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Abstract

Purpose – The purpose of this paper is to present a case report involving environmental performance analysis of a small Brazilian business from the foundry industry.
Design/methodology/approach – An environmental performance indicator was developed (I_{epa}) which is calculated taking into consideration the weighting of potential environmental impacts of each residue/sub product generated, the relative spatial dispersion which each residue/sub product can reach, and the adequacy evaluation of final allocation accomplished by the company for each residue/sub product.
Findings – Despite the evidence that the corporation do not conduct washing of gases emitted from the chimney of the foundry furnace, which consists an environmentally inadequate attitude, the result of $I_{epa} = 97.50$ percent was obtained. This favorable result is due to the adequate allocation given to residues generated in greater volume in the process, the molding sand. This sand is addressed to an industrial landfill, which is an environmentally adequate practice and approved by competent environmental authorities.
Practical implications – The method used can be applied to measure the environmental impact generated by any business of the foundry sector industry.
Originality/value – The originality of the work is in the developed method, which takes into account: the potential impact of each residue/sub product generated, the amount of each residue/sub product generated in a given time period, the dispersion that each residue/sub product can attain, and the evaluation of eventual allocation of each residue/sub product.

Keywords Analytic hierarchy process (AHP), Environmental management, Environmental analysis index, Environmental indicators, Foundry

Paper type Case study

1. Introduction

The foundry industry provides products to most of other types of manufacturing. This industry's contribution is vital and crucial for many economies throughout the world (Carmelio, 2009). However, it is regarded as one of the economic activities that spend most water and energy, apart from generating numerous residues and sub products with the potential of contaminating soil, air and water. The increasing awareness about environmental disputes has led the issues related to pollution caused by the foundry industry to be seriously and urgently reviewed. Consequently, pollution mitigation evolved into a management priority in this sector (Fore and Mbohwa, 2010).

Pollution prevention is preferable to mitigation of consequences from environmental degradation. In this context, cleaner production (CP) works on production processes and management procedures that allow reducing the use of resources and low generation of residues and toxic substances. CP emphasizes human and organizational dimensions of

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environmental management, including satisfactory plant operation to avoid intentional or accidental discharges (Fatta *et al.*, 2004). Nonetheless, few worldwide studies focused on the wide application of the CP approach in the foundry industry with the objective of world development (Fore and Mbohwa, 2010).

In the context of CP, the search for productive goals leveled with environmental issues has become essential, which imposes the necessity for the development of environmental performance indicators that are able to expose impacts of industrial operation on the environment (Rebelato *et al.*, 2014). Considering that several functional areas of the industry impact the environment in many different ways (Donaire, 2000), the definition of indicators for environmental performance analysis (EPA) must take into consideration the specifications of produced goods and the nature of adopted processes, once each industry generates and discards a diverse range of chemical products, gases, particulate materials, metals, solvents, organic compounds, etc. (Rebelato *et al.*, 2013). As a corollary, the employment of EPA demands knowledge of each stage of each transformation process in order to identify the set of generated residues, pointing out their potential effects on the environment (Seiffert, 2009).

In light of foregoing, the issue involving this study is how to construct a methodologically valid structure that allows EPA of foundry corporations equipped with cupola furnaces based on the adequacy of generated residues/sub products allocation?

In line with the complication of the research, this study aims to evaluate environmental performance of the productive process of a foundry company located in the city of Ribeirão Preto, State of São Paulo, Brazil. The focus is the potentially dangerous impacts of residues and sub products generated by the foundry industry regarding the absorption capacity of basic ecosystems that surround it. As a copula furnace is the most used equipment in the Brazilian foundry sector (Cimm, 2008), the research is relevant, since it contributes to the reflection on the sustainability in the sector, to the development of more effective indicators applied in the evaluation of environmental impacts caused by companies of this industrial field, and as a support for the development of environmental management methodologies that contribute to the mitigation of environmental passiveness of its industrial activities.

2. Method

First of all, it must be elucidated that the term "residue" is conceptualized and will be henceforth employed as any remainder derived from manufacturing that is not characterized as a sub product, either a gas or a liquid effluent, or a solid. Second, in order to be regarded as a sub product, according to Fipa (2007), the remainder originated in manufacturing requires harmony with three conditions: there must be probability of future employment for it; a possibility of direct employment with its current shape, which means, without going through alterations; and be an integrated part of a continuous production process.

Complementarily, it is highlighted that a sub product residue can be considered as a pollutant, once a polluting material is a material or substance that do not accommodate to a natural system in case of introduction of a quantity exceeding the natural system's assimilation capacity.

The research method employed in this study was comprised six stages, as follows:

(1) Mapping of productive stages of the foundry process – in this stage, identification and study of unit operations of transforming the raw material input into castings and into residues/sub products generated by the industrial process.

(2) Identification and study of generated residues/sub products – in this stage, an inventory was constructed with residues/sub products generated by the manufacturing operations, identifying its characteristics, composition, applicable legislation and possible allocations.

