$r_B(t) = R_B \cdot x_B(t) \tag{2}$$

where: $x_A(t)$ and $x_B(t)$ stand for the amount of output produced by A and B at time *t*, respectively, W_A stands for the amount of waste generated by A to produce one unit of output, and R_B stands for the amount of input required by B to produce one unit of output. The values of W_A and R_B depend on the production technologies adopted by companies and therefore they cannot be changed in the short period (This is the reason why W_A and R_B are not function of the time) (Sonis and Hewings, 2007).

When companies establish an IS relationship at time *t*, $e_{AB}(t) = \min\left\{ w_A(t); \frac{r_B(t)}{s_{AB}} \right\}$ units of waste are exchanged between them, where s_{AB} stands for a technical substitution coefficient, i.e., how many units of input can be replaced by one unit of waste. As a result, firm A does not discharge $e_{AB}(t)$ units of waste and firm B do not purchase $s_{AB} \cdot e_{AB}(t)$ units of input from conventional suppliers. However, it may happen that the waste needs a treatment process (e.g., grounding, filtration) before it can be used as input (e.g., Aviso, 2014; Yune et al., 2016). The generic waste treatment process can require *n* additional inputs and generate *m* additional wastes. In this regard, let $\vec{r}_T(t)$ be the *n*×1 vector of the additional inputs required by the waste treatment process at time *t* and let $\vec{w}_T(t)$ be the *m*×1 vector of additional wastes generated by the waste treatment at time *t*. These vectors can be computed as Eqs. (3-4):

$$\vec{r}_T(t) = \vec{R}_T \cdot e_{AB}(t) \tag{3}$$

$$\vec{w}_T(t) = \vec{W}_T \cdot e_{AB}(t) \tag{4}$$

where $\vec{R}_T$ is the *n*×1 vector whose generic *i*-th element denotes how many units of input *i* are required for the treatment of one unit of waste and $\vec{W}_T$ is the *m*×1 whose generic *j*-th element denotes how many units of waste *j* are produced for the treatment of one unit of waste. Fig. 1 shows all the physical flows of inputs and wastes created by the IS relationship as well as two upstream supply chains: (1) the chain supplying the input required by B (highlighted in blue); (2) the chain supplying the inputs required by the waste treatment process (highlighted in orange).

2.2. The upstream supply chains

In this section, we model the above-mentioned upstream supply chains. According to the EIO approach, each chain is modeled as a network of firms, each of them requiring primary inputs from outside the chain and intermediate products from other companies belonging to the chain, transforming them into one output, and producing wastes (Albino et al., 2003). Fig. 2 shows a generic supply chain for the generic *p*-th input. Let us consider the supply chain of the generic focal company (fc) and let us suppose that *n* firms belong to this chain. Let $\vec{x}^{fc}(t)$ be the *n*×1 vector whose generic *i*-th element denotes the amount of output produced by firm *i* at time *t*.

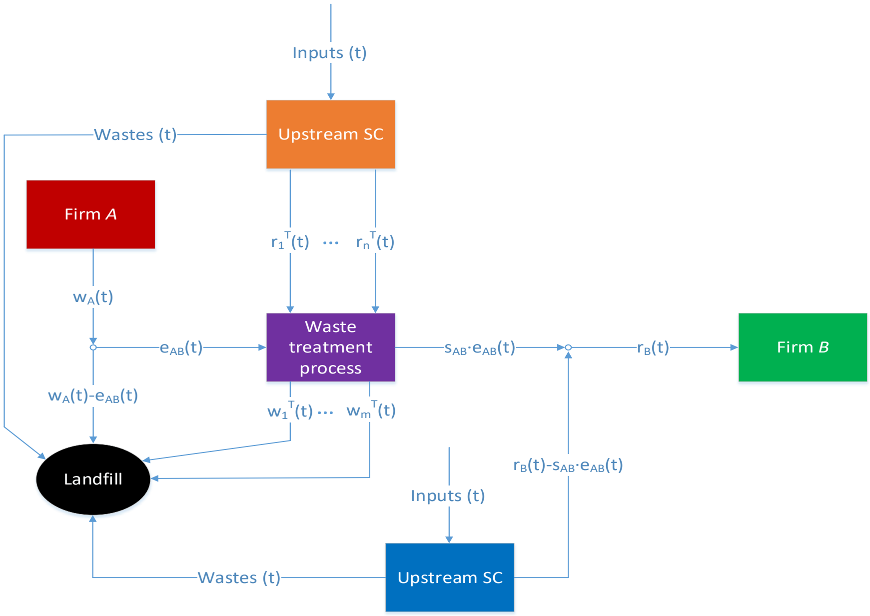


Fig. 1. Physical flows of inputs and wastes generated by IS

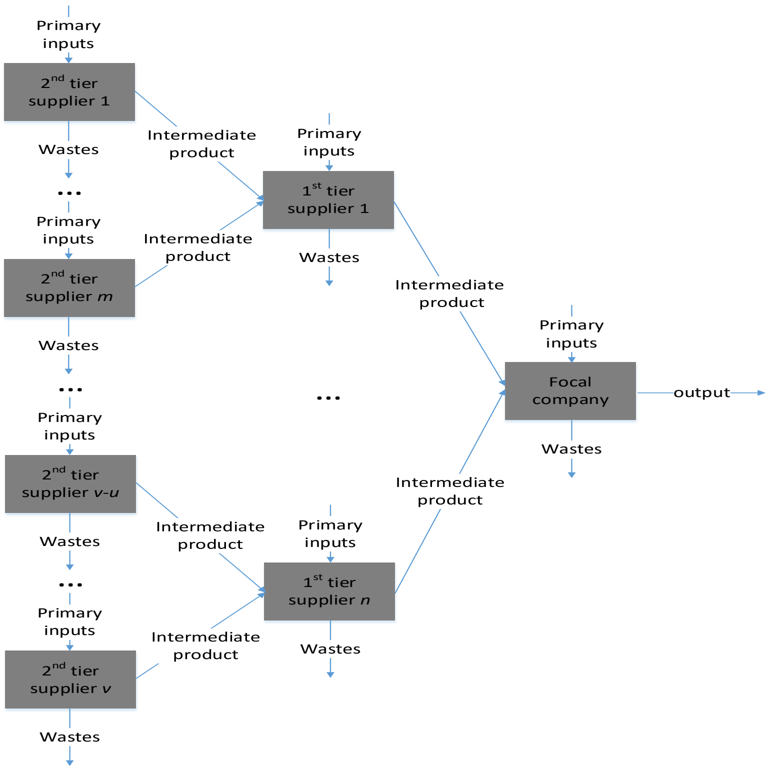


Fig. 2. Scheme of a generic supply chain for the *p*-th input

This vector can be computed as Eq. (5):

$$\vec{x}^{fc}(t) = (I^{fc} - A^{fc})^{-1} \cdot \vec{f}^{fc}(t) \tag{5}$$

where I^{fc} is the $n \times n$ identity matrix, A^{fc} is the $n \times n$ matrix whose generic element A_{ij}^{fc} denotes how many units of output produced by firm *i* are used as intermediate product by firm *j* to produce one unit of output, and $\vec{f}^{fc}(t)$ is the $n \times 1$ vector whose generic *i*-th element denotes how many units of output are demanded to the firm *i* by the focal company at time *t*. Let us suppose that companies belonging to the chain overall require *n(p)* primary inputs and produce *n(w)* wastes. In this regard, let $\vec{p}^{fc}(t)$ be the $n(p) \times 1$ vector whose generic *i*-th element denotes the amount of primary input *i* required by the firms belonging to the chain and let $\vec{w}^{fc}(t)$ be the $n(w) \times 1$ vector whose generic *j*-th element denotes the amount of waste *j* required by the firms belonging to the chain. These vectors can be computed as Eqs. (6-7):

$$\vec{p}^{fc}(t) = P^{fc} \cdot \vec{x}^{fc}(t) \tag{6}$$

$$\vec{w}^{fc}(t) = W^{fc} \cdot \vec{x}^{fc}(t) \tag{7}$$

where P^{fc} is the $n(p) \times n$ matrix whose generic element *ij* denotes how many units of primary input *i* are required by firm *j* to produce one unit of output and W^{fc} is the $n(w) \times n$ matrix whose generic element *ij* denotes how many units of waste *i* are generated by firm *j* to produce one unit of output.

2.3. The effects of industrial symbiosis on the upstream supply chains

In this section, we model the effect of the IS relationship described in the previous section on the two supply chains mentioned in Section 2.1: (1) the supply chain of the input required by firm B; (2) the supply chain of the inputs required by the waste treatment process.

When $e_{AB}(t)$ units of wastes are used by firm B, the company does not purchase $s_{AB} \cdot e_{AB}(t)$ units of input from the conventional supplier, which will reduce the amount of output produced. As a consequence, all the companies involved in the upstream supply chain will reduce their production levels. Let us suppose that *nB* companies belong to the chain. Let $\Delta\vec{x}^{B}$ be the $nB \times 1$ vector whose generic element *i*-th element denotes the reduction in the amount of output produced by firm *i*. Such a vector can be computed as Eq. (8):

$$\Delta\vec{x}^{B}(t) = (I^{B} - A^{B})^{-1} \cdot \begin{bmatrix} 0 \\ 0 \\ \ldots \\ -s_{AB} \cdot e_{AB}(t) \end{bmatrix} \tag{8}$$

where I^{B} and A^{B} are $nB \times nB$ matrices (see Eq. 5). According to Eq. 6 and Eq. 7, the amount of the *nB(p)* primary inputs required and the amount of *nB(w)* wastes produced by the companies belonging to the chain will be reduced. Let $\Delta\vec{p}^{B}(t)$ the *nB(p)*×1 vector whose generic *j*-th element denotes the reduction in the amount of primary input *j* required by the companies and let $\Delta\vec{w}^{B}(t)$ be the *nB(w)* ×1 vector whose generic *q*-th element denotes the reduction in the amount of waste *q* produced by the companies. These vectors can be computed as Eqs. (9-10):

$$\Delta\vec{p}^{B}(t) = P^{B} \cdot \Delta\vec{x}^{B}(t) \tag{9}$$

$$\Delta\vec{w}^{B}(t) = W^{B} \cdot \Delta\vec{x}^{B}(t) \tag{10}$$

where P^{B} is a *nB(p)*×*nB* matrix and W^{B} is a *nB(w)*×*nB* matrix (see Eq. 6 and Eq. 7).

When the waste needs a treatment process before being used as input, such a process requires *n* additional inputs (see Eq. 3 for the amounts of these *n* inputs). As a consequence, all the companies involved in the upstream supply chain of the waste treatment company will increase their production levels. Let us suppose that *nT* companies belong to this chain. Let $\Delta\vec{x}^{T}$ be the *nT*×1 vector whose generic element *i*-th element denotes the increase in the amount of output produced by firm *i*, which can be computed as Eq. (11):

$$\Delta\vec{x}^{T}(t) = (I^{T} - A^{T})^{-1} \cdot \begin{bmatrix} 0 \\ 0 \\ \dots \\ \vec{R}_{T} \cdot e_{AB}(t) \end{bmatrix} \tag{11}$$

where I^{T} and A^{T} are *nT*×*nT* matrices (see Eq. 5). According to Eq. 6 and Eq. 7, the amount of the *nT(p)* primary inputs required and the amount of *nT(w)* wastes produced by the companies belonging to the chain will increase. Let $\Delta\vec{p}^{T}(t)$ the *nT(p)*×1 vector whose generic *j*-th element denotes the increase in the amount of primary input *j* required by the companies and let $\Delta\vec{w}^{T}(t)$ be the *nT(w)* ×1 vector whose generic *q*-th element denotes the increase in the amount of waste *q* produced by the companies. These vectors can be computed as follows:

$$\Delta\vec{r}^{T}(t) = R^{T} \cdot \Delta\vec{x}^{T}(t) \tag{12}$$

$$\Delta\vec{w}^{T}(t) = W^{T} \cdot \Delta\vec{x}^{T}(t) \tag{13}$$

where P^{T} is a *nT(p)*×*nT* matrix and W^{T} is a *nT(w)*×*nT* matrix (see Eq. 6 and Eq. 7).

3. Numerical example

In this section, a numerical example is presented to show how the model works. Let us consider the case whose data are reported in Table 1. Under the hypothesis that , ten units of waste can be exchanged between Firm A and Firm B at time t, i.e., . Hence, Firm A does not dispose any units of waste of in the landfill whereas Firm B reduces the amount of input purchased from conventional suppliers by 10 units. Section 3.1 addresses the impact of IS on the upstream supply chain of Firm B. Section 3.2 addresses the impact of IS on the upstream supply chain of the waste treatment process. Finally, Section 3.3 shows a dynamic application of the EIO model.

Table 1. Numerical data for the considered example.

Firm A	***Firm B***
$x_A(t) = 100$	$x_B(t) = 20$
$W_A = 0.1$	$R_B = 2.5$
$w_A(t) = 10$	$r_B(t) = 50$

3.1. The effects of industrial symbiosis on upstream supply chain of Firm B

Let us consider the supply chain shown in Fig. 3, composed of six companies, where Firm B6 provides Firm B with the input replaced by waste.

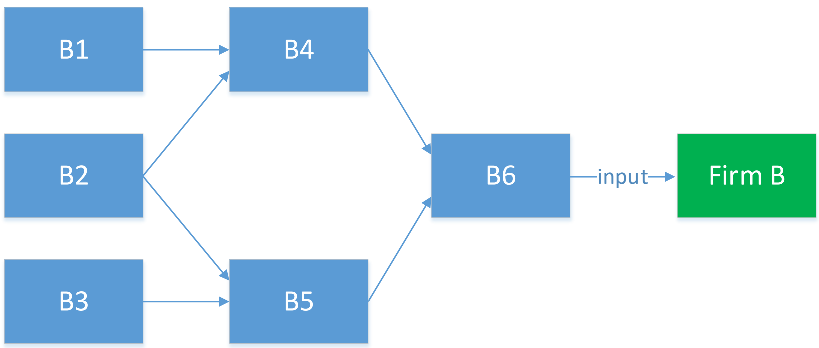


Fig. 3. Upstream supply chain of the Firm B.

The matrix A^B that describes the structure of the supply chain is shown as follows:

$$A^B = \begin{bmatrix} 0 & 0 & 0 & 10 & 0 & 0 \\ 0 & 0 & 0 & 2 & 4 & 0 \\ 0 & 0 & 0 & 0 & 3 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 2 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Accordingly, Firm B4 needs ten units of output from Firm B1 ($A_{14}^B = 10$) and two units from Firm B2 ($A_{24}^B = 2$) per unit of produced output. Firm B5 needs four units of output from Firm B2 ($A_{25}^B = 4$) and three units from Firm B3 ($A_{35}^B = 3$) per unit of produced output. Finally, Firm B6 needs one unit of output from Firm B4 ($A_{46}^B = 1$) and two units from Firm B5 ($A_{56}^B = 2$) per unit of produced output. Let us suppose that companies overall require two inputs (e.g., energy and workforce) and produce three wastes (e.g., wastewater, metal scraps, and plastic wastes). Matrices P^B and W^B are shown as follows:

$$P^B = \begin{bmatrix} 2 & 5 & 3 & 1 & 4 & 3 \\ 0.1 & 0.2 & 0.15 & 0.5 & 0.3 & 0.1 \end{bmatrix} \qquad W^B = \begin{bmatrix} 1 & 0 & 5 & 3 & 0 & 0 \\ 0 & 2 & 2 & 0 & 0.5 & 1 \\ 5 & 5 & 0 & 0 & 0 & 0 \end{bmatrix}$$

For example, to produce one unit of output, Firm 2 requires five units of energy ($P_{12}^B = 5$) and 0.2 units of workforce ($P_{22}^B = 0.2$) and produces two units of metal scraps ($W_{22}^B = 2$) and five units of plastic wastes ($W_{32}^B = 5$). According to Eq. 8, the impact of IS on the amount of output produced by the companies can be computed as follows:

$$\Delta\vec{x}^B(t) = \left\{ \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} - \begin{bmatrix} 0 & 0 & 0 & 10 & 0 & 0 \\ 0 & 0 & 0 & 2 & 4 & 0 \\ 0 & 0 & 0 & 0 & 3 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 2 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \right\}^{-1} \cdot \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ -10 \end{bmatrix} = \begin{bmatrix} -100 \\ -100 \\ -60 \\ -10 \\ -20 \\ -10 \end{bmatrix}$$

For example, the amount of output produced by Firm B1 is reduced by 100 units whereas the amount of output produced by Firm B4 is reduced by 10 units. The impact of IS on the amount of inputs required and wastes produced can be computed as follows, according to Eq. (9) and Eq. (10):

$$\Delta\vec{p}^B(t) = \begin{bmatrix} 2 & 5 & 3 & 1 & 4 & 3 \\ 0.1 & 0.2 & 0.15 & 0.5 & 0.3 & 0.1 \end{bmatrix} \cdot \begin{bmatrix} -100 \\ -100 \\ -60 \\ -10 \\ -20 \\ -10 \end{bmatrix} = \begin{bmatrix} -1000 \\ -51 \end{bmatrix}$$

$$\Delta\vec{w}^B(t) = \begin{bmatrix} 1 & 0 & 5 & 3 & 0 & 0 \\ 0 & 2 & 2 & 0 & 0.5 & 1 \\ 5 & 5 & 0 & 0 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} -100 \\ -100 \\ -60 \\ -10 \\ -20 \\ -10 \end{bmatrix} = \begin{bmatrix} -430 \\ -340 \\ -1000 \end{bmatrix}$$

Hence, the energy and workforce required are reduced by 1000 and 51 units, respectively. As a consequence of IS, the production of wastewater is reduced by 430 units, the production of metal scraps by 340 units, and the production of plastic wastes by 1000 units.

3.2. The effects of industrial symbiosis on upstream supply chain of waste treatment process

Let us consider the supply chain shown in Fig. 4, composed of four companies, where Firm T3 and Firm T4 provide the waste treatment process with two additional inputs.

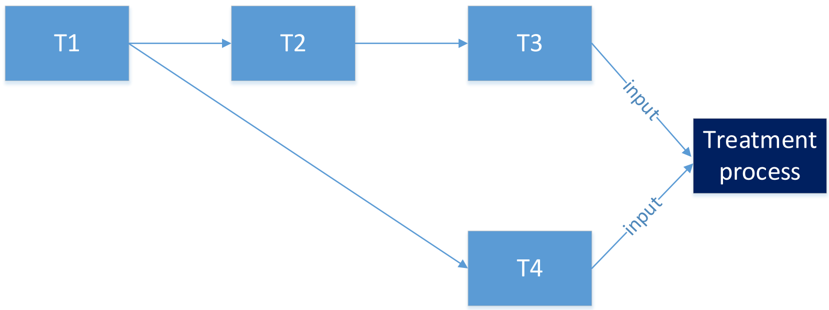


Fig. 4. Upstream supply chain of waste treatment process.

The matrix A^T that describes the structure of the supply chain is shown as follows:

$$A^T = \begin{bmatrix} 0 & 0.25 & 0 & 1 \\ 0 & 0 & 2 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Accordingly, 0.25 units of Firm T1 output are required by Firm T2 per unit of produced output. To produce one unit of output, Firm T3 requires two units of Firm T2 output. Finally, one unit of Firm T1 is required by Firm T4 per unit of produced output. Let us suppose that companies overall require two inputs (e.g., energy and workforce) and produce four wastes (e.g., waste heat, waste oil, fly ash, and wastewater). Matrices P^T and W^T are shown as follows:

$$P^T = \begin{bmatrix} 2 & 1 & 2 & 1.5 \\ 0.2 & 0.1 & 0.1 & 2 \end{bmatrix} \qquad W^T = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 2 & 3 & 1 & 2 \\ 0 & 3 & 0 & 0 \\ 1 & 2 & 5 & 0.5 \end{bmatrix}$$

According to Eq. (8), the impact of IS on the amount of output produced by the companies can be computed as follows:

$$\Delta\vec{x}^T(t) = \left\{ \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} - \begin{bmatrix} 0 & 0.25 & 0 & 1 \\ 0 & 0 & 2 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \right\}^{-1} \cdot \begin{bmatrix} 0 \\ 0 \\ 40 \\ 20 \end{bmatrix} = \begin{bmatrix} 40 \\ 80 \\ 40 \\ 20 \end{bmatrix}$$

The amount of output produced by Firm T1 and Firm T2 is increased by 40 units and by 80 units, respectively. The impact of IS on the amount of inputs required and wastes produced can be computed as follows, according to Eq. 9 and Eq. 10:

$$\Delta\vec{p}^T(t) = \begin{bmatrix} 2 & 1 & 2 & 1.5 \\ 0.2 & 0.1 & 0.1 & 2 \end{bmatrix} \cdot \begin{bmatrix} 40 \\ 80 \\ 40 \\ 20 \end{bmatrix} = \begin{bmatrix} 270 \\ 28 \end{bmatrix}$$

$$\Delta\vec{w}^T(t) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 2 & 3 & 1 & 2 \\ 0 & 3 & 0 & 0 \\ 1 & 2 & 5 & 0.5 \end{bmatrix} \cdot \begin{bmatrix} 40 \\ 80 \\ 40 \\ 20 \end{bmatrix} = \begin{bmatrix} 40 \\ 400 \\ 240 \\ 410 \end{bmatrix}$$

Hence, the energy and workforce required are increased by 270 and 28 units, respectively. As a consequence of IS, the production of waste heat is increased by 40 units, the production of waste oil by 400 units, the production of fly ash by 240 units, and the production of wastewater by 410 units.

3.3. Dynamic use of the EIO model

In this Section, a dynamic application of the EIO model is presented. In particular, this application shows how $e_{AB}(t)$, $\Delta\vec{x}^B(t)$, $\Delta\vec{p}^B(t)$, $\Delta\vec{w}^B(t)$, $\Delta\vec{x}^T(t)$, $\Delta\vec{p}^T(t)$, and $\Delta\vec{w}^T(t)$ can be easily and quickly computed in case of changes in the amount of main output produced, in the production technologies, and in technical substitution coefficient. Numerical values are shown in Table 2.

Table 2. Numerical values concerning changes in main output, production technologies, technical substitution coefficient

	Changes in main output		***Changes in production technologies***		***Changes in technical substitution coefficient***
	$x_A(t)=150$	$x_B(t)=2$	$W_A=0.08$	$R_B=0.2$	$s_{AB}=0.7$
$e_{AB}(t)$	15	5	8	4	10
$\Delta\vec{x}^B(t)$	$\begin{bmatrix} -150 \\ -150 \\ -90 \\ -15 \\ -30 \\ -15 \end{bmatrix}$	$\begin{bmatrix} -50 \\ -50 \\ -30 \\ -5 \\ -10 \\ -5 \end{bmatrix}$	$\begin{bmatrix} -80 \\ -80 \\ -48 \\ -8 \\ -16 \\ -8 \end{bmatrix}$	$\begin{bmatrix} -40 \\ -40 \\ -24 \\ -4 \\ -8 \\ -4 \end{bmatrix}$	$\begin{bmatrix} -80 \\ -80 \\ -48 \\ -8 \\ -16 \\ -8 \end{bmatrix}$
$\Delta\vec{p}^B(t)$	$\begin{bmatrix} -1500 \\ -76.5 \end{bmatrix}$	$\begin{bmatrix} -500 \\ -25.5 \end{bmatrix}$	$\begin{bmatrix} -800 \\ -40.8 \end{bmatrix}$	$\begin{bmatrix} -400 \\ -20.4 \end{bmatrix}$	$\begin{bmatrix} -800 \\ -40.8 \end{bmatrix}$
$\Delta\vec{w}^B(t)$	$\begin{bmatrix} -645 \\ -510 \\ -1500 \end{bmatrix}$	$\begin{bmatrix} -215 \\ -170 \\ -500 \end{bmatrix}$	$\begin{bmatrix} -344 \\ -272 \\ -800 \end{bmatrix}$	$\begin{bmatrix} -172 \\ -136 \\ -400 \end{bmatrix}$	$\begin{bmatrix} -344 \\ -272 \\ -800 \end{bmatrix}$

$\Delta\vec{x}^T(t)$	$\begin{bmatrix}60\\120\\60\\30\end{bmatrix}$	$\begin{bmatrix}20\\40\\20\\10\end{bmatrix}$	$\begin{bmatrix}32\\64\\32\\16\end{bmatrix}$	$\begin{bmatrix}16\\32\\16\\8\end{bmatrix}$	$\begin{bmatrix}40\\80\\40\\20\end{bmatrix}$
$\Delta\vec{p}^T(t)$	$\begin{bmatrix}405\\42\end{bmatrix}$	$\begin{bmatrix}135\\14\end{bmatrix}$	$\begin{bmatrix}216\\22.4\end{bmatrix}$	$\begin{bmatrix}108\\11.2\end{bmatrix}$	$\begin{bmatrix}270\\28\end{bmatrix}$
$\Delta\vec{w}^T(t)$	$\begin{bmatrix}60\\600\\360\\615\end{bmatrix}$	$\begin{bmatrix}20\\200\\120\\205\end{bmatrix}$	$\begin{bmatrix}32\\320\\192\\328\end{bmatrix}$	$\begin{bmatrix}16\\160\\96\\164\end{bmatrix}$	$\begin{bmatrix}40\\400\\240\\410\end{bmatrix}$

4. Discussion

While implementing IS, companies usually care about the direct economic impacts as well as their relationships with traditional suppliers. However, IS triggers a thorough change in the material and energy flows among the upstream supply chain actors. This paper investigates how such changes take place within the supply chain and allow further waste, material, and energy savings and consumptions. Input-output modeling is a strong tool to compute such effects as observed in the numerical example.

The findings of the numerical case example indicate that the above-mentioned effects strongly depend on the topology of the supply chain under investigation. The total produced waste quantity (influenced by waste technical coefficient) as well as the total required primary input (influenced by primary input coefficient) are decisive for the total substitution quantity. Furthermore, the substitution rate between the waste and replaced primary input influences the total quantity of substitution, which is further influenced by the efficiency of waste treatment process. The topology of the supply chain is embedded in the A matrix, which gives a clue about the potential influence of the IS on the upstream flows, as it visualizes the interdependencies between production processes. While the above-mentioned parameters represent the technological efficiency of production processes and can be considered as internal factors, the total final demand for main products of the involved companies is an external factor shaped by the market conditions. Hence, all these parameters should be considered while computing the overall impacts of circular economic business implementation based on IS.

The model is capable of measuring a variety of sustainability indicators such as resource and waste savings, total energy use reduction, employment creation, which are shown in terms of units in the numerical example. Depending on the goal of the study, sustainability indicators such as GHG emissions, water consumption can also be computed. In addition, the model can be linked to a monetary input-output model to compute the economic impacts of implementing IS through the supply chain.

5. Conclusions

The model proposed in this work is useful for scenario analysis and may assist replying further questions, e.g.: (1) what would be the reaction of traditional suppliers to IS, such as increasing the prices of traditional primary inputs or trying to enter in the business of waste treatment? (2) How would the employment level of the sector producing traditional primary resources be influenced? (3) What if the energy consumption level of the waste treatment process is very high pushing the IS-based business through trade-offs between waste and primary resource savings and energy consumption increase? (4) How can such trade-offs be mitigated? The main shortcoming of the input-output model proposed in this paper is that it is a linear model, which cannot carefully reply to all of the above.

Hence, there is a need for developing dynamic input-output models that consider day-to-day operational factors to better tackle with such questions. Thus, this paper can be considered as a seminal one for computing overall SC impacts of IS and for investigating the above-mentioned questions as future research.

Acknowledgements
The project leading to this work has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 680843.

References

Albino V., Dietzenbacher E., Kühtz S., (2003), Analysing materials and energy flows in an industrial district using an enterprise input–output model, *Economic Systems Research*, **15**, 457–480.

Aviso K.B., (2014), Design of robust water exchange networks for eco-industrial symbiosis, *Process Safety and Environmental Protection*, **92**, 160–170.

Bain A., Shenoy M., Ashton W., Chertow M.R., (2010), Industrial symbiosis and waste recovery in an Indian industrial area. *Resoures Conservation and Recycling*, **54**, 1278–1287.

Chertow M.R., (2000), Industrial symbiosis: literature and taxonomy, *Annual Review of Energy and the Environment*, **25**, 313–337.

Grubbstrom R.W., Tang O., (2000), An overview of input-output analysis applied to production-inventory systems, *Economic Systems Research*, **12**, 3–25.

Jacobsen N.B., (2006), Industrial symbiosis in Kalundborg, Denmark: A quantitative assessment of economic and environmental aspects, *Journal of Industrial Ecology*, **10**, 239–255.

Lüdeke-Freund F., Carroux S., Joyce A., Massa L., Breuer H., (2018), The sustainable business model pattern taxonomy-45 patterns to support sustainability-oriented business model innovation, *Sustainable Production and Consumption*, **15**, 145–162.

Saavedra Y.M.B., Iritani D.R., Pavan A.L.R., Ometto A.R., (2018), Theoretical contribution of industrial ecology to circular economy, *Journal of Cleaner Production*, **170**, 1514–1522.

Sendra C., Gabarrell X., Vicent T., (2007), Material flow analysis adapted to an industrial area. *Journal of Cleaner Production*, **15**, 1706–1715.

Sonis M., Hewings G.J.D., (2007), *Coefficient Change and Innovation Spread in Input-Output Models*, Universidade Federal de Juiz de Fora.

Yune J.H., Tian J., Liu W., Chen L., Descamps-Large C., (2016), Greening Chinese chemical industrial park by implementing industrial ecology strategies: A case study, *Resoures Conservation and Recycling*, **112**, 54–64.

Procedia
Environmental Science,
Engineering and Management
http://www.procedia-esem.eu

Procedia Environmental Science, Engineering and Management **5** (2018) (2) 73-83

22th International Trade Fair of Material & Energy Recovery and Sustainable Development, ECOMONDO, 6th-9th November, 2018, Rimini, Italy

INDUSTRIAL SYMBIOSIS AND URBAN AREAS: A SYSTEMATIC LITERATURE REVIEW AND FUTURE RESEARCH DIRECTIONS *

Luca Fraccascia[1,2]**

[1] "University of Twente", Faculty of Behavioral, Management, and Social Sciences, Department of Industrial Engineering and Business Information Systems, 5 Drienerlolaan, Enschede 7522 NB, The Netherlands
[2] "Sapienza University of Rome", Faculty of Information Engineering, Informatics, and Statistics, Department of Computer, Control, and Management Engineering, 25 via Ariosto, Roma 00185, Italy

Abstract

This paper proposes a systematic literature review concerning the implementation of industrial symbiosis (IS) within urban areas, a concept that has been defined by the literature as "urban symbiosis" and "urban-industrial symbiosis", indifferently. 26 papers published between 2009 and 2018 are analyzed. This review is aimed at highlighting: (1) the specific research goals addressed; (2) the IS synergies currently implemented within urban areas; and (3) barriers and enablers to the implementation of IS within urban areas. Suggestions for future research are also proposed.

Keywords: circular economy, industrial symbiosis, literature review, urban symbiosis, urban areas

1. Introduction

Actually, cities are responsible for huge environmental impacts in terms of resource and energy consumption, waste generation, and greenhouse gas (GHG) emissions (e.g., Grimm et al., 2008; Yang et al., 2018). However, the polluting role of cities is further critical if we consider the expected future trends: in fact, recent estimations preview that cities will use 80% of global energy by 2040 (Shell International BV, 2014) and will double waste production by 2025 (The World Bank, 2012). Industrial symbiosis (IS) applied at the urban

---

* Selection and peer-review under responsibility of the ECOMONDO

** Corresponding author: e-mail: federica.amato.76@gmail.com

level can be an effective strategy to make cities more environmentally sustainable (Van Berkel et al., 2009a).

IS refers to the use of industrial wastes as alternative inputs to production processes (Chertow, 2000). By implementing IS synergies, different companies can reduce the amount of wastes landfilled and primary inputs used and create economic benefits simultaneously, because reducing their production costs (e.g., Jacobsen, 2006). In recent years, the literature has investigated the adoption of IS strategies within urban areas, i.e., synergies concerning the use of urban wastes as alternative raw materials and energy sources in industrial operations that conventionally do not accept wastes. The literature refers to these synergies as "IS at urban level" (Albino et al., 2015), "urban symbiosis" (Van Berkel et al., 2009a), and "urban-industrial symbiosis" (e.g., Ohnishi et al., 2017), indifferently. These synergies have been proved effective in reducing the amount of wastes disposed of in landfills, the amount of inputs used in industrial operations, and the amount of GHG emissions (e.g., Huang et al., 2016).

So far, the literature limited to present case studies with the aim to disclose IS synergies and highlight the economic and environmental benefits that can be created thanks to their adoption. However, these studies are highly case-specific and a comprehensive view for this practice is lacking. This paper aims at filling this gap by providing a systematic literature review on IS adopted within urban areas. In particular, the review is aimed at highlighting: (1) the specific research goals addressed; (2) the IS synergies currently implemented within urban areas; and (3) barriers and enablers to the implementation of IS within urban areas.

The paper is structured as follows. Section 2 describes the methodology adopted for this study. Section 3 shows the results of the literature review. Finally, Section 4 presents conclusions and suggestions for future research.

2. Methodology

The study is based on a bibliographic research conducted on 3rd May 2018. The first step was to collect papers. The data were retrieved from Scopus, an academic citation indexing and search service of Elsevier. The following research keywords have been applied to title, abstract, and keywords of papers: ["*Industrial symbiosis*" **AND** (*city* **OR** *cities* **OR** "*urban area**")] **OR** "*Urban symbiosis*". The analysis was restricted to papers published in English in international journals. As result of the research, 80 papers were collected. A first post-processing of the literature data was operated aimed at excluding papers not relevant enough (e.g., papers where the IS within urban areas was not the main research topic but was only mentioned as a suggestion for future works). A second post-processing was carried out aimed at reducing the number of duplicated entities that occurred in the analysis. The final database is made of 26 papers.

3. Results

3.1. General insights

The 26 papers belonging to the final database are displayed in Table 1. They have been published between 2009 and 2018 in 13 journals (Table 2).

64 researchers were found among the authors of the analyzed papers. Fig. 1 shows the co-authorship map, where nodes denote researchers and two nodes are linked if the correspondent researchers co-authored at least one paper. In particular, the size of the node is

proportional to the number of authored papers. A high level of connection among these researchers exists, meaning that the research is not fragmented. However, five isolated research groups can be noted, each of them authoring one paper.

Table 1. Papers analyzed in the literature review

Title	***Reference***
A comprehensive evaluation on industrial & urban symbiosis by combining MFA, carbon footprint and emergy methods—Case of Kawasaki, Japan	(Ohnishi et al., 2017)
A design of rural energy system by industrial symbiosis considering availability of regional resources	(Kanematsu et al., 2017)
Achieving carbon emission reduction through industrial & urban symbiosis: A case of Kawasaki	(Dong et al., 2014a)
Carbon footprints of urban transition: Tracking circular economy promotions in Guiyang, China	(Fang et al., 2017)
Co-benefit potential of industrial and urban symbiosis using waste heat from industrial park in Ulsan, Korea	(Kim et al., 2018)
Eco-benefits assessment on urban industrial symbiosis based on material flows analysis and emergy evaluation approach: A case of Liuzhou city, China	(Sun et al., 2017)
Eco-industrial networking for sustainable development: review of issues and development strategies	(Gibbs and Deutz, 2005)
Eco-industrial zones in the context of sustainability development of urban areas	(Sacirovic et al., 2018)
Effect of urban symbiosis development in China on GHG emissions reduction	(Huang et al., 2016)
Efficient energy recovery through a combination of waste-to-energy systems for a low-carbon city	(Ohnishi et al., 2018)
Environmental and economic gains of industrial symbiosis for Chinese iron/steel industry: Kawasaki’s experience and practice in Liuzhou and Jinan	(Dong et al., 2013b)
Evaluation of innovative municipal solid waste management through urban symbiosis: A case study of Kawasaki	(Geng et al., 2010)
Highlighting regional eco-industrial development: Life cycle benefits of an urban industrial symbiosis and implications in China	(Dong et al., 2017)
Industrial and urban symbiosis in Japan: Analysis of the Eco-Town program 1997-2006	(Van Berkel et al., 2009a)
Industrial symbiosis as a countermeasure for resource dependent city: a case study of Guiyang, China	(Li et al., 2015)
Industrial symbiosis for a sustainable city: technical, economical and organizational issues	(Albino et al., 2015)
Innovative planning and evaluation system for district heating using waste heat considering spatial configuration: A case in Fukushima, Japan	(Dou et al., 2018b)
Low-carbon benefit of industrial symbiosis from a scope-3 perspective: A case study in China	(Li et al., 2017)
Possibility of developing low-carbon industries through urban symbiosis in Asian cities	(Fujii et al., 2016)
Promoting low-carbon city through industrial symbiosis: A case in China by applying HPIMO model	(Dong et al., 2013a)
Quantitative assessment of urban and industrial symbiosis in Kawasaki, Japan	(Van Berkel et al., 2009b)
Realizing CO2 emission reduction through industrial symbiosis: A cement production case study for Kawasaki	(Hashimoto et al., 2010)
Strategies for sustainable development of industrial park in Ulsan, South	(Park et al., 2008)