(3) Quantitative weighting of the environmental impact referring to each residue/sub product identified in the previous stage – in this stage the improved analytic hierarchy process (IAHP) method, a supporting tool for decisions on complex issues, was applied. IAHP is a variant of the conventional analytic hierarchy process (AHP) method developed by Saaty (1991). In the original version of AHP, the method requires pairwise comparison of various alternatives with respect to each of the attributes and a pairwise comparison of attributes themselves. The size and the number of the comparison matrices increase rapidly as the number of alternatives and/or attributes increases (Rao, 2013). This can be placed as one of the major problems with the conventional AHP technique; in other words, a quadratic increase in the number of comparisons depending on the number of alternatives (more precisely, $(n \times n - n)/2$). Five to seven alternatives is quite an acceptable case. However, with more of this, it is desirable to have effective methods of reducing the number or time needed for pairwise comparisons, even with the inevitable loss of some accuracy (Roodchenko and Banin, 2015). In order to achieve results rapidly and to deal with the original AHP method weakness, the MindDecider software (www.minddecider.com) was used. This tool has an interesting option that is to enable the so-called "auto solve dependencies", which drastically reduces the number of questions based on the previously entered correlation significances. For example, Roodchenko and Banin (2015), if the user enters the following proportions during the binary comparison: $A < B$ and $C > B$, the "auto solve" makes a logical assumption that $A < C$. Alternatively, when it was entered: $A < B$ and $B = C$, the "auto solve" formulates that $A < C$. Thus, depending on a comparison order the "auto solve" function can reduce the number of requests up to nearly linear in the most appropriate case.

(4) Development of the Environmental Performance Analysis Index (I_{epa}) – this index was developed with the aim of representing, in a single percentage value, how intensely the allocation of the set of all residues/sub products generated in production is environmentally adequate. The I_{epa} was judged in a way to be directly proportional:

- to the relative environmental impact of each residue/sub product originated in production, once the nature between them is extremely diverse;
- to the relative quantity of each residue/sub product generated in a given time period, once there are residues/sub products with a high relative quantity, such as molding sand, and low relative quantity, such as resin batches;
- to the relative geographic coverage or relative spatial dispersion that each residue/sub product can reach, once each of them is capable to attain a distinct extension in accordance with the processing technology, composition and physical condition; and
- to the categorical evaluation of final allocation adequacy practiced by the company for each residue/sub product, once organizations can employ adequate or inadequate methods in the final allocation.

The general formula of the I_{epa} is defined as follows:

$$I_{epa} = \sum_{i=1}^{n} \left[\frac{\left(V_{(a)i} Q_i A_i\right)}{\sum_{j=1}^{n} \left(V_{(a)j} Q_j A_j\right)} k_i \right] \times 100, \tag{1}$$

where n is the number of generated residues or sub products and $V_{(a)i}$ the value of the analyzed alternative (previously presented in item c). In this case, it is the relative weight of the potential environmental impact of each residue/sub product i; Q_i the relative quantity of each generated residue/sub product i:

$$Q_i = \frac{b_i}{\sum_{j=1}^{n} bj} \times 100, \quad (2)$$

where b_i is the absolute quantity (produced per week, month or year) of each residue/sub product I and A_i the relative coverage of the impact of each residue/sub product:

$$A_i = \frac{x_i}{\sum_{j=1}^{n} xj} \times 100, \quad (3)$$

where x = value (1, 2, 3) assigned according to the geographic coverage of the impact of each residue/sub product based on Table I.

K_i is the categorical evaluation of allocation adequacy of each residue/sub product I practiced by the company. Thus, k was set to 1 for an environment-friendly final allocation; otherwise, it was set to 0. As environment-friendly allocation, it was considered that the manufacturing residues be directed to reuse, recycling, composting, energy recovery and use, as well as other destinations that do not cause damage or risks to public health and security, minimizing unfavorable environmental impacts (Lei 12305, 2010). It is important to highlight that the gas release from chimneys (derived from combustion) directly into the atmosphere is a practice considered legal by the environmental regulatory agencies. Nevertheless, gases emitted through burning fuels from foundry furnaces are pollutants to the atmosphere, causing the greenhouse effect. Thereby, this practice is here recognized as environmentally inadequate even though it is legally acknowledged.

(5) Data collection – this stage was carried out by observing the studied place and gathering documented information of the company, such as the produced quantities of each residue/sub product and final allocation given to each of them.

(6) Final results quantification – this stage was conducted through analysis of the obtained data and computation of necessary parameters to the I_{epa} calculation.