Korea-From spontaneous evolution to systematic expansion of industrial symbiosis	
Towards preventative eco-industrial development: an industrial and urban symbiosis case in one typical industrial city in China	(Dong et al., 2016)
Transforming the Cement Industry into a Key Environmental Infrastructure for Urban Ecosystem	(Cao et al., 2017)
Uncovering opportunity of low-carbon city promotion with industrial system innovation: Case study on industrial symbiosis projects	(Dong et al., 2014b)

Table 2. Journals where the considered papers are published

Journal	*Number of papers*	*Impact factor*	*H-index*
Journal of cleaner production	7 (29.62%)	5.651	132
Resources, conservation and recycling	5 (19.23%)	5.120	94
Ecological modelling	2 (7.69%)	2.507	132
Energy policy	2 (7.69%)	4.039	159
Journal of industrial ecology	2 (7.69%)	4.356	80
Advances in climate change research	1 (3.85%)	---	10
Applied ecology and environmental research	1 (3.85%)	---	23
Computer aided chemical engineering	1 (3.85%)	---	21
Ecological indicators	1 (3.85%)	3.983	84
Energy	1 (3.85%)	4.968	146
Environmental science and technology	1 (3.85%)	6.653	319
Journal of environmental management	1 (3.85%)	4.005	131
Procedia engineering	1 (3.85%)	---	40

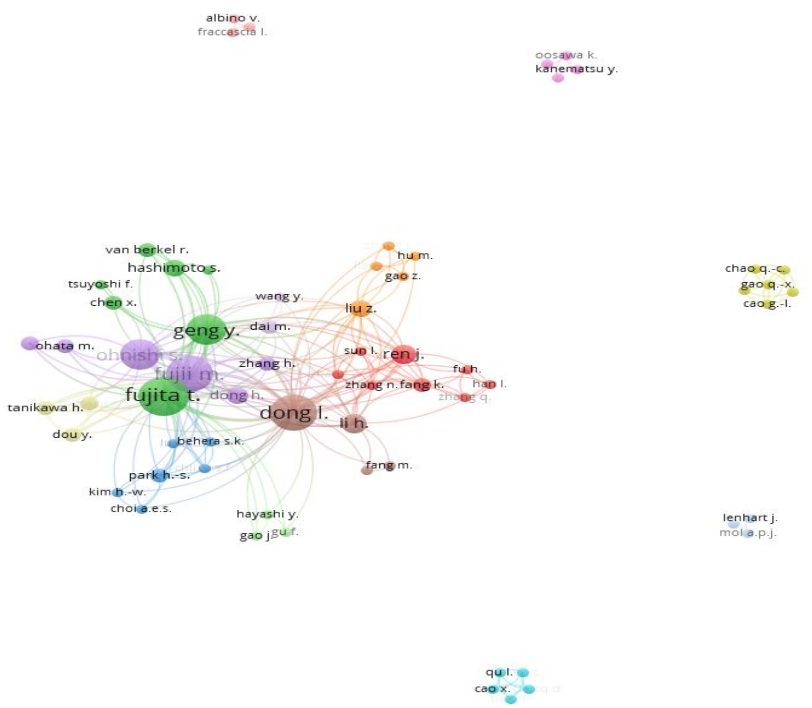


Fig. 1. Co-authorship map

Eight case studies are described by the literature: four cases in China (Liuzhou, Jinan, Guiyang, Shenyang), three cases in Japan (Kawasaki, Shinchi Town, Tanegashima), and one in South Korea (Ulsan).

3.2. Literature overview

Five main topics can be highlighted: (1) description of case studies; (2) assessment of benefits created by IS; (3) methodological contributions; (4) factors affecting the implementation of IS; and (5) energy-based IS. They are presented as follows.

Description of case studies. The early-published papers are mainly descriptive, aimed at showing projects of IS in urban areas. Van Berkel et al. (2009b, p. 1545) first provide a formal definition for the concept of urban symbiosis, i.e., "the use of by-products (wastes) from cities (or urban areas) as alternative raw materials or energy source in industrial operations". Then, they present Japan's Eco-Town Program, which is aimed at creating economic and environmental benefits through implementing processes of urban symbiosis. For each city involved in the project, they highlight the investment required, the subsidies provided by the government, and the amount of wastes diverted from landfill. Van Berkel et al. (2009a) focus on the city of Kawasaki: they describe the processes of urban symbiosis implemented within the framework of Japan's Eco-Town Programme and assess the environmental and economic benefits created. Dong et al. (2013b) describe the symbiotic processes implemented in the two Chinese cities of Liuzhou and Jinan, highlighting the amount of wastes saved from landfills and assessing the economic benefits created.

Assessment of benefits created by IS. Then, the literature focused on assessing the environmental and the economic benefits created by adopting the IS at the urban level. L. Dong et al. (2014a) compute CO_2 emissions reduction potential under promoting IS projects in the two Chinese cities of Jinan and Liuzhou. Geng et al. (2010), Hashimoto et al. (2010), and H. Dong et al. (2014b) compute the reduction in CO_2 emissions in Kawasaki by adopting the LCA approach. In addition to the emissions avoided by replacing inputs with wastes, they also consider the CO_2 emissions due to waste collection and pretreatment, as well as the emissions due to building new facilities. Dong et al. (2013a) propose an urban-level hybrid physical input and monetary output model, which covers physical energy inputs and air pollutants emissions, to assess the reduction in air pollutant emissions (i.e., CO_2, NO_x, SO_2) in Liuzhou thanks to the adoption of urban symbiosis. Li et al. (2015) present the symbiotic processes adopted in the city of Guyang and provide a quantitative assessment of the environmental benefits through a material flow analysis approach. They also compute the reduction in CO_2 emission thanks to the symbiotic processes. Huang et al. (2016) conduct a statistical analysis of the emissions reduction of CO_2 and CH_4 thanks to symbiotic processes in Chinese cities. Cao et al. (2017) show the symbiotic projects involving urban wastes that can be implemented by cement plants, evaluating their environmental and economic performance, identifying barriers in promotion, and proposing supportive policies.

Methodological contributions. Dong et al. (2016) analyze the environmental benefits created in the same city by adopting an integrated input-output and process LCA. Such a methodology has been also used to assess benefits created in Liuzhou (Dong et al., 2017) and Guiyang (Fang et al., 2017). Other methodologies have been proposed, aimed at computing environmental benefits of IS in urban areas, and tested for real cases: the Scope 3 CO_2 emissions (Kawasaki) (Li et al., 2017), an integrated material flows analysis (MFA) and emergy evaluation model (Liuzhou) (Sun et al., 2017), a combined material flow analysis (MFA), carbon footprint (CF) and emerging methods (Kawasaki) (Ohnishi et al., 2017).

Factors impacting on the implementation of IS. Chen et al. (2012) analyze how environmental benefits and operational performance of Eco-Towns can be affected by project scale (i.e., the amount of wastes used as inputs), the recycling boundary, and types of waste. Fujii et al. (2016) examine the feasibility of urban symbiosis projects in three Asian cities: Kawasaki (Japan), Ulsan (South Korea), and Shenyang (China). For each city, the potential for reduction in CO_2 emissions as well as the costs of promoting hybrid industries are evaluated. The study discusses the factors able to affect the cost-effectiveness of symbiotic projects, including the spatial density of waste generation, the waste composition, the relative labor cost for collection and pre-treatment of wastes compared with construction cost of an incinerator and avoided costs through product and fossil resource substitution, and the willingness of citizens to separate wastes. Lenhart et al. (2015) investigate how urban actors, mainly the local authorities, can facilitate the implementation of IS projects in urban areas by analyzing the case of Rotterdam Energy Approach and Planning. In particular, they focus on geographic boundaries, local collaboration and partnership among actors, and government policy intervention. Albino et al. (2015) propose a theoretical framework highlighting the main urban processes responsible for organic waste generation and discuss how urban characteristics might the implementation of IS projects involving these wastes.

Energy-based IS. Some papers focus on energy production from urban wastes. Ohnishi et al. (2018) propose a model that evaluates energy recovery efficiency by considering the costs and benefits of a waste-to-energy system. They analyze several scenarios characterized by different waste quantity/quality, waste separation system, and waste-to-energy production technologies. Other papers are focused on recovering heat produced as waste by incinerators (Dou et al., 2018a) or companies (Dou et al., 2018b; Kanematsu et al., 2017; Kim et al., 2018). In particular, Dou et al. (2018a) develop an integrated model to assess the economic and environmental feasibility of developing a heat exchange network between incineration facilities and industries in city scale. Dou et al. (2018b) combine the system development of district heating system and land use scenarios into a symbiotic design based on inventory survey and geographic database and conduct a cost-benefit analysis to scientifically and quantitatively evaluate the effects brought from land-use policies. Kanematsu et al. (2017) propose a model and simulations of a plant using wastes produced by sugar plant to produce heat for the district heating system. Finally, Kim et al. (2018) conduct an analysis of different scenarios of heat recovery of heat produced in Ulsan eco-industrial park, assessing the economic and environmental benefits of each scenario.

3.3. Symbiotic synergies implemented

The IS synergies described by the analyzed papers are displayed in Table 3. Each synergy is categorized as material-based, water-based, or energy-based.

3.4. Barriers and enablers

Urban symbiosis projects are characterized by a high level of complexity because involving multiple stakeholders (e.g., citizenships, companies producing and using wastes, government, companies collecting wastes) that have usually different interests (Sun et al., 2017). In this regard, the literature shows that a strong cooperation among all the above-mentioned stakeholders is a *conditio sine qua non* for the effective implementation of IS projects. In this sense, a widespread recognition among all stakeholders that the industrial environmental pollution needs to be reversed acts as a facilitator for the development of IS projects (Van Berkel et al., 2009b). Alternatively, where this awareness is low, the adoption of the IS approach is more difficult (Dong et al., 2013a). Hence, in order to improve the stakeholders' awareness on IS, activities related to the IS concept such as TV promotions, newsletters, achievement exhibitions, and workshops might be promoted (Dong et al., 2013a).

From the technical perspective, some important issues affecting the adoption of IS can be highlighted. First, a minimum amount of waste is required to ensure the technical and economic feasibility of IS (Li et al., 2015; Ohnishi et al., 2017). If the amount of the available wastes is lower than the minimum amount required, companies have no willingness to implement IS.

Table 3. Synergies of IS proposed, designed, or developed for urban areas

Waste	*Producer*	*Use/Input replaced*	*User(s)*	*Category*	*Cities*
Mixed urban wastes	Households	Coal	Cement production	Energy-based	Kawasaki
Plastic wastes	Households	Coal	Cement production	Energy-based	Kawasaki
			Iron and steel production	Energy-based	Liuzhou, Jinan, Guiyang
Waste tires	Households	Coal	Cement production	Energy-based	Liuzhou
			Iron and steel production	Energy-based	Guiyang
Fly ash	Households		Cement production	Material-based	Kawasaki
Wastewater sludge	Wastewater treatment plant	Limestone	Cement production	Material-based	Kawasaki
Mixed plastic	Households	Used to produce synthesis gas	Ammonia production process	Energy-based	Kawasaki
		Plywood	Concrete production	Material-based	
Treated water	Wastewater treatment process	Industrial water	Paper production	Water-based	Kawasaki
			Cement production	Water-based	
			Iron and steel production	Water-based	Jinan
Surplus soil	Urban construction sites	Clay	Cement production	Material-based	Kawasaki
Food waste	Households	Incinerated for energy production	Incinerator	Energy-based	Liuzhou
Waste heat	Companies	Heat	Households	Energy-based	Shinchi Town, Ulsan
Organic wastes	Companies	Heat	Households	Energy-based	Tanegashima

In addition to the quantity, the stability of waste flows is a fundamental requisite. In this regard, one of the main barriers in China is the difficulty to provide a stable urban waste supply to companies, due the lack of a stable waste recycling system (Dong et al., 2014a) and information obstacles (Dong et al., 2016). In fact, both the amount and the characteristics of urban wastes (e.g., the content of plastic wastes) supplied to companies may fluctuate over time (Dong et al., 2013b). Such a fluctuation might lead to inefficiencies from the operational perspective, so that designing and managing IS relationships becomes a hard task (Cao et al., 2017). Hence, establishing an urban waste recycling system is fundamental for the application of IS, so that adequate wastes can be collected and delivered to the right users (Dong et al., 2013a). Of course, city governments should ensure a detailed separation program for urban wastes collection and all urban waste producers should be encouraged to take part (Hashimoto et al., 2010; Ohnishi et al., 2017). For example, the waste collection and separation system can be improved through social education system, which may lead to a higher public awareness on implementing source separation through voluntary actions (Dong et al., 2014b). Concerning the information obstacles, companies might face difficulties in exploiting urban wastes because not aware of what kind of wastes are produced in a specific urban area, the amount produced, and the production rate (Dong et al., 2016). To overcome this obstacle, governments can create online information platforms collecting data concerning potential supply and demand for wastes produced at the urban level and sharing them with the local companies (Chen et al., 2012; Fraccascia and Yazan, 2018). Finally, some wastes might require a treatment process before being used as inputs by companies. For example, the use of plastic waste as an alternative fuel requires that the waste is sorted for removing impurities (Hashimoto et al., 2010). Waste treatment technology is a fundamental enabler for the application of IS since it determines whether urban wastes can be reused by local companies (Dong et al., 2014b; Dong et al., 2016; Li et al., 2015). If appropriate technologies are not available or not economically affordable, the IS becomes no more feasible.

From the economic perspective, the economic feasibility of IS projects is strongly affected by: (1) the price of waste disposal and input purchasing; and (2) the additional investments required to implement IS synergies. In particular, the higher the price of waste disposal and input purchasing, the more economically feasible the IS project will be, *ceteris paribus*. However, some studies put in evidence that in China these prices are low and, for this reason, companies might be not motivated enough to replace inputs with wastes (Cao et al., 2017; Li et al., 2015). Additional investments can be required to implement IS synergies, for instance to build infrastructure and facilities (Dong et al., 2017, 2013a; Geng et al., 2010). This makes the IS costly in the short time, as the required investments are usually high (Dong et al., 2017). Furthermore, investing in symbiotic projects might be considered as risky by companies, mainly because of the above-mentioned uncertainty in waste flows in the long period, which affects revenues (Van Berkel et al., 2009b). Governments can play a fundamental role in the implementation of IS through policy actions and economic incentives. In fact, governments can adopt a waste management legislation which motivates companies to participate in IS projects, for example by introducing mandatory recycling targets for urban wastes (Dong et al., 2013b; Van Berkel et al., 2009a), taxes on environmental emissions (Dong et al., 2016), and applying ecological compensation policies impacting on the market prices of inputs (Sun et al., 2017). Furthermore, governments can provide companies with financial subsidies aimed at establishing IS projects (Dong et al., 2013b), subsidizing the physical infrastructures required (e.g., pipelines for waste energy exchanges) (Dong et al., 2014a), and providing research funds for R&D activities aimed at improving waste recycling technologies (Dong et al., 2016).

4. Conclusions

This is the first paper providing a comprehensive view of how IS within urban areas has been addressed so far by the literature. 26 papers published between 2009 and 2018 have been analyzed, aimed at highlighting the specific research goals addressed, the IS synergies currently implemented within urban areas, and barriers and enablers to the implementation of IS within urban areas. Here, there are some suggestions for future research:

- According to results, different IS synergies can be implemented in different cities. Hence, identifying in a systematic way the urban features able to affect the implementation of IS synergies can be a matter for future research.
- Waste collection processes could be optimized in order to take into account operational constraints stemming from IS synergies (e.g., the demand for wastes by companies) in addition to economic and environmental constraints already considered by the literature.
- IS synergies within urban area could be integrated with traditional IS synergies among companies.
- The business models behind this approach need to be analyzed. Furthermore, specific contractual clauses should be developed in order to ensure that the economic benefits created will be fairly shared between companies and citizens.

References

Albino V., Fraccascia L., Savino T., (2015), Industrial Symbiosis for a Sustainable City: Technical, Economical and Organizational Issues, *Procedia Engineering*, **118**, 950–957.

Cao X., Wen Z., Tian H., De Clercq D., Qu L., (2017), Transforming the Cement Industry into a Key Environmental Infrastructure for Urban Ecosystem: A Case Study of an Industrial City in China, *Journal of Industrial Ecology*, **22**, 881–893.

Chen X., Fujita T., Ohnishi S., Fujii M., Geng Y., (2012), The Impact of Scale, Recycling Boundary, and Type of Waste on Symbiosis and Recycling, *Journal of Industrial Ecology*, **16**, 129–141.

Chertow M.R., (2000), Industrial Symbiosis: Literature and Taxonomy, *Annual Review of Energy and the Environment*, **25**, 313–337.

Dong L., Fujita T., Zhang H., Dai M., Fujii M., Ohnishi S., Geng Y., Liu Z., (2013a), Promoting low-carbon city through industrial symbiosis: A case in China by applying HPIMO model, *Energy Policy*, **61**, 864–873.

Dong L., Zhang H., Fujita T., Ohnishi S., Li H., Fujii M., Dong H., (2013b), Environmental and economic gains of industrial symbiosis for Chinese iron/steel industry: Kawasaki's experience and practice in Liuzhou and Jinan, *Journal of Cleaner Production*, **59**, 226–238.

Dong L., Gu F., Fujita T., Hayashi Y., Gao J., (2014a), Uncovering opportunity of low-carbon city promotion with industrial system innovation: Case study on industrial symbiosis projects in China, *Energy Policy*, **65**, 388–397.

Dong H., Ohnishi S., Fujita T., Geng Y., Fujii M., Dong L., (2014b), Achieving carbon emission reduction through industrial and urban symbiosis: A case of Kawasaki, *Energy*, **64**, 277–286.

Dong L., Dai M., Ren J., Fujii M., Wang Y., Ohnishi S., (2016), Towards preventative eco-industrial development: an industrial and urban symbiosis case in one typical industrial city in China, *Journal of Cleaner Production*, **114**, 387–400.

Dong L., Liang H., Zhang L., Liu Z., Gao Z., Hu M., (2017), Highlighting regional eco-industrial development: Life cycle benefits of an urban industrial symbiosis and implications in China, *Ecological Modelling*, **361**, 164–176.

Dou Y., Ohnishi S., Fujii M., Togawa T., Fujita T., Tanikawa H., Dong L., (2018a), Feasibility of developing heat exchange network between incineration facilities and industries in cities: Case of Tokyo Metropolitan Area, *Journal of Cleaner Production*, **170**, 548–558.

Dou Y., Togawa T., Dong L., Fujii M., Ohnishi S., Tanikawa H., Fujita T., (2018b), Innovative planning and evaluation system for district heating using waste heat considering spatial configuration: A case in Fukushima, Japan, *Resources Conservation and Recycling*, **128**, 406–416.