3. EPA

Motivated by the society's new pressures or due to financial targets, organizations have adopted cleaner procedures in their production processes. The study of environmental impacts throughout the products' life cycle, the reuse of scrap materials during processing, and the reannexation of products that no longer present useful life to the process are practices that have been increasingly employed. Thereby, from the end of 1980s onwards, a great portion of industries, seen as environmentally destructive, starts a metamorphose, in order to be recognized as promoters of environmental preservation (Rodrigues and Rodrigues, 2003).

x	1	2	3
Criterion	The impact is local, the effects affect the production place and its surroundings	The impact is regional, it is relevant beyond the surroundings of the production place	The impact is strategic, its effects might have relevant effects coverage in national or global scope

Table I. Criteria used in the evaluation of impact coverage of each residue/sub product

EPA is a process that aims to facilitate management decisions about environmental performance of organizations by means of selection of indicators, collection and data analysis, information evaluation, according to the environmental performance criteria, dissemination, revision and improvement of this process (Abnt NBR ISO 14031:2004, 2004). According to Searcy *et al.* (2005), there is no absolute consensus on the environmental topics that should be measured in EPA. However, in the opinion of Delai and Takahashi (2011), there is a degree of agreement between the main investigations pointed by the literature: atmosphere, water, soil, energy and materials. Some important questions such as biodiversity, hazardous materials and generation of hazardous residues, harmful emissions to human health, and water quality are fundamental as they are related to human well-being as well as to life permanence in natural environments.

The pursuit for productive goals aligned with environmental topics leads to the development of indicators of EPA that can not only measure environmental damage caused by production processes, but are also capable of showing the progress of environmental action (Rohrich and Cunha, 2004). Several researchers offer theoretical structures to science and for the judgment of environmental management stages. Hunt and Auster (1990) focused on the apprehension of companies with environmental exteriorities, indicating one example of five stages for the categorization of studied corporations: from novice organization, without any environmental concern to companies that are highly committed to the subject, perceived as a proactive organization. Rohrich and Cunha (2004) indicate taxonomy for the environmental management systems of manufacturing companies and ponder the analogy of environmental management with technological novelties. Tahir and Darton (2010) suggest a more extensive procedure in order to measure the environmental performance of an enterprise from five stages: business general spectrum, meaning of sustainability and derivation of business expectations, definition of the system's outline, meaning of indicators and metrics, inquiries and alterations. Campos and Melo (2008) accomplish a theoretical examination regarding the probable indicators that can be employed for the valuation of system behavior of environmental management associated and adjusted according to the conditions of ISO 14001. Following similar principles, the proposals of Thoresen (1999) and Jasch (2000) were conducted. The series ISO 14000 offers, in accordance with the norms ISO 14031 and ISO 14034, a set of suggestion for environmental indicators' planning.

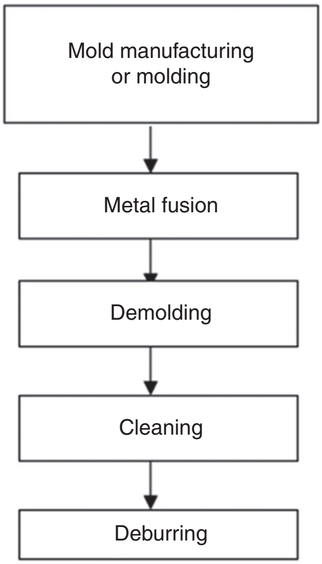
As previously cited, each manufacturing procedure has a specific character, which imposes exclusive aspects to be considered in the screening process of the most appropriate environmental indicators (Jung *et al.*, 2001). In this context, Perotto *et al.* (2008) notice that the plan of environmental performance indicators must appreciate the nature of production goods, recommending a weighted lien of these factors as a constitutional condition of indicators that can measure the environmental performance of the organization.

According to Pegado *et al.* (2004), there are two basic approaches for EPA: by environmental pressure indicators and by environmental impact indicators. Environmental pressure indicators measure the magnitude or the activity potential of causing impact. Environmental pressure is marked by the production factors that determine the expenditure of natural resources or resources with a potential of environmental degradation, such as material and water consumption, area occupation, potentiality of global warming and pollutant emissions. Indicators of environmental impact judge the consequence or transformation caused in the environment by a manufactured activity. As reported by Jasch (2000), the environmental indicators must: be comparable; have a purpose and be oriented toward the company's goal; reflect the environmental performance in a clear, concise and balanced way; be derived from the same criteria at the corresponding time units in order to be compared to each other; be frequently measured; comprehensible and match the user's necessities.

4. Foundry process and its residues and sub products

The foundry process is, first and foremost, the production of metallic parts by shedding liquid metal into a mold or formwork of a desired part formed out of sand or iron. After the effusion of liquid metal into the mold, it is necessary to remove the part from the mold interior, in a way that the part is semi-finished, with dirt, burrs and imperfections, requiring cleaning, which is its "deburring" (Jain, 2009). The foundry industry achieves as a result, metal parts that cannot be produced through laminating processes, forge or welding. The operations conducted in each foundry can vary, depending on the type of molten metal (ferrous metals, such as gray iron, molten iron, steel and non-ferrous metals, such as aluminum, brass, copper, zinc, lead and nickel, among others), methods and applied technologies. The different methods used to obtain the parts will depend on the quantity and the type of a component to be produced. Generally, it involves the following stages: handling and storage of materials, production of molds and cores, metal foundry, foundry and cleaning of molten parts (Sosa *et al.*, 2013). Figure 1 illustrates the flowchart of the foundry process stages: the mold of the part to be melted is manufactured, the metal is melted, the molten part is taken out of the mold (after the liquid metal is solidified), the part is cleaned, burrs and imperfections are removed, and grit blasting can also be carried out in order to improve external finishing (Dantas, 2003).