Fang K., Dong L., Ren J., Zhang Q., Han L., Fu H., (2017), Carbon footprints of urban transition: Tracking circular economy promotions in Guiyang, China, *Ecological Modelling*, **365**, 30–44. doi:10.1016/j.ecolmodel.2017.09.024

Fraccascia L., Yazan D.M., (2018), The role of online information-sharing platforms on the performance of industrial symbiosis networks, *Resources Conservation and Recycling*, **136**, 473–485.

Fujii M., Dong L., Lu C., Behera S.K., Park H.-S., Chiu A.S.F., (2016), Possibility of developing low-carbon industries through urban symbiosis in Asian cities, *Journal of Cleaner Production*, **114**, 376–386.

Geng Y., Tsuyoshi F., Chen X., (2010), Evaluation of innovative municipal solid waste management through urban symbiosis: a case study of Kawasaki, *Journal of Cleaner Production*, **18**, 993–1000.

Gibbs D., Deutz P., (2005), Implementing industrial ecology? Planning for eco-industrial parks in the USA, *Geoforum*, **36**, 452–464.

Grimm N.B., Faeth S.H., Golubiewski N.E., Redman C.L., Wu J., Bai X., Briggs J.M., (2008). Global change and the ecology of cities, *Science*, **319**, 756–60.

Hashimoto S., Fujita T., Geng Y., Nagasawa E., (2010), Realizing CO2 emission reduction through industrial symbiosis: A cement production case study for Kawasaki. *Resources Conservation and Recycling*, **54**, 704–710.

Huang W., Gao Q.-X., Cao G., Ma Z.-Y., Zhang W.-D., Chao Q.-C., (2016), Effect of urban symbiosis development in China on GHG emissions reduction. *Advances in Climate Change Research*, **7**, 247–252.

Jacobsen N.B., (2006), Industrial Symbiosis in Kalundborg, Denmark: A Quantitative Assessment of Economic and Environmental Aspects, *Journal of Industrial Ecology*, **10**, 239–255.

Kanematsu Y., Oosawa K., Okubo T., Kikuchi Y., (2017), A design of rural energy system by industrial symbiosis considering availability of regional resources, *Computer Aided Chemical Engineering*, **40**, 1987–1992.

Kim H.-W., Dong L., Choi A.E.S., Fujii M., Fujita T., Park H.-S., (2018), Co-benefit potential of industrial and urban symbiosis using waste heat from industrial park in Ulsan, Korea, *Resources Conservation and Recycling*, **135**, 225–234.

Lenhart J., van Vliet B., Mol A.P.J., (2015), New roles for local authorities in a time of climate change: the Rotterdam Energy Approach and Planning as a case of urban symbiosis, *Journal of Cleaner Production*, **107**, 593–601.

Li H., Dong L., Ren J., (2015), Industrial symbiosis as a countermeasure for resource dependent city: a case study of Guiyang, China, *Journal of Cleaner Production*, **107**, 252–266.

Li H., Dong L., Xie Y.T., Fang M., (2017), Low-carbon benefits of industrial symbiosis from a scope-3 perspective: a case study in China, *Applied Ecology and Environmental Research*, **15**, 135–153.

Ohnishi S., Dong H., Geng Y., Fujii M., Fujita T., (2017), A comprehensive evaluation on industrial & urban symbiosis by combining MFA, carbon footprint and emergy methods—Case of Kawasaki, Japan, *Ecological Indicators*, **73**, 315–324.

Ohnishi S., Fujii M., Ohata M., Rokuta I., Fujita T., (2018), Efficient energy recovery through a combination of waste-to-energy systems for a low-carbon city, *Resources Conservation and Recycling*, **128**, 394–405.

Park H.-S., Rene E.R., Choi S.-M., Chiu A.S.F., (2008), Strategies for sustainable development of industrial park in Ulsan, South Korea—From spontaneous evolution to systematic expansion of industrial symbiosis, *Journal of Environmental Management*, **87**, 1–13.

Sacirovic S., Ketin S., Vignjevic N., (2018), Eco-industrial zones in the context of sustainability development of urban areas, *Environmental Science Pollution Research*, 1–11.

Shell International BV (2014), *New Lenses on Future Cities*, online at http://s05.static-shell.com/content/dam/shell-new/local/country/sgp/downloads/pdf/new-lenses-on-future-cities.pdf.

Sun L., Li H., Dong L., Fang K., Ren J., Geng Y., Fujii M., Zhang W., Zhang N., Liu Z., (2017), Eco-benefits assessment on urban industrial symbiosis based on material flows analysis and emergy evaluation approach: A case of Liuzhou city, China, *Resources Conservation and Recycling*, **119**,

78–88.
The World Bank, (2012), *What a waste. A global review on solid waste management*, online at: https://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1334852610766/What_a_Waste2012_Final.pdf
Van Berkel R., Fujita T., Hashimoto S., Fujii M., (2009a), Quantitative Assessment of Urban and Industrial Symbiosis in Kawasaki, Japan, *Environmental Science & Technology*, **43**, 1271–1281.
Van Berkel R., Fujita T., Hashimoto S., Geng Y., (2009b), Industrial and urban symbiosis in Japan: Analysis of the Eco-Town program 1997-2006, *Journal of Environmental Management*, **90**, 1544–1556.
Yang X., Wang Y., Sun M., Wang R., Zheng P., (2018), Exploring the environmental pressures in urban sectors: An energy-water-carbon nexus perspective, *Applied Energy*, **228**, 2298–2307.

Procedia
Environmental Science, Engineering and Management
http://www.procedia-esem.eu

Procedia Environmental Science, Engineering and Management **5** (2018) (2) 85-92

22th International Trade Fair of Material & Energy Recovery and Sustainable Development, ECOMONDO, 6th-9th November, 2018, Rimini, Italy

USE OF CORPORATE ENVIRONMENTAL TOOLS IN THE PERSPECTIVE OF INDUSTRIAL SYMBIOSIS*

Federica Giunta[1], Andrea Leanza[1], Agata Matarazzo[1], Alberto Di Silvestro[1], Carlo Gigli[2], Enrico Lombardo[2]**

Department of Economics and Business, University of Catania, Corso Italia 55, 95129 Catania, Italy 2GE.S.P.I. S.R.L., Via Capitaneria 26, 96011 Augusta (SR), Italy

Abstract

The Environmental Management Accounting (EMA) proposes appropriate voluntary tools that allows companies and public administrations to be supported in the accounting of all the environmental variables involved in production processes. They are recorded both in terms of input and output, therefore as withdrawals and releases of materials and substances in the ecosystem, with an eye on the economic aspect and the other on the purely physical/environmental one. These tools monitor and evaluate the eco-sustainable performance and policies of public bodies and organizations in an effective manner, orienting company policies, investments and activities towards a proactive approach aimed at a continuous improvement of environmental performance.

The aim of this paper is to propose the adoption of voluntary EMA tools to a Sicilian company operating in the waste-to-energy incineration sector, through a study aimed at re-elaborating and classifying the main business information suitable for quantifying specific environmental performance indicators, in the compartments of water, air, soil and waste. The company chosen is GE.S.P.I. S.R.L., located in Augusta (SR), leader in the sector in southern Italy and owner of the one and only plant for incinerating special waste (hazardous and non-hazardous) in the Sicilian territory. The proposed environmental accounting tools become an important means for decision-making support and sustainable communication with local communities and institutions, with the purpose of evaluating future corporate structural investments able to pay particular attention to environmental performance. Therefore, a strategy is applied with the objective of correctly informing stakeholders about the eco-sustainable business management; this method is effective for the resolutive support of production, organizational and management processes between different companies operating in the same territory, thus facilitating the start of processes of industrial symbiosis with a view to improving the well-being of the entire society.

Keywords: Environmental Management Accounting, incineration, industrial symbiosis, special waste

* Selection and peer-review under responsibility of the ECOMONDO

** Corresponding author: e-mail: FEDERICA.GIUNTA96@gmail.com

1. Introduction

In this study, environmental accounting concepts, methods and tools were analyzed and it was shown how using these techniques can help companies in their relationship with the environment, and in particular contribute to:

- the process decision-making;
- prevention of environmental damage;
- management costs and investments;
- implementation of environmental management systems;
- improvement of relations with stakeholders and the company image.

The aim of this work and of a larger study performed by authors is to analyze and demonstrate the applicability of the tools previously mentioned, in a Sicilian company whose core business is closely related to the environmental aspect. The company is GE.S.P.I. S.R.L., located in Augusta (SR) that operates in the waste sector, and that in its main activity deals with incineration of special waste. The company was initially chosen for an internship and then as a fulcrum for the implementation of the study and the achievement of the objectives set as the leader of a sector at the center of socio-environmental issues, because:

- its direct connection with the environment is in both a positive sense, since its role is to dispose of polluting and possibly dangerous waste, and in a negative sense, due to the possible emissions strongly impacting the ecosystem;
- it is subjected to increasingly stringent regulations on environmental compliance;
- it is targeted by decades of discussions and social contrasts, due to the perceived risk of the citizen and the lack of technical information disseminated in society.

Furthermore, the sector in Italy is a growing sector: special waste produced in Italy is more than four times higher than urban waste. For example, in 2014, about 130.6 million tons of "special" waste were produced for 30 million tons of urban waste; in the same year more waste than those produced was recycled or disposed of, this because 2014 was also attributed to the treatment of waste that had been stored or subjected to intermediate recycling operations (www.repubblica.it). So, it is interesting to analyze a company operating in a sector that, in addition to being closely related to the term environment, gains a relevant position in the economy of the country and falls under public attention and substitution.

2. Presentation of case study and methods

The SWOT analysis, which stands for Strengths, Weaknesses, Opportunities and Threats, originated in the 1960s (Learned et al., 1965) and is an instrument that aims to identify the strengths and weakness of an organization and the opportunities and threats present in the environment. In particular, the strengths depend on the capabilities and resources of a company, the weaknesses on its internal fragilities. Opportunities and threats are instead due to the possibility of exploitation or influence of elements of the context in which the company operates.

After identifying these factors, strategies can be developed that can be based on strengths, eliminate weaknesses, exploit opportunities or counter threats (Dyson, 2004). The SWOT analysis is a very versatile tool, as it can be applied, as well as to a company, to other subjects, such as groups of companies, industrial systems, territories. Therefore, in the present case the SWOT analysis is a useful tool for analyzing and evaluating the development and conditions of a territory (in particular the high-risk area of Syracuse), the characteristics of a company rooted in it (GE.S.P.I. S.R.L.), and subsequently the relationships that bind these two entities.

To carry out the above-mentioned comparison between the company and the territory, we start by applying the SWOT analysis to the company in question. First of all, thanks to its position, as we saw earlier, the company is able to work with customers for the most part (both in terms of quantity and in terms of relative turnover) on the site: this allows it to lower costs and to support the local economy. Moreover, the proximity to the port guarantees a rapid service for ship waste and also allows an evacuation service of the docks in the event of an accident. In fact, the company manages different types of hazardous waste (industrial, hospital waste) and treats the different types in specific proportion for the correct functioning of the plant. The production process is based on a "make" structure; the technicians are at the same time the company managers, who with an internal point of view are able to identify the best available technologies: continuous improvement is one of the pillars of GE.S.P.I. to maintain its leadership position. The strengths and the presence on the territory for a long time have allowed the company to increase its reputation and know-how, reaching a very high level of reliability. If the position (proximity to the port and the petrochemical center) is a force for the company, it can be considered, at the same time, a limit from social point of view: historically, this type of company has always been negatively judged by the company due to the lack of information. Incineration is a controversial technology. Although it has been widely used to reduce the amount of waste produced in urban areas, and in spite of the fact that companies such as the one analyzed perform a social function (problem solving function), they are associated with atmospheric pollution and its implementation always leads to social protests.

Another weak point for the company is the distance from the most important urban centers, due to the lack of services such as the airport and the railways and the difficulty for customers to reach the facility. Furthermore, limited spaces cause less risk distribution and do not give the possibility to satisfy all customer requests. Precisely for this reason, the company is already planning the construction of another production line. Another important aspect concerns the lack of adequate infrastructure, which represents a constant risk in the transport phase and a threat to the company. Finally, the growing impediment of legislation is another obstacle in recent decades: if regulatory progress aims to protect the environment in a more rigorous way, on the other hand, it is a greater responsibility for this type of companies that must always respect more restrictive limitations, in a legal system full of ambiguity (Leanza et al., 2017).

Table 1. SWOT analysis in GE.S.P.I. S.R.L.

STRENGTH • Reliability • Technicians / Managers • Innovative technologies • Energy production • Treatment of different types of waste	**WEAKNESS** • Proximity to the social context • Limited spaces • Distance from the most important urban centers
OPPORTUNITIES • Expansion of the plant • Proximity to the port and other facilities • Implementation of industrial symbiosis	**THREATS** • Lack of adequate infrastructure • Progress in regulation and fragility of the legal and bureaucratic system • Social disinformation and disturbing behavior

3. Environmental analysis

The concepts and tools of environmental accounting have been analyzed, the contexts in which they can be applied to the best, showing their functions and the advantages consequent to their use. The instrument of the environmental balance has been studied in its various facets and its possibilities of use, and the environmental performance indicators that, starting from the data available from it, can be constructed, in order to give an immediate idea of what the policies are.

The company object of the case study was presented, namely GE.S.P.I. S.R.L., in all its most relevant characteristics, and the problems related to the activity it performs have been exposed. The environmental results of the company were considered and the instrument of the SWOT analysis was finally applied, in order to carry out a more or less complete description of both the structure of the company and the political, social and environmental context in which it operates, so as to be able to relate them. Policies and the work of the company itself were analyzed. The study is part of a large project.

In the current paragraph, knowledge will be applied exposed throughout the entire project: the objective of the same, and consequently of the overall work is to detect all company information pertaining to the issues analyzed and quantify the main indicators, to place them within the most relevant sectors (i.e. the areas of expertise identified as most significant to describe the environmental impacts of the company) and to prepare the foundations for the implementation of an environmental balance. With the present document, therefore, the budget will not be drafted, but the road will be paved for the future construction of it by the company. The following problems have been analyzed:

- atmospheric pollution;
- noise pollution;
- consumption of resources;
- waste;
- internal traffic;
- employee involvement (environment and safety);
- certification system.

In this study we present the main sectors analyzed: atmospheric pollution and waste.

3.1. Atmospheric pollution

Due to its production process, the main impact of the plant can be evaluated in terms of atmospheric emissions. In plant running conditions, the main pollutants emitted into the atmosphere are HCl, CO, NO_x, SO_2 and particulates. The national and European legislation, implemented in the authorization decrees of the plant, defines concentration limits for the different types of pollutants contained in the fumes emitted from the combustion of waste (Matarazzo et al., 2018). The company is attentive to the legal requirements and works by committing itself to keeping emissions below the mandatory limits; a fume purification plant is installed, and the concentrations of pollutants in the fumes coming from the chimney are monitored throughout the year. Leaving aside monthly issues, Tables 2-4 show what are the core values of emissions into the atmosphere during the years 2015, 2016 and 2017.

From Tables 2-4 we can see how the values in the three years considered have remained more or less stable: in fact, in the course of the three years for the different pollutants discontinuous variations are observed no particular positive or negative trend is highlighted, except a stabilization of the concentration of particulates at a lower level in the years 2016/17 compared to the year 2015.

Table 2. Pollutants concentrations in fumes, year 2015

Month	**CO (mg/Nm³)**	**NO (mg/Nm³)**	**SO_2 (mg/Nm³)**	**TOC (mg/Nm³)**	**HCl (mg/Nm³)**	**O_2 chimney (%)**	**Particula-tes (mg/Nm³)**	**Payload (m³/h)**
Min	6.7	117.8	16.6	0.0	0.2	12.2	0.6	33664
Average	8.8	125.2	19.9	0.1	1.0	13.1	1.0	36346
Max	11.96	136.77	21.95	0.85	3.88	13.76	2.28	39476
S.D.	1.51	6.77	1.99	0.25	1.21	0.48	0.51	1847
Tot	105.67	1502.12	238.23	1.11	12.36	157.07	12.4	436155

Table 3. Pollutants concentrations in fumes, year 2016

Month	**CO (mg/Nm³)**	**NO (mg/Nm³)**	**SO_2 (mg/Nm³)**	**TOC (mg/Nm³)**	**HCl (mg/Nm³)**	**O_2 chimney (%)**	**Particula-tes (mg/Nm³)**	**Payload (m³/h)**
Min	10.96	41.85	16.79	0	0.36	12.52	0.36	34775.9
Average	14.19	81.35	20.99	0.13	1.24	13.02	0.86	37409.50
Max	18.89	103.08	22.58	1.28	5.46	13.82	1.45	39058.82
S.D.	2.24	16.05	1.55	0.37	1.49	0.44	0.38	1111.29
Tot	170.33	976.18	251.86	1.52	14.86	156.28	10.28	448913.98

Table 4. Pollutants concentrations in fumes, year 2017

Month	**CO (mg/Nm³)**	**NO (mg/Nm³)**	**SO_2 (mg/Nm³)**	**TOC (mg/Nm³)**	**HCl (mg/Nm³)**	**O_2 chimney (%)**	**Particula-tes (mg/Nm³)**	**Payload (m³/h)**
Min	11.74	118.13	15.72	0.06	0.96	13.71	0.86	36262.5
Average	8.39	92.58	11.03	0.00	0.00	12.29	0.4	21474.5
Max	20.58	131.68	22.14	0.25	3.38	15.95	1.36	41811.2
S.D.	3.37	13.22	3.84	0.08	0.92	0.96	0.35	5377.7
Tot	140.86	1417.57	188.59	0.690	11.49	164.53	10.29	435150.1

3.2 Waste

In the company under study, waste is the fundamental input for carrying out the entire production process. In particular, as mentioned above, incoming waste is in particular hazardous waste (hazardous and non-hazardous), mainly industrial, sanitary-hospital and port waste; however, all the individual waste classes that can be treated within the plant, are explicitly indicated in the AIA (Integrated Environmental Authorization) provision, and they are specified through the CER codes (European Waste Code), an identification code (effective from 1 January 2002) composed of six Figures that is assigned to each type of waste based on the composition and the process of origin. At the entrance the waste receives various checks, in particular for checking the correspondence to what was agreed in homologation in terms of type and quantity of waste, as well as to ensure that there are no radioactive components. Table 5 shows the quantities entering in the years 2015, 2016 and 2017.

It is clear, however, that the production process and the other activities carried out within the plant, in turn generate large quantities of waste. In the total amount of waste generated in the plant, most of the waste is incineration, that is:

- heavy ash and slag containing dangerous and not dangerous substances;
- dirt and rocks;
- light ash (irrelevant quantities).

In Table 6 we can see the quantities of waste generated in the three years of referencing, with the percentages constituted by the residues of incineration.