The indicators of environmental conditions of the foundry process are especially related to gas emissions and solid residues. Many of the materials in the form of loose particles containing metal compounds and non-metallic, hot gases, such as CO_2, SO_2 and CO are burned in the form of fine ash (Mukherjee, 2011). Taking into account the current technologies of processing, the liquid effluents are considered irrelevant regarding the environmental aspect of the activity. However, the contamination risk of groundwater is considered crucial due to possible inadequate disposal of foundry sands. Other secondary aspects that can be cited are the generation of diffuse emissions, odors, and gases that cause discomfort, noise of industrial operations, loading and unloading of materials, residues and molten parts (Sosa *et al.*, 2013).



Source: Adapted from Mastella (2013, p. 46)

Figure 1. Simplified flowchart of the foundry process

Table II illustrates the main residues and sub products generated by foundry industries with the corresponding process stages in which they are generated. The table also illustrates the potential impact of each one considering an environmentally inadequate allocation.

5. Results and discussion

The case report was conducted in a foundry company founded approximately 20 years ago. It operates in Ribeirão Preto city, São Paulo state, Brazil, with 4.000 m^2 of constructed area and acts in the segment of gray iron foundry, nodular and special iron alloys. The study was conducted between March and August 2015. The installed capacity is of 400 tons/month, with its foundry process conducted with a cupola furnace and the process is manually handled, which means there is no automation for mold manufacturing.

In order to achieve pairwise weightings of the IAHP method, a group focused on problem analysis was selected; the group constituted of four professionals from environmental management area, experts in properties of foundry residues, having worked in the sector for a period of at least three years. Table III brings the characteristics of composition of the evaluators' group.

The three main environments addressed the designed hierarchical structure: soil, water and atmosphere. These, in the IAHP method, were portrayed as the evaluation criteria, which were employed as indicators in the pairwise weighting among the alternatives. These alternatives were composed of identified residues/sub products. Figure 2 illustrates the hierarchical structure.

The application of the previously cited software obtained the relative weighting of the criteria "impact on atmosphere," "impact on water" and "impact on soil" with regard to residues/sub products generated by the foundry industry in general. Figure 3 displays the obtained results in the form of a pie chart.

In sequence, relative weighting of potential environmental impact of each residue/sub product was obtained considering as environmentally inappropriate allocation or disposals, in this case, directly on the soil surface, in water, and atmosphere without any prior treatment. It is highlighted that this weighting was addressed to foundry processes that employ a cupola furnace and use gas (liquefied petroleum gas) instead of coke as fuel, since the gas residues generated by these two fuels are significantly different. Figure 4 graphically illustrates the results of this analysis.

Table IV complements Figure 4, presenting the ascending quantitative results of *Va(i)*. Graphic analysis shows that the six most featured residues are glue (4.61 percent), foundry sand (4.53 percent), slag (4.37 percent), catalyst (4.33 percent), effluent of gas washer (4.23 percent) and cleaning products (4.19 percent).

The glue is composed of a synthetic organic polymer that is non-biodegradable with relative impact potential for pollution on watercourse. Remainders of this residue cannot have contact with soil and water and must be incinerated in licensed facilities, according to the current Brazilian regulation. Regarding the catalyst that can be alkaline or acidic compounds, the disposal onto soil or into watercourse will promote pH alterations in these environments, decreasing or increasing pH, according to the acidic or alkaline nature of the catalysts. Moreover, depending on its composition, as in the case of barium hydroxide and oxalic acid, in addition to pH alterations, the introduction of toxic species into the environment, such as Ba^{2+} ions and oxalic acid also occurs. With respect to foundry sand, this might contain heavy metals, resulting from the foundry process, which are toxic to animals. Furthermore, it might include resins derived from binding substances, such as sodium silicate and phenol, and the latter is a toxic element to animals. In the case of cleaning products, the disposal into rivers might cause a decrease in dissolved oxygen, increment in the concentration of xenobiotic compounds and bioaccumulation. The slag, in turn, is a resulting residue from metal melting (fusion) and can present metal oxides, such as