Table 5. Waste entering the plant in 2015, 2016 and 2017

	2015	***2016***	***2017***
Quantity (kg)	32750000	33676000	30327000

Table 6. Waste generated in the plant in 2015, 2016 and 2017

	2015	2016	2017
Quantity (kg)	17708786.2	17616851.5	10441239.5
Heavy ash and slag (%)	66.52	75.27	60.53
Dirt and rocks (%)	19.42	7.66	9.19

4. Result and discussion

Local governments ask to strictly respect the waste hierarchy, putting waste prevention first. In fact (www.rifiutologia.it):

- first, we must evaluate the possibility of re-using an object or a product to avoid it becoming waste (attention);
- if you can't go back to trying to recycle it (that is, you must recover the raw materials from the object that has become a famous refusal for a second life to the subjects);
- if it is no longer in the foreground for recycling, we move on to recovery of energy (waste-to-energy) and then to the landfill.

However, waste-to-energy is recognized as a necessary tool to progress towards a more sustainable circular economy, as it appears to avoid landfilling and generate energy (www.cor.europa.eu). In fact, by decreasing the volume of waste by up to 90%, landfill exploitation decreases considerably, and furthermore by incineration it is possible to dispose of waste with other biological, hygienic and sanitary risks (such as hospitals) (www.rifiutologia.it).

Although thermal destruction offers many advantages over other hazardous waste disposal conditions it can be considered a waste management factor, in the previous years the opposition of public opinion to the granting of new thermal destruction operations was strong. This is primarily because, as previously mentioned, the issue of incineration is a very sensitive issue because it is related to a perception of the excessive risk of the community due to the lack of information and a correct communication with the companies; but also because, information, protection problems, great cautions and a particular attention of the management that can be considered and proactive on the subject, cannot be limited to rationalize the regulatory limits but be really engage and innovate to protect the ecosystem.

The company takes the object of analysis regarding environmental implementation. The present experimental thesis makes an accurate quantification of the flows of materials and energy of GE.S.P.I. S.R.L., but the other side of environmental accounting is not analyzed, that is the one concerning the economic-financial aspect with the quantification of financial flows and environmental costs. It is therefore proposed to the company to proceed for the first time with a proactive logic to carry out a deepening of its environmental performance in relation to the financial aspect, between the flows of materials and flu in order to quantify in a clear and analytical way the links economic and consequently to implement a concrete environmental balance which on the basis of its characteristics may allow:

- constant monitoring and relative surveys of environmental performance;
- greater awareness of all company personnel;
- support for the implementation and renewal of environmental management systems;
- a better relationship with the competent institutions;
- an effective communication approach that is better towards the local community that allows coexistence and greater social acceptance of the company.

Finally, to achieve maximum performance on the last two points indicated, and therefore in general to improve and optimize relations and communication with stakeholders, in a complex socio-political action such as the one in which the company lives, the implementation is proposed. On the basis of the evidence presented in this study, of an environmental report, which as previously shown is an important tool to be approached to the environmental balance by reworking the data collected from it to make them optimal and effective for the purpose of external communication.

5. Conclusions

The proposed case study offers the necessary technical knowledge, with all the knowledge and skills, the possibility to implement an environmental and effective budget in order to obtain all the advantages demonstrated in a simple way that the use of environmental accounting tools it can lead to a company operating in continuous relation with the environment. Starting from this study, the company can then implement this tool that will be the basis for possible innovative activities and investments in environmental issues, such as the adoption of new certifications for the management systems of the environment and safety, the development of a communicative relationship with the community and local institutions and in-depth evaluation of the best plant investments with particular attention to environmental performance.

The tools used and proposed in the case study could (and should) be applied not only to the company being examined, but to the waste recovery / disposal sector, as for all companies, as already seen, an impacting sector and it enjoys little confidence from the public opinion, these instruments could represent, as well as the means useful for the correct management of the company for the efficiency of the productive, organizational and management processes, of the pledge and symbols indicative of the attention of the enterprises towards the welfare of society, and therefore of "bridges" between citizens and economic operators to improve social acceptability and the operating conditions of the companies themselves. If there are difficulties in adopting and implementing these tools, it is because first of all there is a strong lack of information on the part of companies (especially smaller ones) on the existence of such tools, on their functions and on their they boast; secondly because, despite these means continue to improve and spread among companies and public administrations, there are no general rules on implementable models, homogeneous information on their structure, and clarifications on contexts in which it is preferable to adopt them: all this entails the passage of a wrong message, so that these tools can be seen as a means still in. On the basis of these presuppositions, and therefore embryonic phase and therefore hitherto not very useful. of the advantages of these tools and of the problems in their adoption, a future institutionalization of the instruments in question is proposed, so that they can be made obligatory for the companies that work in contact with the ecosystem and can be dictated the univocal rules for their immediate and uniform implementation.

References

Dyson R.G., (2004), Strategic development and SWOT analysis at the University of Warwick, *European Journal of Operational Research*, **152**, 631–640.

Leanza A., Bonanno S., Suriano E., Amara G., Gigli C., (2017), The SWOT analysis applied to a high risk area as a strategy to increase sustainable local value chain, *Procedia Environmental Science, Engineering and Management*, **4**, 69-76.

Learned E.P., Christensen C.R., Andrews K.E., Guth W.D., (1965), *Business Policy: Text and Cases*, Homewood Publisher, United States.

Matarazzo A., Clasadonte M.T., Ingrao C., (2018), The (dominance based) rough set approach applied to air pollution in a high risk rate industrial area, *Environmental Engineering and Management Journal*, **17**, 591-599.

Web sites:

http://www.repubblica.it/ambiente/2016/07/06/news/ispra_rapporto_rifiuti_speciali-143534099/
http://rifiutologia.it/la-gestione-dei-rifiuti-italia/
https://cor.europa.eu/it/news/Pages/what-role-for-waste-incineration.aspx
http://rifiutologia.it/incenerimento-rifiuti/

Procedia
Environmental Science,
Engineering and Management
http://www.procedia-esem.eu

Procedia Environmental Science, Engineering and Management **5** (2018) (2) 93-99

22th International Trade Fair of Material & Energy Recovery and Sustainable Development, ECOMONDO, 6th-9th November, 2018, Rimini, Italy

TECHNIQUES OF REUSE FOR SLAGS AND FLAKES FROM THE STEEL INDUSTRY: A CIRCULAR ECONOMY PERSPECTIVE *

Piero Guadagnino[1], Lorenzo Cantone[1], Pierpaolo Conte[1], Giorgio Pocina[1], Agata Matarazzo[1], Alberto Bertino[2]**

[1]Department Economics and Business - University of Catania, Corso Italia 55 – 95129, Catania (Italy)
[2]Acciaierie di Sicilia S.p.A, Via Passo Cavaliere 1, 95121, Catania (Italy)

Abstract

The steel industry has always been characterized by the model of a linear economy as industrial waste was considered waste to be dumped in landfill sites. This principle is opposed to the circular economy model, defined as an economic system where companies that adopt it reuse waste materials coming from a production cycle in any subsequent production cycles. In this regard, waste from steel production is the subject of this paper: more in-depth, the reuse of flake obtained during the flaking of the billets, furnace slag and ladle slag will be dealt with. This analysis has been carried out in collaboration with the Acciaierie di Sicilia S.p.A. that currently produce eco-sustainable bars, through the electrofusion of ferrous scrap. The objective of this paper is to identify possible alternatives for reusing the furnace slags, for the ladle slags and for the flakes. This would lead to economic advantages deriving from the conversion of landfill costs to revenues obtained from the sale of waste and to increase of the environmental commitment of the steel industry towards the green economy.

Keywords: Circular economy, electric furnace, flake, slag, steel

1. Introduction

Until the 1970s, the extent of the damage generated by waste released into the environment by industries was ignored. Industries adopted an unsustainable model of linear economy and environmental waste pollution into the environment was the main cause of biosphere destruction. Subsequently, the research conducted by the European Commission contributed to the diffusion of a new waste management model, which allowed for the

---

[*] Selection and peer-review under responsibility of the ECOMONDO

[**] Corresponding author: e-mail: guadagninop@gmail.com

extension of the useful life of the products, as well as the reduction of industrial waste released in the ecosystem. This model, called "the circular economy", came from social awareness that the Earth's resources are limited, as well as the space where waste can be placed is limited. The circular economy aims to increase the efficient use of resources, with particular attention to urban and industrial waste, to achieve a better balance between economy, environment and society (Ghisellini et al., 2016). This represents the most recent attempt to conceptualize the integration of economic activity and environmental wellbeing in a sustainable way. It is based on the concept according to which waste from a production cycle is reused as secondary raw materials in a subsequent production cycle (Murray et al., 2017). The use of the second raw material is also convenient since it allows to reduce costs from extracting raw materials from the Earth.

In the collective imagination, the iron and steel industry are one of the most responsible for the quantity of waste introduced into the environment and for the quantity of fumes released into the atmosphere. Contrary to this, more and more steel mills have shown interest in the issue of eco-sustainability in recent years. More in-depth, the management of slags and flakes from steel industry becomes increasingly relevant and, simultaneously with the development of the circular economy model, these two elements have lost the negative meaning of waste, gaining the meaning of resource for a new production cycle. In fact, transforming them into another form to be reused is not only essential for the protection of the environment, but it is also a way to obtain new resources at low cost (Das et al., 2007).

The most important producer of steel in the world is China, which alone generates about 50% of the steel on the market. This gives to China a significant responsibility for waste and pollution created during production processes. Currently, China reuses only 22% of the waste it produces, very far from France, Japan, the USA, and Germany that reuse almost 100% of the waste produced. This has involved an increase in research on the methods of re-using steel waste in recent years (Yi et al., 2012). Companies of steel industry who decide to invest in the green economy, reusing their waste or giving it to other industries, have first of all economic objectives: costs of the landfill are translated both in reduction of expenditure for the purchase of raw materials, through the reintroduction of waste upstream of its production cycle, as well as in revenues resulting from the sale of wastes to other parties. These companies also have environmental and marketing objectives, as a company which obtains certifications is a company that always tends to reduce its environmental impact to a minimum, as well as improving their reputation in the eyes of suppliers, customers, investors and institutions. Furthermore, environmental certifications must not be underestimated because, through these tools, a company defines its goals to continuously improve its operational efficiency, to attract new market opportunities and, in this way, it is subject to continuous monitoring of compliance with the rules.

The objectives of this research are to propose valid re-use alternatives for electrical furnace slags, for ladle furnace slags and for steel flakes. The paper must take into account the methods of reuse already implemented by Acciaierie di Sicilia S.p.A. to achieve this objective, proposing to the company solutions that have been tested in recent years in other parts of the world.

2. Material and methods

Slags and flakes are solid wastes from steel production. Slags are obtained during the melting of wrecks in the furnace and they are mainly composed of SiO_2, CaO, Fe_2O_3, FeO, Al_2O_3, MgO, MnO, P_2O_5. Steel slags are generally considered non-hazardous wastes due to the low leavability of their residues. The waste can be classified into electric furnace slags and ladle furnace slags (Baciocchi et al., 2009). Steel flakes, on the other hand, come from the steel rolling (which can be hot or cold) and they are composed of 95% iron oxides.

2.1. Electric furnace slags

The analysis of the chemical and physical characteristics of steel slags is strictly related to the methods of reuse of the same (Tables 1, 2).

Table 1. Chemical composition of steel slags

Oxides/%	***CaO***	***SiO_2***	***Al_2O_3***	***Fe_2O_3***	***FeO***	***MgO***	***MnO***	***P_2O_5***
Electrical Furnace Slags	30-50	11-20	10-18	5-6	8-22	8-13	5-10	2-5

Table 2. Characteristics and applications of steel slags

Characteristics	***Applications***
Hard, wear-resistant, adhesive, rough	Aggregates for road and hydraulic construction
Porous, alkaline	Waste water treatment
FeOx, Fe components	Iron reclamation
Cementitious components (C_3S, C_2S and C_4AF)	Cement and concrete production
Fertilizer Components (CaO, SiO_2, MgO, FeO)	Fertilizer and soil improvement

2.2. Utilization for road and hydraulic construction

The high density, the high level of resistance and abrasion, as well as the rough structure qualify steel slags among the best construction materials for hydraulic engineering purposes. Since 1993 the Nippon Slag Association has been involved in the research on application technology for the use of electric furnace slags as material for port construction. In 2008, it published the "Guide to the Use of Steelmaking Slag in Port and Harbor Construction "(Yi et al., 2012). Electric furnace slags also have a high resistance to friction and abrasion, and this allows their use not only in the surface layers of the floors, but also in the surface layers of the asphalt. In Japan and Europe, almost 60% of slags is used in road engineering.

Asphalt composed by slags was placed on the highway between Wuhan and Huangshi and, after two years of monitoring, the results and performance of the asphalt were excellent. Furthermore, in recent years research in China has led to the conclusion that electric furnace slags flooring has even better characteristics than traditional asphalt (Yi H. et al., 2012).

2.3. Utilization for materials of waste water treatment

The application of steel wastes in the waste water treatment has received intense attention in recent years. In fact, some experiments have shown how steel slags can set in motion absorption processes for some water polluting substances. For example, Chamteut et al. (2012) demonstrated that slags could be used as a low-cost adsorbent for arsenic in aqueous system, showing 95–100% removal efficiency. Shi et al. (2011), on the other hand, has studied the absorption of mercury into sea water by slags. Furthermore, the combined use of slags and H_2O_2 can decompose organic pollutants, due to the ferrous ion produced by the FeO released thanks to the reaction with hydrogen peroxide (Yi et al., 2012).

2.4. Utilization for production of cement and concrete

If ground, electric furnace slags are transformed into fine powder, they can be used as an additive for cement and concrete. Feng et al., (2011) has mixed the steel slag powders with fly ash and cement clinker, forming a composite cement, and Feng discovered that the porosity of the cement can be reduced thanks to the use of slag powders, that increase its consistency. The pulverization of steel slag is convenient both for low energy consumption and for the low grinding index. It has been observed that concrete made of steel slag powders has a compressive strength from 1.1 to 1.3 times more than common concrete. Ducman et al., (2011) produced refractory concrete during an experiment, using electric furnace slag as an additive. It has been noted that if the waste reaches a temperature of 1000 ° C, the final product consisting of the refractory concrete has mechanical properties comparable to those of the concrete produced through bauxite (Yi et al., 2012).

2.5. Application in agriculture

Steel slags, containing components such as CaO, SiO_2, MgO, FeO, MnO e P_2O_5, can be used for a wide range of agricultural purposes: above all, the alkaline property is noteable, useful for correcting the acidity of soils. In developed countries such as Germany, USA, France and Japan, steel slag is used for the production of siliceous fertilizer and micronutrient fertilizer (Yi et al., 2012).

2.6. Ladle furnace slags

Natural spelling - clayey soil have often to be stabilized by mixing them with materials as cement and lime, so that they acquire the necessary properties for public works. Ladle furnace slags can be used for this purpose and it was studied that the behaviour of the soil composed by slags is similar to the behaviour of the soil composed by lime or cement (Manso et al., 2013).

2.7. Steel flakes

Until a few years ago, steel flakes were considered unreusable wastes. After having studied their use in the constitution of iron alloys and in the production of cement, it has been discovered that the lamination flakes, composed of about 70% of iron oxides, can be reused also in the production of pellets (Table 3). In the experiment, flakes were reduced to a size of about 40 μm, then they were mixed in magnetite concentrations. Subsequently, bentonite (with binder function) was added, 0.8% in each mixture.

Table 3. The chemical composition of steel flakes in weight per cent

Component	***Total iron***	***Elemental iron***	***Fe^{+2}***	***Fe^{+3}***	***Cu***	***Mn***	***Si***
Content, wt%	71.06	1.15	39.06	30.85	0.35	0.67	0.22

Three batches were prepared, one of which without lamination flakes, so that the pellet consisting essentially of magnetite concentrate could be evaluated. The operation was carried out in a 40 cm-diameter multipex pelletizing disc by adding water to the mixture.

The produced pellet was then dried a first time at 110 ° C for ten hours; then it was dried again at 1250 ° C for one hour. Finally, the pellet was subjected to a crushing and fall test from about 50 cm in height, where the number of falls necessary for the fracture of the product was recorded (Şeşen et al., 2016).

3. Case study: Acciaierie di Sicilia S.p.A.

The company "Acciaierie di Sicilia S.p.A." is located in the industrial area of Catania, and it is a member of the "Alfa Acciai" Group. Thanks to its geographical position, the company represents a valid point of reference for the southern Italian market, as well as for exports to the Mediterranean countries. The production cycle begins from wrecks, the fundamental raw materials for the steel mill, which are first separated and classified, then refined in a 70-ton electric oven. Here, electric furnace slags are produced, consisting of complex solutions of oxides, and to a lesser extent of sulphides and phosphates, which are formed in all the processes of treatment of ferrous alloys in the liquid state and which float on the metallic bath. They are sold by the company to third parties and then they are reused both as road surface and for the construction of asphalt. After the melting of wrecks, the continuous casting of the molten steel produces billets with a square section of 130 mm per side and 11 meters of length, intended for hot rolling, occurs through a group of rough and intermediate cages. The rolling phase determines the formation of the flakes, collected, sold and reused as additives in the production of special cements. They are also sold to other steel mills, which reuse them for the furnace feeding, an opportunity that cannot be exploited by Acciaierie di Sicilia SpA, which uses an electric furnace. Ladle furnace slags, on the other hand, are obtained by casting cast iron into a ladle. This type of slag is sent to recovery plants.

The steel mill, in addition to representing an excellence in terms of eco-sustainability for Sicily is by far the most proactive steel industries in Europe. This result was achieved thanks to the large investments made for the construction of a new plant for collecting and removing dust from the melting furnace, in August 2010. It is characterized by a filtering area of 12,000 m^2 and it is able to reach minimum levels of emissions, well below the legal limits. Acciaierie di Sicilia S.p.A. mission consists not only in obtaining a product of the highest quality, but also in environmental sustainability: the two conditions are achieved together through the production of eco-sustainable steel of the B450C S type, highly performing in relation to the anti-seismic behavior of structures.

The company has confirmed its commitment to the green economy for many years, obtaining environmental certifications such as EN ISO 14001: 2015, which allows the company to reduce its CO_2 emissions by 40%, water and energy respectively of 14 % and 20%, as well as allowing a better awareness of waste management (Milazzo et al., 2017). Another important certification obtained by Acciaierie di Sicilia S.p.A. is the Environmental Product Declaration (EPD), which, besides being a useful safeguard for the protection of the consumer, is also a valid support tool for the decisions made by the management, in order to implement actions that can minimize the environmental impact during all phases of the production cycle (Palmieri et al., 2017). Other certifications achieved by the company are ISO 14025, LCA, SUSTSTEEL.