Residue/sub product	Process stage	Composition	Potential impact
Foundry sands	Molding	The employed foundry sand can be from various types: silica sand, SiO_2; zirconite sand, ZrO_2SiO_2; chromite sand, $FeOCr_2O_3$; olivine sand, $Mg_2SiO_4Fe_2SiO_4$ The foundry sand might contain as aggregates: clay (mainly bentonite), dextrin, gelatinized corn meal, pitch dust, coal dust, wooden dust, silica dust, iron oxide	The solid residue is a potential polluter of soils and superficial water and/or groundwater
Sulfur oxides	Metal fusion	SO_x	The gas residue is a potential polluter of atmosphere
Nitrogen oxides	Metal fusion	NO_x	The gas residue is a potential polluter of atmosphere
Particulate material	Metal fusion	Material comprised of soot particles and unburnt fuel	The solid residue is a potential polluter of soils and superficial water and/or groundwater
Carbon dioxide	Metal fusion	CO_2	The gas residue is a potential polluter of atmosphere
Wooden dust	Mold manufacturing	Solid organic material in which cellulose fibers and hemicelluloses united by lignin are predominant	The solid residue is a potential polluter of soils and superficial water and/or groundwater
Carbon monoxide	Metal fusion	CO	The gas residue is a potential polluter of atmosphere
Polystyrene (Styrofoam)	Mold manufacturing	Polystyrene, synthetic product originated from petroleum	The solid residue is a potential polluter of soils and superficial water and/or groundwater
Effluent of gas washer	Metal fusion	It might contain Fe and oxides such as FeO, SiO_2, Al_2O_3, Fe_2O_3, MnO, CaO and MgO. The effluents depend on the raw material to be molded, and might also contain zinc and lead oxides and elements such as manganese, chromium, tin, titanium, molybdenum, zirconium, nickel, cadmium, copper, cobalt and silver	The liquid residue is a potential polluter of soils and superficial water and/or groundwater
Glue	Mold manufacturing	It is a glue for wood, an emulsion constituted by water and polyvinyl acetate (commonly represented by the abbreviations PVA or PVAc) which is an organic synthetic polymer, obtained from vinyl acetate	The solid residue is a potential polluter of soils and superficial water and/or groundwater
Slag	Metal fusion	Mixture of metal oxides (SiO_2, Al_2O_3, CaO, MnO, FeO)	The solid residue is a potential polluter of soils and superficial water and/or groundwater
Grit	Cleaning of parts	Mainly composed of steel particles (greater proportion of iron with various types of oxides: SiO_2, Al_2O_3, CaO, MnO, Na_2O, MgO, SrO, ZrO_2, Cr_2O_3, K_2O, P_2O_5, TiO_2, BaO, etc.)	The solid residue is a potential polluter of soils and superficial water and/or groundwater
Refractory mass	Metal fusion	Composed of kaolinite, with addition of bentonite, kaolin, calcium carbonate, quartz, dolomite, feldspar, talc and chamote	The solid residue is a potential polluter of soils and superficial water and/or groundwater
Wood	Mold manufacturing	Solid organic material in which cellulose fibers and hemicelluloses united by lignin are predominant	The solid residue is a potential polluter of soils and superficial water and/or groundwater

(*continued*)

Table II. Main residues and sub products generated by foundry industries

Residue/sub product	Process stage	Composition	Potential impact
Catalyst	Molding	There are alkaline catalysts, such as sodium hydroxide, potassium hydroxide, barium hydroxide, etc., and acid catalysts like oxalic acid, sulfuric acid, hydrochloric acid, etc.	The solid residue is a potential polluter of soils and superficial water and/or groundwater
Resin dispenser	Molding	Material commonly manufactured with plastic	The solid residue is a potential polluter of soils and superficial water and/or groundwater
Furnace refractory brick	Metal fusion	Usually manufactured with special ceramic, made of aluminum oxide and sand	The solid residue is a potential polluter of soils and superficial water and/or groundwater
Leather apron	Metal fusion	Its raw material is bovine leather, composed of crude protein, Ca, P, Mg, Na and K	The solid residue is a potential polluter of soils and superficial water and/or groundwater
Boots	Metal fusion	Its raw material is leather but also presents polyurethane in its composition	The solid residue is a potential polluter of soils and superficial water and/or groundwater
Tow	Entire production process	Tow is a product originated from linen	The solid residue is a potential polluter of soils and superficial water and/or groundwater
Plastic tapes	Molding	Plastic tapes are composed of polypropylene and polyester	The solid residue is a potential polluter of soils and superficial water and/or groundwater
Gloves	Metal fusion	Gloves are produced from different materials such as latex, nitrile and vinyl	The solid residue is a potential polluter of soils and superficial water and/or groundwater
Goggles	Entire production process	Safety goggles present acrylic in its composition	The solid residue is a potential polluter of soils and superficial water and/or groundwater
Cleaning products	Entire production process	Comprised of water-soluble compounds such as sodium hydroxide, sodium alkyl-benzene sulphonate, glycerin, triethanolamine, fatty acid	The liquid residue is a potential polluter of soils and superficial water and/or groundwater
Earplugs	Entire production process	The earplugs are composed of polyurethane foam	The solid residue is a potential polluter of soils and superficial water and/or groundwater
Respirator	Entire production process	It is a product molded in rubber or silicon, which is a synthetic polymer (polisiloxan)	The solid residue is a potential polluter of soils and superficial water and/or groundwater
Squeegee	Entire production process	The squeegees are usually manufactured with wood and rubber	The solid residue is a potential polluter of soils and superficial water and/or groundwater
Straw brooms	Entire production process	Composed of wood and straw	The solid residue is a potential polluter of soils and superficial water and/or groundwater

Table II.