4. Results and discussion

4.1. Electrical furnace slags

The various technologies for the reuse of the furnace slags described in this paper demonstrate how these products were considered as wastes until recently. Indeed, furnace slags are versatile resources, which can be employed in different uses based on the constituent element that must be exploited. Some of these methods of re-use may represent a starting point to work on for future technologies for Acciaierie di Sicilia S.p.A. The use of slags in the production of agricultural fertilizers differs from the other methods: it was launched in China, where the first steel slags fertilizer program was implemented by the joint venture established in 2011 by Taiyuan Steel Group and Harsco Corporation.

Through the joint venture, which will end in 2036, Harsco Corporation will apply its separation technologies to extract some useful metals from the waste produced by Yaiyuan Steel Group: Harsco's separation processes recover over 99.8% of all metals from slags of stainless steel and also give rise to a product rich in calcium silicate that has shown significant benefits for agricultural productivity.

4.2. Ladle furnace slags

After many experiments, it was observed that the mixtures of clayey soils and ladle furnace slags have resulted in improvements to their bearing capacity in relation to the natural ground soil and the results are very similar to those obtained for the stabilization of soils with lime. This method of reuse is related to the production of asphalt and road sub-base already put in place by Acciaierie di Sicilia S.p.A. for the utilization of the electrical furnace slags.

4.3. Steel flakes

The experiment on the re-use of flakes in the production of pellets showed that, following the pellet drop test, the number of falls necessary for the fracture of the product decreased with the increase in the quantity of lamination flakes present in the pellet itself. In particular, the batch of pellets composed of 50% flakes has resisted 5 falls from a height of 50 cm before fracturing. A similar correlation was also noted in the crushing test, where the same batch of pellets resisted up to a force of 9 N, less than the lot consisting of 40% flakes. This is a significant result because, depending on the industrial use that the pellet could obtain, the most efficient results were recorded with pellets containing a percentage of lamination flakes ranging from 40% and 60%.

It is important to specify that the lamination flakes cannot be reused in plants that use the electric oven, due to the absence of the sintering function of the plants themselves. This use is related to the method already adopted by Acciaierie di Sicilia S.p.A. related to the production of ferrous alloys, so this is not a technology unknown to the company. Despite this, the use of flakes in pellet production could represent a future opportunity, although research on this topic is still in its infancy and only a few industries adopt this method of reuse.

5. Conclusions

Among the alternatives studied in this research, those relating to the electric furnace slags are still in an embryonic phase and they need time to be able to be more concretely explored. On the contrary, the most technologically advanced methods of reuse, such as the use of slag for the production of asphalt or steel flakes for the production of iron alloys, are reuse methods already adopted for some time by Acciaierie di Sicilia S.p.A.

It can be said, for this reason, it can be said that the company is among the most proactive in Europe in relation to environmental management problems, as well as it is a leader in the management and research of alternative solutions for the reuse of slags and steel flakes from steel mills.

References

Baciocchi, (2009), Influence of particle size on the carbonation of stainless steel slag for CO_2 storage, *Energy Procedia*, **1**, 4859-4866.

Chamteut, (2012), Removal characteristics of As (III) and As (V) from acidic aqueous solution by steel making slag, *Journal of Hazardous Materials*, **213-214**, 147-155.

Das B., (2007), An overview of utilization of slag and sludge from steel industries, *Resources, Conservation and Recycling*, **50**, 40-57.

Ducman V, Mladenovic A., (2011), The potential use of steel slag in refractory concrete, *Materials Characterization*, **62**, 716-723.

Feng CH, Dou yan, Li DX., (2011), Steel slag used as admixture in composite cement, *Journal of Nanjing University of Technology*, **33**, 74-79.

Şeşen F.E., (2016), A study on usability of mill scale in pellet production, *Metallurgical and Mining Industry*, **5**, 110-119.

Ghisellini P., (2016), A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems, *Journal of Cleaner Production*, **114**, 11-32.

Manso J.M., (2013), The use of ladle furnace slag in soil stabilization, *Construction and Building Materials*, **40**, 126-134.

Milazzo P., (2017), The new ISO 14001:2015 standard as a strategic application of life cycle thinking, *Procedia Environmental Science, Engineering and Management*, **4**, 119-126.

Murray A., (2017), The Circular Economy: An interdisciplinary exploration of the concept and application in a global context, *Journal of Business Ethics*, **140**, 369-380.

Palmieri M., (2017), Environmental product declaration as a strategy to apply bio economy in the sustainable steel sector, *Procedia Environmental Science, Engineering and Management*, **4**, 149-154.

Shi Y.D., Wang J., Tan P.G., (2011), Study on the treatment of mercury in sea water with steel slag, *Journal of Qingdao Technological University*, **32**, 80-83.

Yi H., (2012), An overview of utilization of steel slag, *Procedia Environmental Sciences*, **16**, 791-801.

Procedia
Environmental Science, Engineering and Management
http://www.procedia-esem.eu

Procedia Environmental Science, Engineering and Management **5** (2018) (2) 101-104

22th International Trade Fair of Material & Energy Recovery and Sustainable Development, ECOMONDO, 6th-9th November, 2018, Rimini, Italy

Re-DUST: WASTE FROM DUST *

Matteo Lombardi **

Technical manager and Environmental Engineer at Ellequadro Ingegneria S.r.l.s., Via E. d'Onofrio 57, 00155 Rome - Italy

Abstract

The "Re-dust" project was born from the idea of the Research & Development Team of Ellequadro Ingegneria srls, a company successfully present in the design, authorization and development of companies operating in the waste sector. The company wanted to focus attention on the product fractions within the fraction of undifferentiated waste produced in domestic homes. Attention was paid to the percentage share deriving from cleaning and daily household sweeping.
The design concept lays its foundations on the theory of recycling as a source of innovation, energy saving and social well-being and aims to identify every single undifferentiated fraction and determine a new use.

Keywords: environmental impact, LCA, recovery, special waste

1. Introduction

The "Re-dust" project was born from the idea of the R & D team of the company Ellequadro Ingegneria srls, a structure successfully presents in the design, authorization and development of companies operating in the waste sector (http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=3734&docType=pdf).

The main objective of this study is to analyze the environmental sustainability of this new waste dump to break it down from the fraction of the waste collected as undifferentiated and be able to determine an effective recovery and another recovery chain (Lacy and Rutqvist, 2015; Porter and Kramer, 2011). This fraction has not been specifically registered and the same could in any case be associated with the street sweeping fraction that already

* Selection and peer-review under responsibility of the ECOMONDO
** Corresponding author: e-mail: federica.amato.76@gmail.com

determines specific collection fractions that are sent to suitable plants other than those that treat the undifferentiated waste. In fact the powder is then probably dispersed during the plant handling of waste being powder and then finishing in the various fume treatment systems going to increase the special waste produced (Lombardi et al., 2017).

This work has been developed in three main parts:

• selection of effective management of waste deriving from the cleaning of houses;

• evaluate the differences between the waste management systems in progress and the new system;

• analysis of the results, conclusion of the conclusion and formulation of recommendations for policy makers and decision makers in the field of solid urban waste management.

2. Materials and methods

This paper presents an important study on the environmental impact of dust produced inside homes. The production was calculated on civil dwellings using commercial robots equipped with a predetermined volume of the loading tank and thus determining daily the weights of the fraction of powder produced (Tables 1 and 2).

Table 1. Results on dust production and collection

Description	***Value***	***UM***
Living area	100	mq
Dust collector	0.01	m^3
Weight (solo Robot)	6.86	gr/d
Weight	0.0069	kg/d
Surface clean from Robot	68	mq
Density	0.69	kg/m^3
Weigh dust	2.50	kg/year
Linear density	0.00010	kg/m^2

Table 2. Description of yearly dust production

Description	**Value**	**UM**
Waste production year	487	kg/ab/year
Dust Production	2.50	kg/ab/year
Undifferentiated waste	33	% Total
Undifferentiated waste	160	kg/ab/year
% dust	1.6%	% of undifferentiated

After these measurements, the main fractions present in the sample were analyzed and showed the presence of the following materials (Table 3 – PCS from internet research). From the compositions emerged different materials that have an interesting average of higher calorific value that is possible to see in the Fig. 1 and Fig. 2.

3. Results and discussion

This paper presents an important study on the environmental impact of dust produced inside homes. The production was calculated on civil dwellings using commercial robots equipped with a predetermined volume of the loading tank and thus determining daily the weights of the fraction of powder produced.

Table 3. ®PCS from internet research

Description	*PCS®*	*um*
hair	np	kcal/kg
part of skin	np	kcal/kg
mites	np	kcal/kg
part of textile	4998	kcal/kg
crumbs	2856	kcal/kg
paper	4046	kcal/kg
plastic	10980	kcal/kg
average	5720	kcal/kg

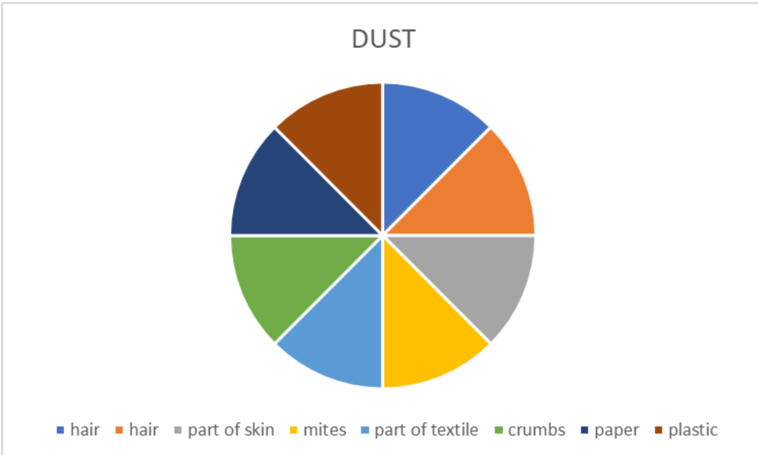


Fig. 1. Dust composition

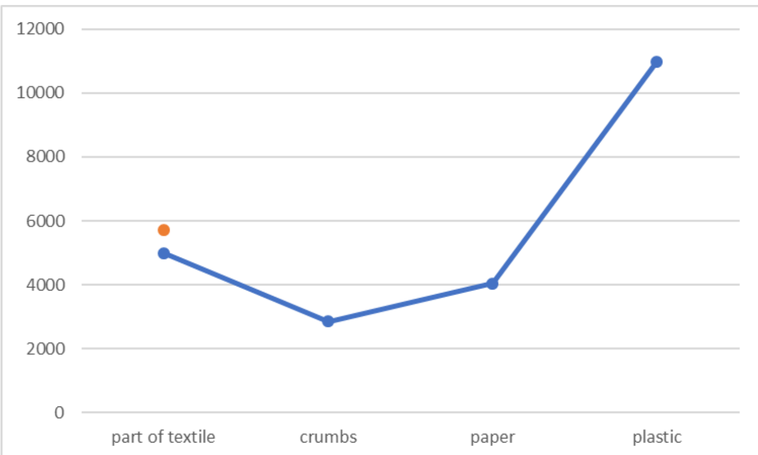


Fig. 2. PCS of dust

Considering the results that we show before, it's incredible thinking that we can produce so many dusts and until now:

1. dust doesn't exist;
2. dust don't have a real cost (we can imagine that now we pay this with indifferentiable waste);
3. actually, this waste became a waste of the plant;
4. for recovery it the common system are made with a water.

4. Concluding remarks

We firmly believe that differentiating the undifferentiated waste, can help the reflection to develop new technologies and to give new possible entrepreneurial activities. We have seen that the dust if managed would even lead to an increase in recycling of more than one and a half points leading to further growth and environmental benefit. This gives us the incentive to reflect on how even the smallest nuances in waste management need to be explored to determine possible solutions and possible future scenarios.

References

Lacy P., Rutqvist J., (2015), *Waste to Wealth: The Circular Economy Advantage*, Palgrave Press, Macmillan, UK.

Lombardi M., Fiorani G., Lupi F., (2017), The Ricigen for Eco-Innovation: energy from waste without cost, *Procedia Environmental Science, Engineering and Management*, **4**, 85-90.

Porter M.E., Kramer M.R., (2011), Creating Shared Value, Harvard Business Review, On line at: https://hbr.org/2011/01/the-big-idea-creating-shared-value.

Procedia
Environmental Science, Engineering and Management
http://www.procedia-esem.eu

Procedia Environmental Science, Engineering and Management **5** (2018) (2) 105-113

22th International Trade Fair of Material & Energy Recovery and Sustainable Development, ECOMONDO, 6th-9th November, 2018, Rimini, Italy

AN APPROACH TO OPTIMIZE CHEMICAL PARTIAL STABILIZATION OF HAZARDOUS WASTES*

Giuseppe Mancini **, Mattia Cirasa

Department of Electric, Electronic and Computer Engineering, University of Catania, Italy;

Abstract

The issues of the treatment of hazardous wastes cannot be solved easily and must be properly faced to avoid management and legal problems. In this work the stabilization process of different hazardous wastes containing metals was investigated at lab and full scale to understand if a "common approach" can be defined, at least for some categories of wastes, in order to provide useful information to the managers of waste treatment plants on the wastes that can be more efficiently and safely treated together within the same "mix". Results indicated that, for the investigated metals, most of the wastes shows a similar predictable pH-dependent behavior, with the exception of the molybdenum. For waste containing this metal a different approach is proposed in order to achieve the partial stabilization goal. Specifically, the efficiency of using of zero valent iron and the sodium sulphate was confirmed by experimental results indicating that this approach can be used successfully. However, the narrow border of economic convenience in applying this treatment to such specific typologies of wastes strictly depends on the current market scenario.

Keywords: Stabilization, metals, treatment, landfill, molybdenum

1. Introduction

Waste characterization for the proper final disposal selection is regulated in Italy by DM 27/09/2010 so to ensure that the landfill receiving the waste has no environmental impact in the surrounding area, especially with regards to groundwater contamination. However, also hazardous wastes can be disposed into not-hazardous waste landfill if the waste are properly treated before the disposal so to respect some specific conditions regulated by Art. 6 of DM 27/09/2010 (now updated by DM 24.6.2015).

---

* Selection and peer-review under responsibility of the ECOMONDO

** Corresponding author: e-mail: federica.amato.76@gmail.com

The main requirement is that the eluate from the leaching test on the treated waste (Gerassimidou and Komilis, 2015) respects the limits of table 5a of the DM 27/09/2010. Other important requirements for the stabilized and not reactive waste to be disposed-off in a not-hazardous waste landfill are:

- A total organic carbon concentration (TOC) less than 5%;
- A pH higher than 6;
- A dry matter content higher than 25%;
- The treated waste has to be subjected to appropriate geotechnical tests that demonstrate adequate physical stability and load capacity.

One of the potential treatment, able to achieve all these requirements, is the stabilization or partial stabilization of the waste consisting in creating a mixture with additives defined as ‘chemicals’ (Basegio et al., 2006), which have the main purpose of reducing the release in the eluate of the target pollutants and so its potential impacts.

There is only one specific legal prohibition for this treatment, as stated by Article 6, co. 2 of Legislative Decree 36/2003 and Directive 1999/31/EC that forbids to mix the wastes with the sole purpose of reducing the contaminants’ concentrations. This prohibition prevents the mixing of waste with other substances to reduce the concentration of contaminants in the eluate from the treated waste and therefore to achieve the compatibility with Table 5a by "mere dilution".

Waste stabilization processes) are widely used in the treatment of a large variety of industrial hazardous wastes such as by-product of industrial production, exhausted catalysts, incineration products etc. (Bernstein et al., 2002; Sun et al., 2001; Tsai et al., 2009; Yuan et al., 2010). On one hand, these processes allow to considerably reduce the release to the environment of the polluting substances present in the waste through the formation of insoluble compounds that create a stable polymeric or crystalline structure capable of trapping the toxic elements (Conner and Hoeffner, 1998); on the other hand, they improve the physical characteristics of the material and therefore its manipulability, lowering the risks for the operators and the environment (Hot et al., 2016; Sebag et al., 2009). The wide heterogeneity of wastes of different origin, composition and response to the treatment (Youcai et al., 2002), makes particularly difficult for the operators to accurately identify the multiple reactions that takes place within the treatment process (Janusa et al., 1998). As a consequence, there is no definitive scientific and technical literature that regulates the percentage of chemicals to be used as the variety of wastes makes a schematic procedure complicated to be uniquely defined (Malviya and Chaudhary, 2006; Shi and Spence, 2010).

pH is however fundamental to understand the chemical behavior that occurs when a mix is created (Guo et al., 2017). Generally, the mixes achieve a high alkaline pH that rarely fall below 12. Most of the metals react positively to this high increase in pH (Baba et al., 2010; Izquierdo and Querol, 2012, Oresanin et al., 2007). On the contrary, it is necessary to correct the pH of the waste if it is too low, since waste with a pH less than 6 is not allowed in the landfill. An exception is represented by wastes containing Molybdenum as in the case of some by-products of industrial production, exhausted catalysts, incineration products, etc.

Molybdenum responds to the increase in pH becoming more soluble; this behavior causes a serious issue to deal with when wastes containing molybdenum have to be treated together with other classes of wastes which responds better to alkaline condition.

In literature various treatments applying additives have been investigated such as Portland cement, Cement kiln dust, Fly ash (e.g. Class F and C pozzolanic fly ashes), Lime (e.g. quicklime, hydrated lime, lime kiln dust) Slag (e.g. ground granulated blast furnace slag), Organoclay, Activated carbon, Cement-based proprietary mixtures, Silicate, phosphate, and sulfate (Bernstein et al., 2002; Gong and Bishop, 2003), among which the ones based on cement and lime, appears to be the most widespread and economically convenient. The amount of additives can be quite relevant, the type and the percentages being considerably variable from case to case, depending on the characteristics of the pollutant, its concentration and the chemical-physical characteristics of the waste (e.g: granulometry, pH, humidity etc).

As frequently reported (Jijo and Kasinatha Pandian, 2016), several wastes can also be used as an additive, as in the case of combustion ash which, thanks to its high concentration of active oxides, can facilitate the stabilization goals. The additives used to stabilize a single waste within the mix, should not exceed 25%, to limit the dilution undesired effects.

The objectives of this work can be summarized as follow:

- To verify which categories of wastes/polluttants can be considered sensitive to the same treatment conditions;
- To investigate some alternative treatment conditions for those waste having pollutants which show different behavior (e.g. wastes containing molybdenum) and not respond positively to the classic high-alkaline approach of stabilization.

2. Material and methods

2.1. Wastes and mixture preparation

A mix is here defined as a mixture between one or more types of wastes with the addition of additives. The purpose of creating a mix is to obtain a reduction in the concentration of pollutants (heavy metals in particular) following the leachate test. Generally, a mix is composed of waste considered dangerous, which are those with a concentration of heavy metals in the eluate from the leaching test higher than the legal limit, provided for in Table 5a of Article 6 of the Ministerial Decree of 27 September 2010. The lab mix is created on the basis of 100 g.

Twelve different mixed were analyzed having different target contaminants including Sb, Mo, Cu, Zn and Ba respectively. Once the composition of the mixture is proposed, its components are weighted individually and mixed manually in a baker, by means of a glass rod. In this mixture consisting of the waste and the additives (lime and ferrous sulphate), water must be added to ensure that all the needed reactions take places.

In order to reduce the gap between the laboratory results and the full scale treatment in the plant, leachate from the landfill where the same stabilized waste is disposed was added to the mixtures, as in the full-scale treatment conditions. The addition of leachate allows all the components of the mix to react but attention must be payed in order not to worsen the consistency of the mix so to compromise its handling within the plant. The amount of leachate added is closely related to the initial humidity of the mixture both in the full scale treatment and in the lab scale experiments;

A two-hour maturation time is necessary to let the mix maturing and to allow all the reactions to reach an equilibrium. It was observed that a longer wait does not entail any improvement in the stabilization process;

2.2. Stabilization tests on wastes containing molybdenum

Six mixes were specifically prepared for wastes containing molybdenum. Fly ashes from incineration of industrial wastes characterized by a concentration of molybdenum in the eluate of 1,7 mg/l were treated using as additive the same percentage of sodium sulphide (1%), and percentages of zero iron valence variable from 0.5% to 1%.

2.3. Leachate analysis

The sample of the waste was placed for a 24-hours in an overhead shaker set at a speed of 9 rpm. The sample was then acidified with 65% purity nitric acid; 100 µl of 65% nitric acid were added to both tubes and 200 µl of internal standard were added to the first tube. An ICP mass (Perkin Elmer nexION 350x) was used for heavy metal concentration analysis.

5. Results and discussion

The main characteristics of a mixture of two hazardous wastes containing both Molybdenum and Antimony respectively are reported, in Fig. 2, as a first example of the procedure. Both the elements cause a release in the leachate in excess with respect to the corresponding legal limit.

Table 1. An example of mix composition containing three wastes with different target contaminant

Waste	*Target contaminant*	*Concentration in the eluate*	*Law Limit*
R1 Carbonate sludge (120814*)	Antimonium	5.64	0.07
R2 Exhaust catalysts (160807*)	Molibdenum	1.3	1
R3 Sludge (100120) as additive			
As Additive (Lime and Iron sulfate)			

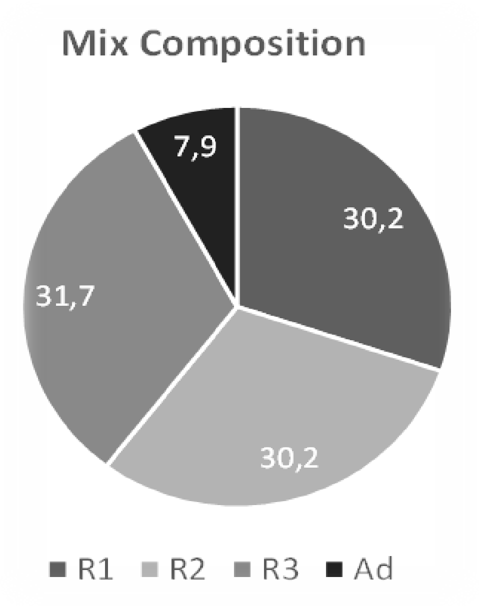
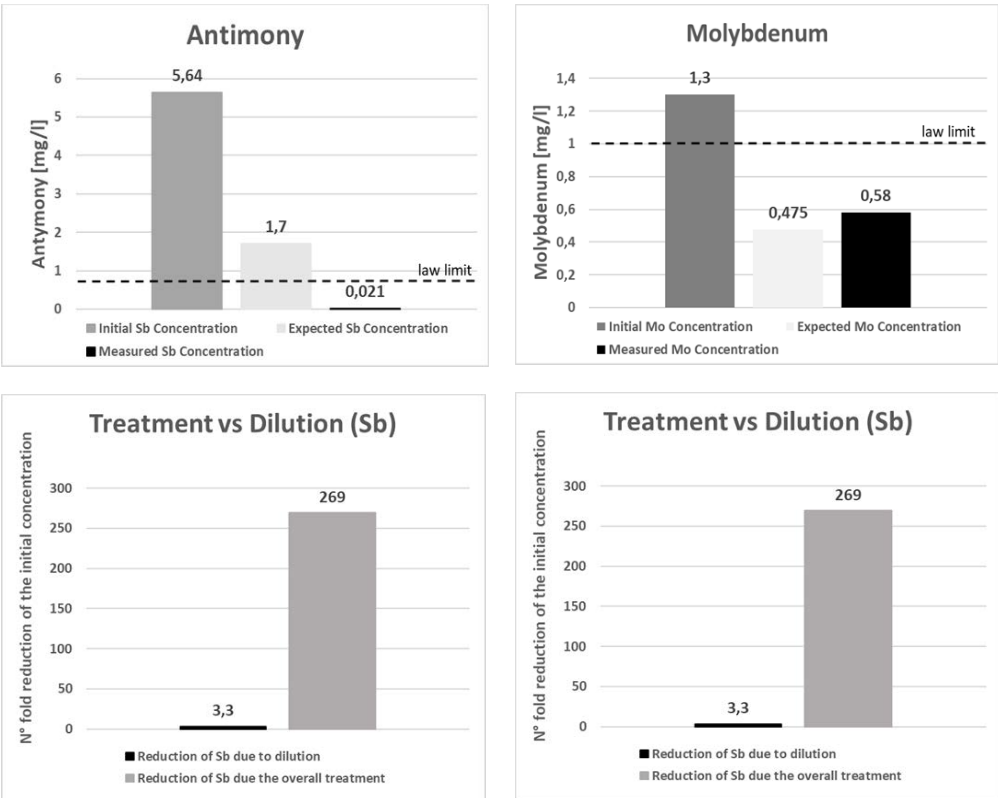


Fig. 1. Mix composition of the three wastes and additives

The calculation of the single contaminant concentration (i.e. Antimony and Molybdenum) in the whole mix, is performed as a simple weighted average of its concentration in each individual waste. In the weighted average additives have been considered, as they contribute to the 'dilution' of the contaminant. While it is evident that antimony in the mixtures has responded well to the treatment, since its reduction is 81 times greater than that one due to the simple dilution in the case of Molybdenum it is evident how the treatment is not only being ineffective, but even detrimental.

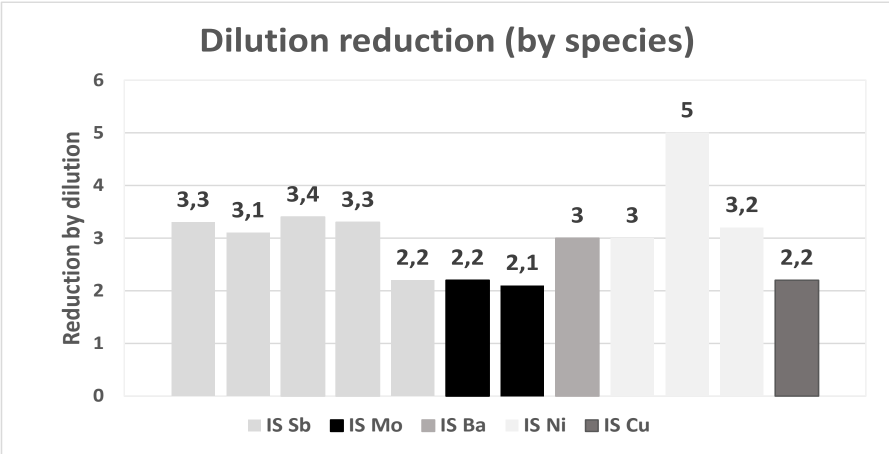
Considering the dilution factor, the mix has obviously made the molybdenum leachable, thus increasing its concentration in the eluate of the test so remaining below the legal limit (1 ppm) only as an effect of the dilution (Fig. 2).



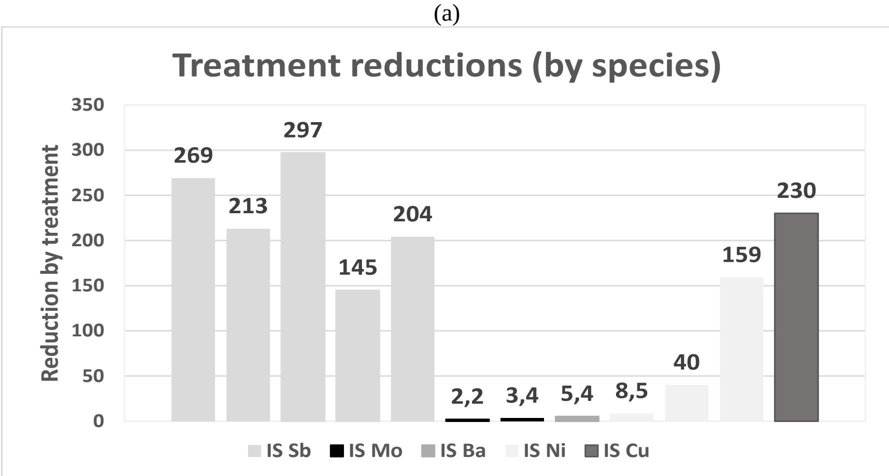
(a) (b)

Fig. 2. Different stabilization effects and comparison with concomitant dilution factors for the target contaminants contained in the examined mix: (a) Antimony; (b) Molybdenum.

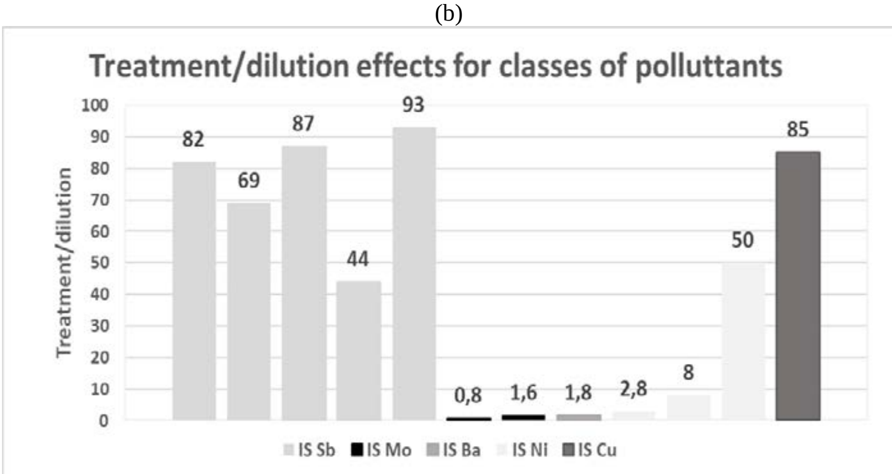
Fig. 3 shows the results of the stabilization treatment for the 8 different mixes, evaluating and comparing the effect of the dilution versus the treatment for each target pollutant having the concentration in the eluate of the original wastes higher than the legal limit.



(a)



(b)



(c)

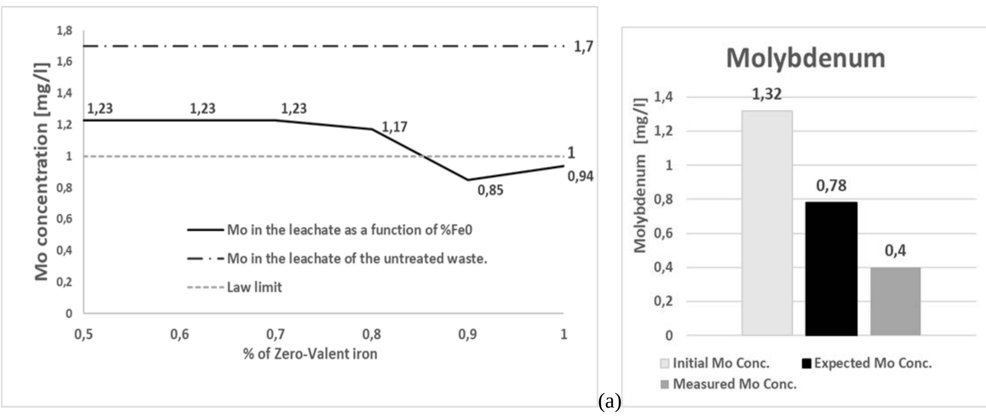
Fig. 3. Separate effects of the dilution (a) and the treatment (b) for different mixes and their comparison by ratio

Three main behavior can be identified for different target contaminants. For those mixtures containing metals such as Antimony and Cu the treatment is significantly effective compared to dilution whose effects are limited to a range between 2 and 5 folds. The graph shows that the antimony has substantially the same trend in all the mixtures, with reductions that can exceed even 100 folds. These wastes react well to the addition of lime and ferrous sulphate. For waste containing molybdenum the effects of the treatment is questionable: in one mixture, it is clear how the decrease in concentration is due mainly to dilution while in the other investigated mixture the result of the treatment is pejorative as it slightly increases the solubility of the metal. The stabilization with lime of wastes contain of molybdenum is two orders of magnitude less effective than that one of the antimonies. Molybdenum responds to the increase in pH becoming more soluble; this behavior causes a serious issue to deal with when waste containing molybdenum have to be treated together with other classes of wastes which responds better to alkaline condition.

A third behavior is shown by the mixtures containing wastes contaminated by nickel whose results show different responses to the treatment achieving a ratio between stabilization and dilution effects ranging between 2.8 and 50. In any of these cases, the effect of the treatment is higher than the one caused by simple dilution. The lower treatment effects are obtained with lime and ferrous sulphate, while, in the last mixture, where cement is used the reduction on nickel leaching is significantly lower.

With respects to the six mixtures containing Molybdenum results confirmed as the addition of zero valent iron and sodium sulphide can decrease the concentration on the molybdenum in the eluate. Fig 4a shows the trend of molybdenum release in the leachate as a function of the percentage of zero iron utilized in the mix and the comparison with the law limit (1 mg/l). Percentage of FeO exceeding 0,9% are needed to achieve the stabilization goal while lower percentages shows not significant effects. At this percentage the resulting concentration is 0,85 corresponding to a reduction of 50% in the leaching expected by simple dilution.

Higher percentage can be used for a safer management but it should be considered that zero-valent iron and sodium sulphide are very expensive additives (about 1100 € per ton), compared to additives such as lime, cement and ferrous sulphate. Therefore, it is necessary to optimize the amount of zero iron for each mixtures containing molybdenum as in the case of ashes from special wastes incineration.



(a) (b)

Fig. 4. Release (a) of Molybdenum in the leachate as a function of the increase of FeO in the mix and comparison (b) between dilution and overall treatment

6. Concluding remarks

The issues of the treatment of hazardous wastes can't be easily solved and must be properly managed. From this work it results evident the difficulty of treating different types of wastes, through the stabilization process, because of their different origins, compositions and responses to the treatment. A multi-choice approach has been formulated to easily determine the effective contribution of the treatment versus dilution. The proposed approach, based can help the operators to understand which metals (i.e. wastes) can be treated together and how to improve the efficiency of the partial stabilization process so to increase its reliability and environmental safety.

Specifically, for those wastes contaminated by molybdenum, it has been demonstrated the effectiveness of using Zero-valent iron and Sodium sulphide, which are able to reduce the concentration of molybdenum in the eluate, allowing the safe disposal in a not – hazardous landfill.

Acknowledgements
The authors want to acknowledge the contribution of Cisma S.p.A. and Siram Laboratory in providing some of the historical data and to partially allow the use of the Society's laboratory for the tests.

References

Baba A., Gurdal G., Sengunalp F., (2010), Leaching characteristics of fly ash from fluidized bed combustion thermal power plant: case study: Can (Canakkale-Turkey), *Fuel Processing Technology*, **91**, 1073–1080.

Basegio T., Haas C., Pokorny A., Bernardes A.M., Bergmann C.P., (2006). Production of materials with alumina and ashes from incineration of chromium tanned leather shavings: environmental and technical aspects, *Journal of Hazardous Materials*, **137**, 1156-64.

Bernstein A.G., Bonsembiante E., Brusatin G., Calzolari G., Colombo P., Dall'Igna R., Hreglich S., Scarinci G., (2002), Inertization of hazardous dredging spoils, *Waste Manag*ement, **22**, 865–869.

Conner J.R., Hoeffner S.L., (1998), Critical review of cement based stabilization/solidification techniques for the disposal of hazardous waste, *Critical Reviews in Environmental Science and Technology*, **28**, 397-462.

Gerassimidou S., Komilis D., (2015), Assessing the leaching of hazardous metals from pharmaceutical wastes and their ashes, *Waste Management and Research*, **33**, 191–198.

Gong P, Bishop P.L., (2003), Evaluation of organics leaching from solidified/stabilized hazardous wastes using a powder reactivated carbon additive, *Environmental Technology*, **4**, 445-455.

Guo B., Liu B., Yang J., Zhang S., (2017), The mechanisms of heavy metal immobilization by cementitious material treatments and thermal treatments: A review, *Journal of Environmental Management*, **193**, 410-422.

Hot J., Sow M., Tribout C., Cyr M., (2016), An investigation of the leaching behavior of trace elements from spreader stoker coal fly ashes-based systems, *Construction and Building Materials*, **110**, 218–226.

Izquierdo M., Querol X., (2012), Leaching behavior of elements from coal combustion fly ash: an overview. *International Journal of Coal Geology*, **94**, 54–66.

Janusa M.A., Heard E.G., Bourgeois J.C., Kliebert N.M. Landry A., (1998), Effects of curing temperature on the leachability of lead undergoing solidification/stabilization with cement, *Microchemical Journal*, **60**, 193-197.

Malviya R., Chaudhary R., (2006), Factors affecting hazardous waste solidification/stabilization, *Journal of Hazardous Materials*, **137**, 267-276.

Oresanin V., Mikelic L., Sofilic T., Rastovcan-Mioc A., Uzˇarevic K., Medunic G., Elez L., Lulic S., (2007), Leaching properties of electric arc furnace dust prior/following alkaline extraction., *Journal of Environmental Science and Healt*, **42**, 323–329

Sebag M.G., Korzenowski C., Bernardes A.M., Vilela A.C., (2009), Evaluation of environmental compatibility of EAFD using different leaching standards, *Journal of Hazardous Materials*, **166**, 670–675.

Shi C., Spence R., (2010), Designing of Cement-Based Formula for Solidification/Stabilization of Hazardous, Radioactive, and Mixed Wastes, *Critical Reviews in Environmental Science and Technology*, **34**, 391-417.

Sun D.D., Tay J.H., Qian C.E.G., Lai D., (2001), Stabilization of heavy metals on spent fluid catalytic cracking catalyst using marine clay, *Water Science and Technology*, **44**, 285–291.

Tsai L.C., Fang H.Y., Lin J.H., Chen C.L., Tsai F.C. (2009), Recovery and stabilization of heavy metal sludge (Cu and Ni) from etching and electroplating plants by electrolysis and sintering, *Science in China, Series B: Chem*istry, **52**, 644–651.