Table III.
Characteristics of the expert evaluators

Evaluator	Experience with foundry processes	Experience with environmental management	Training
A	5 years	3 years	Mechanical engineer
B	6 years	4 years	Mechanical engineer
C	4 years	6 years	Environmental engineer
D	4 years	4 years	Production engineer

Al_2O_3 and MnO, capable of causing negative impacts to the environment, if directly disposed onto soil or into superficial water. Al^{3+} ions are toxic to plants, if presented in high concentrations on the soil surface. In the case of effluent of gas washer, this can contain particulate material composed of toxic and bio-accumulative heavy metals, such as cadmium and lead, among others; therefore, it cannot be released onto the soil surface or released into the watercourse without prior treatment.

Subsequently to relative weighting of potential environmental impact of each residue/sub product, absolute quantity (b_i) of each residue/sub product generated in the manufacturing process of the studied company was identified, and from it, the relative quantities (Q_i) were calculated. Afterwards, relative coverage (A_i) and categorical evaluation (K_i) of each considered residue/sub product were defined. Table V displays the allocation of each residue/sub product adopted by the company with the corresponding categorical evaluation of allocations, represented by K_i.

Table VI presents the results of the $V_{(a)i}$, b_i, Q_i, A_i and I_{epa} in the studied industry. It is observed a 0 value assigned to absolute quantity (b_i) of effluent of gas washer and particulate material. This is due to the fact that the company does not possess and does not use any washing equipment for gases and particulates expelled by the chimney, therefore, does not generate these two residues. Taking into account that the company casually uses metals derived from scrap as raw materials, this situation denotes not only an environmentally irresponsible attitude, but also a legally irregular activity.

Even though the pertinent legislation does not oppose the release of combustion gases directly into the atmosphere, all gases received a zero grade in the categorical evaluation (*Ki*) about allocation adequacy. This is due to the fact that gases are residues categorized as greenhouse gases and, therefore, contribute to the undesirable effect of global warming.

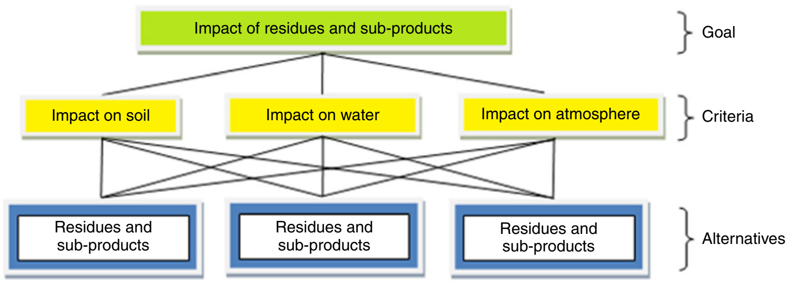


Figure 2.
Hierarchical structure for weighting of residues/sub products

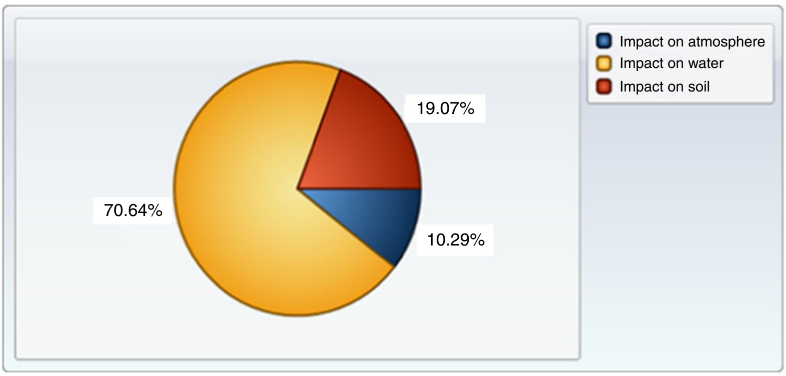


Figure 3.
Pie chart corresponding to the relative weight of potential impact of residues/sub products generated by the foundry industry on atmosphere, water and soil

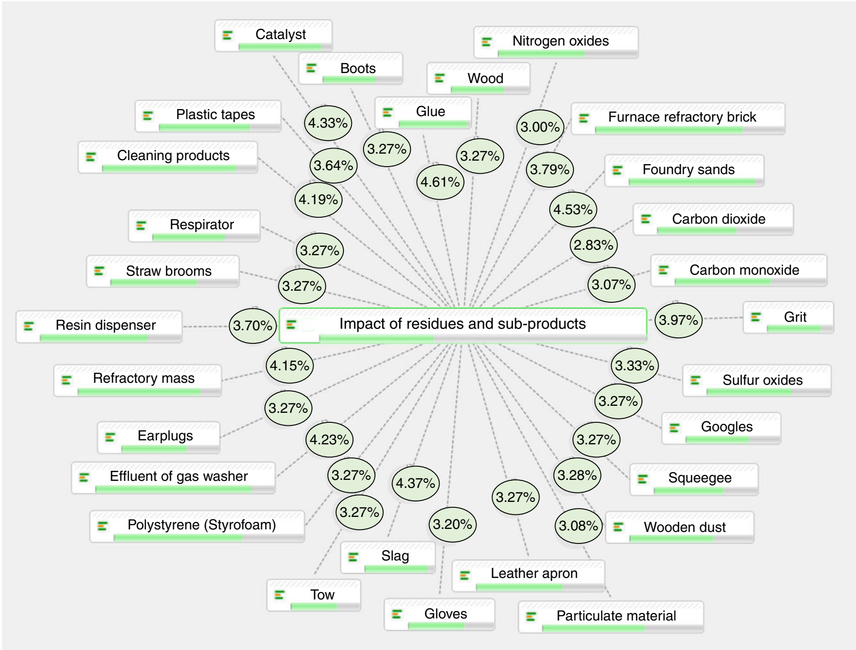


Figure 4.
Graph of the relative weighting ($V_{(a)i}$) of each residue/sub product potential impact

Table IV.
Total impact ($V_{(a)i}$), in ascending order, corresponding to Figure 4

Residue/sub product	Total impact, $V_{a(i)}$ (%)
Carbon dioxide	2.83
Nitrogen oxides	3.00
Carbon monoxide	3.07
Particulate material	3.08
Gloves	3.20
Goggles	3.27
Leather apron	3.27
Wood	3.27
Boots	3.27
Squeegee	3.27
Polystyrene	3.27
Earplugs	3.27
Respirator	3.27
Tow	3.27
Straw broom	3.27
Wooden dust	3.28
Sulfur oxides	3.33
Plastic tapes	3.64
Resin dispenser	3.70
Refractory brick	3.79
Grit	3.97
Refractory mass	4.15
Cleaning products	4.19
Effluent of gas washer	4.23
Catalyst	4.33
Slag	4.37
Sand	4.53
Glue	4.61

Residue/sub product	Allocation given by the company	Ki
Goggles	Sanitary landfill	1
Carbon monoxide	Released into the atmosphere	0
Leather apron	Sanitary landfill	1
Wood	Industrial landfill with Cadri[a]	1
Boots	Sanitary landfill	1
Squeegee	Sanitary landfill	1
Wooden dust	Sanitary landfill	1
Polystyrene (Styrofoam)	Commercialized with third parties	1
Earplugs	Sanitary landfill	1
Respirator	Sanitary landfill	1
Tow	Industrial landfill with Cadri	1
Straw brooms	Sanitary landfill	1
Gloves	Sanitary landfill	1
Carbon dioxide	Released into the atmosphere	0
Particulate material	Released into the atmosphere	0
Nitrogen oxides	Released into the atmosphere	0
Sulfur oxides	Released into the atmosphere	0
Refractory brick	Return to manufacturer	1
Grit	Industrial landfill with Cadri	1
Plastic tapes	Sanitary landfill	1
Refractory mass	Industrial landfill with Cadri	1
Resin dispenser	Industrial landfill with Cadri	1
Effluent of gas washer	Do not present gas washer and do not generate this effluent	0
Slag	Industrial landfill with Cadri	1
Cleaning products	Sanitary landfill	1
Sand	Industrial landfill with Cadri	1
Catalyst	Commercialized with third parties	1
Glue	Commercialized with third parties	1

Note: [a]Cadri means “Residues movement certificate of collective environmental interest”

Table V. Residues/sub products generated, allocation given by the company and categorical evaluation (K_i) of each one

Table VI shows that sand is the residue that presents, among all others, the highest participation percentage in the I_{epa}. This happens because, in spite of being classified in the third place in the relative weighting of environmental impact ($V_{(a)i}$), the quantity of sand generated by the company compared to other residues is very expressive (91.02 percent) and, at the same time, the company employs an environmentally adequate and responsible practice in the allocation of this residue.

In that way, although there are negative points, the $I_{epa} = 94.8$ percent shows that 94.8 percent of residues/sub products have environmentally appropriate allocation, in terms of the EPA methodology applied in this study.

6. Concluding remarks

On the assumption that the EPA of a productive entrepreneurship cannot continue on activity without focusing on industrial operations, this study had the objective to conduct a case report about environmental performance of a Brazilian company in the foundry sector. In order to accomplish this goal, an index called I_{epa} was developed, which represents a single percentage point, of how environmentally adequate is the allocation of all residues/sub products generated in production. The developed method is based on the presupposition that the effort efficiency measurement of environmental management of a company will be directly proportional to the efficiency rating of environmental adequacy of allocations given to the generated residues/sub products.