Youcai Z., Lijie S., Guojian L., (2002), Chemical stabilization of MSW incinerator fly ashes*. Journal of Hazardous Materials* **95**, 47–63.

Yuan C.G., Yin L.Q., Liu S.T., He, B., (2010), Leaching behavior and bioavailability of arsenic and selenium in fly ash from coal-fired power plants, *Fresenius Environmental Bulletin,* **19**, 221–225.

Procedia
Environmental Science, Engineering and Management
http://www.procedia-esem.eu

Procedia Environmental Science, Engineering and Management **5** (2018) (2) 115-122

22th International Trade Fair of Material & Energy Recovery and Sustainable Development, ECOMONDO, 6th-9th November, 2018, Rimini, Italy

ENVIRONMENTAL PRODUCT DECLARATION: SUSTAINABLE DEVELOPMENT STRATEGY IN THE STEEL INDUSTRY*

Rita Jessica Martines[1], Maria Elisabetta Canciullo[1], Alberto Bertino[2], Federica Caruso[1], Veronica Galiano[1]**

[1]*Department Economics and Business, University of Catania, Corso Italia 55- 95129 Catania, Italy,*
[2]*Acciaierie di Sicilia S.p.A., Via Passo Cavaliere, 1, 95121 Catania, Italy,*
[3]*Department of Engineering and Architecture, University of Enna Kore, 94100 Enna, Italy*

Abstract

In the recent years, the environmental sustainability theme has aroused growing social interest which has caused companies to develop strategies that provide an ecological approach of production processes including the environmental variable in their market strategy. Furthermore, after the approval of the Green Procurement Program (GPP), a program sanctioned by the European Union to give guidance about purchasing more environmentally friendly products, companies are increasingly active from an environmental point of view. Especially in the building industry, in response to the increasingly pressing needs of transparency of the national procedures, there has been an increase in certifications of the sustainability requirements. This scenario includes the international standard ISO 14020, defined by ISO 14025, which specifies the general rules of three environmental labels, founded on the explicit use of the LCA methodology. One of these standards is the Environmental label "III", also known as Environmental Product Declaration (EPD), a voluntary third-party certification tool which contains a quantification based on established parameters of the environmental impacts associated with the life cycle of the product.

Keywords: Acciaierie di Sicilia, biosustainability, Environmental Product Declaration, Life Cycle Analysis, steel industry

* Selection and peer-review under responsibility of the ECOMONDO

** Corresponding author: e-mail: federica.amato.76@gmail.com

1. Introduction

Recently, the effects of globalization have influenced the construction sector, giving rise to the need to implement new proactive strategies and company policies as well as new sustainable tools which respect the environment such as certifications, trademarks and environmental methodologies. All of it is going to implement the most transparent corporate communication possible, in respect and importance given to environment. With the use of quantitative and qualitative data that allow the continuous economic and social efforts of the company to be explained in the sphere of the green economy. Several national and supranational eco-label programs aim to encourage sustainable consumption patterns. (Lavallèe, Plouffe, 2004). ISO has proposed three categories of environmental labels based on the aspects treated and the rigor required to obtain the certification: type I (ISO 14024, 2002); type II (ISO 14021, 2001); and type III (ISO 14025, 2006). This paper will focus on EPD® (Environmental Product Declaration), a certification that communicates transparent and comparable information on the environmental impact of products on the life cycle (http: //www.environdec.com/it/), on the environmental impact with a data comparison methodology obtained from the introduction in 2017 of a new scrap treatment system in the production cycle.

EPD® is part of one of the three voluntary ecological brands, as well as one dedicated to the estimation of potential environmental impacts associated with the product life cycle. EPD® contains information (objective, comparable and credible) on the environmental performance of the entire life cycle of products and services. It is an information tool that covers all environmental aspects and potential impacts: design, production, use and disposal, also guarantees the advantages in the tender process compared to competitors with the product information EPD®, and the evaluation of the life cycle, which is calculated in the process of creating an EPD, allows it to identify areas for improvement of the environmental footprint. In this context, the Italian steel sector aims to contain emissions in any environmental system (air, water, soil) to use resources in a rational way and manage plants in a sustainable way. Their introduction into the territory is today both a priority and a challenge the steel sector cannot lose. Companies that aim at the highest quality of processes and products also guarantee an adequate environmental ethics sustain these goals.

Acciaierie di Sicilia S.p.A. company that has been selected in the analysis, is a leading company in the European steel industry and in the eco-sustainable building field. Since 2017, the company has implemented a new mechanical approach in terms of environmental sustainability. It has introduced a new scrap treatment plant, with the aim of contributing to a lower environmental impact through a more careful process management of the treatment of scrap metal, from which second raw materials can be created. The goal of this paper is to analyse and compare the environmental variable before and after the inclusion of the plant in the production process. The importance of this approach is evident in the achievements of the environmental label “III”, applied to a new eco-sustainable steel which ensures higher performance in terms of environmental and quality, ensuring adaptability and flexibility of production.

In 2017 the theme was analyzed in the "Environmental Product Declaration as a strategy to apply the bioeconomy in the sustainable steel sector" (referencing Marco Palmieri (1), Federica Ragaglia (1), Sebastiano Patanè (1), Paolo Piana (1), Carlo Ingrao (2), Alberto Bertino (3)), and by following this paper aims to expand and obtain a complete and exhaustive analysis of the updated data to 2018, obtained by the LCA, to establish the effects of the new instruments introduced and internalized in the company to implement the EPD®.

2. Material and methods

Which tool is widely used in the European context; especially in Italy which owns the highest number of EPD® certifications in the world market. The EPD® system was introduced in Sweden in 1997 and now it is one of the most successful initiatives in the international arena of environmental declarations. EPD® is a tool that represents the category covered by ISO 14025 Type III. It is applicable to all the products or services regardless of their use or position in the chain of production and it's developed using Life Cycle Assessment (LCA) as a methodology that allows identification, mapping and analysis of all environmental impacts of the finished product or service (referencing Bribiàn et al., 2009), supporting an ecological development and approach in the circular economy process. In particular, bio-construction is one of the most active sectors from an environmental point of view, especially after the approval of the Green Procurement Program (GPP), a program sanctioned by the European Union in order to guide public authorities in purchasing procedures, more environmentally friendly products and services. The *Acciaierie di Sicilia company* S.P.A., selected in the analysis carried out, occupies an important position in the European steel industry and it's a leader in the Southern Italy market for the *Alfa Acciai Group*. The goal is the achievement of high environmental performance, with high quality products at low environmental impact, growth of production and organisational efficiency.

In 2017 it was involved in a new mechanical instrumental approach in terms of ductility and environmental sustainability.

EPD® is the most effective tool for the dissemination of certified environmental information on the sustainability of products, its application guarantees:

- Objectivity: the information disseminated by the tool must guarantee verified assessments that allow to emphasize the relevant product lifecycle data useful for internal and external stakeholders.
- Comparability: it is possible to compare different similar products belonging to the same sector.
- Credibility: the release of information is guaranteed by independent organizations, duly accredited, to validate them. After the satisfied requirements, the EPD® allows its products to be positioned in a distinctive way on the market, allowing consumers and business partners to make responsible purchasing choices.

The company that adopts this tool reinforces its commitment to sustainability and implements a system of continuous improvement of the environmental quality of its products and services. In this way, it improves its image within the competitive context where it operates. The limit in the implementation of the EPD®, nowadays, is represented by the partial evaluation of the LCA because it analyzes the finished product and its insertion into the reference market.

The selection and treatment activities are aimed at reducing the environmental impact, recovering and exploiting waste and reducing volumes sent to landfills. *Acciaierie di Sicilia* owns a series of plants located in areas of high industrial concentration in Catania. Upholding the ideal of reducing environmental impacts, since 2017 the company has internalised the organization of the scrap plant, optimizing above all the organizational timing, and have a better monitoring of the route. To optimize the activity of separation and differentiation of waste within the plant, the recoverable fractions are subdivided through mechanical selection and sent to specialized supply chains that allow, after appropriate treatments, reuse as high quality second raw materials to be re-introduced on the market in compliance with specific UNI standards.

3. Case study: *Acciaierie di Sicilia*

Acciaierie di Sicilia S.p.A company, part of the *Alfa Acciai group* since 1998, is the only steel mill in Sicily. Located in the industrial area of Catania, the company has a production capacity of about 500,000 tons / year of rebar for bars and rolls, obtained through the electrofusion of ferrous scrap from the region. This important production company employs a total of 200 people. Thanks to the dimensions reached, to the technology used and to its products, the company has placed itself in a prominent position in the European steel industry. It represents for the *Alfa Acciai Group* the natural reference for the market of southern Italy. Among the company’s main objectives environmental sustainability and product quality are found which are actually used in the production of "eco-sustainable steel" B450C S, which ensures excellent performance in anti-seismic structures. The objective of eco-sustainability is also confirmed by the environmental certifications obtained (EN ISO 14021, ISO 14025 EPD, LCA, SUSTSTEEL). Furthermore, the Company, by using the scrap (waste) as raw material and transforming it into a finished product (round), represents an example of "Circular Economy".

As far as the steel production process is concerned, it is of the so-called "solid charge" type. It involves the fusion of ferrous scrap in the electric furnace with the addition of ferroalloys, fluxes and recarburizers. This process is divided into the following phases:

Preparation of the charge baskets. The packing of the charge baskets take place in the scrapped room, and then everything will be loaded in the oven.

Merger. Fusion of the ferrous scrap in the electric furnace.

Pre-refining. When the last basket is completely melted, liquid steel is collected using an automatic sampler and sent to the Steelwork Laboratory for chemical analysis. At the same time, thanks to continuous oxygen blowing, the steel is decarburized until reaching the desired carbon value for tapping.

Tapping. The melted and slagged steel is tapped into the ladle by a beak-shaped opening on one side of the oven. The tapping operation must be carried out quickly, paying attention that melting slag is not transferred, which due to its highly oxidising characteristic becomes the cause of problems during ladle processing.

Processing in ladle. When the tapping is finished, gas is continued to be blended to homogenize the chemical composition after the addition of the ferroalloys during the tapping. The ladles containing the steel, compliant by chemical composition and temperature, are sent to continuous casting for the production of billets.

Continuous casting. In continuous casting, the greatest importance is attributed to the ingot mould because, the solidification of the steel begins there with the formation of a layer of solid peripheral skin that must withstand the ferrostatic pressure of the liquid steel inside it. During this phase the scrap is transformed and solidified into billets, which are nothing more than parallelepipeds that have sections equal to 330 mm and are 11 m long. These represent a semi-finished product for the company that may be sold as they are, to external or foreign mills that then work them according to their needs, or they can become the raw material for the mill department.

Rolling process. Inside the mill section, the billets are heated again, inside a heating furnace that brings them to the optimal temperature to be then molded inside the rolling mill and transformed into the finished product. The finished product is the rebar for reinforcement (in bars or rolls) with sections ranging from 8 mm to 30 mm and which are identified by the hot stamped company brand during the lamination reproduced longitudinally at a distance of about 800 mm. This trademark, being deposited with the organization issuing the qualifications, allows it to be distinguished at any time even after delivery to the customer. Finally, the finished product is stored inside the warehouses and subsequently sold.

Acciaierie di Sicilia S.p.A is fully aware that a responsible and sustainable economic strategy, addressed to the environmental problems deriving from its activities, is essential to achieve long-term competitive success. Industrial sustainability is intended as a balance between expectations for growth in business value, protection of the environment, protection of health and safety of workers and satisfaction and respect for its customers.

Steel compared to other competing materials in the life cycle has lower energy consumption, high recyclability, conservation of natural resources and extensive reuse of by-products. It is a widely used material, as an important component for a wide range of applications and market products, such as in the automotive, construction and packaging industries. Only after a very careful LCA study of specific activities can the company obtain the EPD. Before identifying the reason / motivation for which a study is conducted, it is necessary to identify the system where it builds the study (with the appropriate limitations).

The analysis of the Life Cycle Inventory (LCI) provides the creation of an inventory of flows to and from nature for a product system (Bribián et al., 2011). Inventory flows must incorporate inputs of water, energy, raw materials and emissions into the air, land and water. To develop the inventory, a flow model of the technical system is constructed using data on input and output, which can subsequently be processed and commented, which is going to be used to make assessments and useful indications at the decisional level (Westkamper et al., 2001).

The study of the LCA type in *Acciaierie di Sicilia S.p.A.* is aimed at analyzing the inventory in order to have all the information useful for the application of the EPD in the company. The study considers the entire production chain consisting of the following phases: UPSTREAM process: Pretreatment, cutting, crushing, sorting, raw materials and energy generation. CORE module: material transport, billet production, hot rolling process, packaging, internal treatment, auxiliary activities, air emissions, water emissions, solid waste. DOWNSTREAM process: transport on the market.

To obtain the final results, various types of materials and substances have been developed, such as: anthracite, calcium oxide, ferroalloys, oxygen, nitrogen, electrodes, scrap, cast iron, Fe - Si - Mn, Fe - Si, lime, coke, melting electrodes, lubricants, refractory, argon, nitrogen, propan.

4. Results and discussion

The Life Cycle Impact Assessment (LCIA) aims to understand and quantify the extent and significance of potential environmental impacts of a product or service throughout its life cycle. Understanding and analyzing these impacts is the first step in prevention, reduction and repair. The LCIA studies the significance of the environmental impacts of a product, building a model based on category indicators of the impacts associated with emissions, obtained through the conversion of the results of the inventory. This phase aims to evaluate the contribution that the product makes to the individual impact categories, such as global warming, acidification, eutrophication of water, etc.

The goal is to capture the consumption and emissions of LCI in specific impact categories, related to known environmental effects. This can lead to a classification or hierarchy of impact classes with respect to their importance and provide a structure that can help draw conclusions about the relative importance of the different impact categories. Natural gas, Electricity from the network, diesel, not for external transport have been used to analyze the energy consumed. As for the total air emissions, they were quantified based on the following substances: cadmium, chrome, manganese, mercury, nickel, lead, copper, CO^2, HCl, HF. Finally, the total emissions of water were analysed through: COD, BOD, total suspended solids, organic substances, zinc, iron, nickel, copper, total surfactants, lead, chrome, cadmium, manganese, nitrite, nitrate, chloride, sulphate. The results listed above are shown in Tables 1-3. It should also be noted that these results are entered in descending order, quantity consumed, or emissions issued, without referring to the detailed quantities as these are sensitive data.

Table 1. Energy consumed the steel industry in 2017

Energy consumed	***Unit***
Electricity from the network (KWh / year) Specify whether it comes from a specific vendor	(kWh / year)
Diesel not for external transport (l / year)	(L / year)
Natural gas	(m^3/year)

Table 2. Total air emissions into air plant *Acciaieria* 2017

Substance	***Unit***
CO_2	t/year
HF	mg/m^3
HCl	mg/m^3
Total powders	mg/m^3
Lead	mg/m^3
Manganese	mg/m^3
Nickel	mg/m^3
Mercury	mg/m^3
Copper	mg/m^3
Total chrome	mg/m^3
Cadmium	mg/m^3
Chrome VI	mg/m^3

Table 3. Emissions into water (after treatment)

Substance	***Unit***
Sulphate	mg / L
Chloride	mg / L
COD	mg / L
Total Suspended Solids	mg / L
Iron	mg / L
BOD	mg / L
Organistannic compounds	mg / L
Nitrate	mg / L
Organic Substances (Total Hydrocarbons)	mg / L
Total phosphorous	mg / L
Manganese	mg / L
Total nitrogen	mg / L
Zinc	mg / L
Copper	mg / L
Nitrite	mg / L
Total surfactants	mg / L
IPA	mg / L
Lead	mg / L

Total cyanides	mg / L
Nickel	mg / L
Chrome	mg / L
Cadmium	mg / L

5. Conclusion

The EPD brand represents an excellent company policy tool for all those companies that want to enter the world of the Green Economy. It has been designed to differentiate products and services that take the environmental performance of products into account, allowing customers to make responsible choices. A complete inventory analysis (LCI) and quantification of environmental emissions (LCIA) is required to achieve this goal.

Companies that choose to adopt an eco-sustainable business policy influence the actions and policies adopted by the various stakeholders, modifying the context in which they operate. In particular, *Acciaierie di Sicilia* is an emblematic case of a proactive company that, by supporting a "green" strategy using credible certifications, has been able to bring economic benefits to Sicilian suppliers, primarily by purchasing their scrap and benefits in terms technical-productive efficiency, thanks to the study of the environmental impacts of the products. Recently, *Acciaierie di Sicilia* has been committed to improving the environmental performance of its production process with various measures: installing a new gas filtration system in August 2010; a new extractor hood integrated with the installation of coal input activated in February 2012. Both systems offer better environmental performance in terms of atmospheric emissions.

Finally, with the internalization of the scrap treatment plant, the data was compared with a consequent positive response for the environmental impact. The EPD, besides being a useful safeguard for the communication of consumers with consumer protection, is also a valid support tool for the decisions taken by management to implement actions that minimize the environmental impact during all phases of the productive cycle.

The contribution of steel to help achieve triple basic line of environmental, economic and social sustainability make it essential to meet today's needs without affecting the company's ability to meet the needs of the future. While competing materials focus their sustainability claims on specific product application stages, superior steel sustainability performance minimizes environmental impact when measured throughout the entire life cycle.

References

Bribiàn I., Usòn A., Scarpellini S., (2009), Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification, *Building and Environment*, **44**, 2510-2520.

Bribián I., Capilla A., Usón A., (2011), Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential, *Building and Environment*, **46**, 1133-1140.

ISO 14024, (2002), Type I environmental labelling– Principles and procedures, On line at: https://www.iso.org/standard/72458.html

ISO 14021, (2001), Environmental labels and declarations – Self-declared environmental claims, On line at: https://www.iso.org/standard/66652.html.

ISO 14025, (2006), Environmental labels and declarations – Type III environmental declarations, On line at: https://www.iso.org/standard/38131.html

Lavallèe S., Plouffe S., (2004), The ecolabel and sustainable development, *The International Journal of Life Cycle Assessment*, **9**, 349-354.

Westkämper E., Alting L., Arndt G., 2001, Life Cycle Management and Assessment: Approaches and visions towards sustainable manufacturing, *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, **215**, 599-626.

Web pages

http://www.alfaacciai.it/acciaierie-di-sicilia/
http://www.environdec.com/en/.
http://www.federacciai.it/wp-content/uploads/2016/11/Rapporto_Ambientale_2011.pdf.
http://www.lc-impact.eu/methodology-home.

P - ESEM

Edited by the ***National Society of Environmental Science and Engineering*** (SNSIM) as Publisher
(http://snsim.ro/)
within the SNSIM Publishing House, Cluj-Napoca, Romania

SNSIM