Table VI.
Results of $V_{(a)i}$, b_i, Q_i, A_i and I_{epa} in studied industry

Residue/sub product	Relative weighting (%) ($V_{(a)i}$)	Absolute quantity (Ton/year) (b_i)	Relative quantity (%) (Qi)	Relative coverage (%) (A_i)	Categorical evaluation (K_i)	I_{epa} (%)
Goggles	3.27	0.02	0.01	2.38	1	0.005
Carbon monoxide	3.07	2.00	1.25	7.14	0	0.0
Leather apron	3.27	0.09	0.06	2.38	1	0.02
Wood	3.27	0.30	0.19	4.76	1	0.14
Boots	3.27	0.02	0.01	2.38	1	0.005
Polystyrene	3.27	0.03	0.02	2.38	1	0.007
Wooden dust	3.28	0.10	0.06	4.76	1	0.05
Squeegee	3.27	0.0005	0.0003	2.38	1	0.00012
Earplugs	3.27	0.002	0.001	2.38	1	0.0005
Respirator	3.27	0.03	0.02	2.38	1	0.007
Tow	3.27	0.0012	0.001	2.38	1	0.0003
Straw broom	3.27	0.0005	0.0003	2.38	1	0.00012
Gloves	3.2	0.024	0.02	2.38	1	0.006
Carbon dioxide	2.83	2.00	1.25	7.14	0	0.0
Particulate material	3.08	4.00	2.50	4.76	0	0.0
Nitrogen oxides	3.00	0.80	0.50	7.14	0	0.0
Sulfur oxides	3.33	0.50	0.31	7.14	0	0.0
Refractory brick	3.79	2.00	1.25	2.38	1	0.54
Grit	3.97	2.00	1.25	4.76	1	1.14
Plastic tapes	3.64	0.025	0.02	2.38	1	0.01
Resin dispenser	3.70	0.004	0.003	2.38	1	0.001
Refractory mass	4.15	1.00	0.63	2.38	1	0.30
Effluent of gas washer	4.23	0.0	0.0	2.38	0	0.0
Slag	4.37	4.40	2.75	2.38	1	1.38
Cleaning products	4.19	0.20	0.13	4.76	1	0.12
Sand	4.53	140.00	87.62	4.76	1	91.02
Catalyst	4.33	0.20	0.13	2.38	1	0.06
Glue	4.61	0.03	0.02	2.38	1	0.01
Total	100.0	159.8	100.0	100.0		94.8

The determination of the I_{epa} considered: the relative weighting of potential impact of each residue/sub product generated by the foundry industry; the relative quantity of each residue/sub product generated in a given time period; the relative dispersion that each residue/sub product can reach; the adequacy evaluation of final allocation of each residue/sub product practiced by the company.

The environmental impact weighting of residues/sub products set of the foundry industry might be considered a complex problem, as its causes and effects can only be noticed through reflection and require deductive view assisted by experience, which means, through previous involvement with the concerned variables. The problem involves residues/sub products with great differences of the physical and chemical nature; several harmful effects that can be caused in case of inappropriate allocation into different natural environments (water, soil and atmosphere) and alterations that these effects can have over time.

The conducted evaluation among the most environment-impacting residues/sub products verified that a much higher relative impact occurs on the water than on the soil or the atmosphere. The highlighted residues were glue, catalyst, foundry sand, cleaning products, slag and effluent from gas washers.

A flaw on the part of its environmental management was revealed since the company does not execute washing of gases emitted by the chimneys of foundry furnaces'. Given that, not always the raw material has its composition totally known and, as the company casually conducts melting of metal scrap, it consequently leads to a risk of release of particulate material composed of heavy metal oxides directly into the air, with harmful implications to the health of the surrounding population. The gas washer also acts on minimizing gas release into the atmosphere, which amplifies the omission in this process stage. Even though it is a small-sized company, the practice is legally irregular.

On the other hand, there are attenuating factors. Considering that the company uses gas as a heating fuel in a cupola furnace, instead of coke, which is most commonly used for this type of furnace, the estimated value of the $V_{(a)i}$ for emissions of sulfur oxide, nitrogen oxide, carbon dioxide, carbon monoxide and particulate material tended to be much less expressive.

Contrarily, the company demonstrated properly allocating a residue of higher volume generated in the process, the sand. This residue is sent to an industrial landfill with approval of the competent environmental authority of São Paulo State. Thereby, given that sand is responsible for 91.02 percent of the I_{epa} composition, the final value of the I_{epa} (94.8 percent) was fairly favorable to the company regarding environmental adequacy of allocation of its residues/sub products. The proposed indicator I_{epa} was established for the foundry industry and cannot be used for other sectors.

References

Abnt NBR ISO 14031:2004 (2004), *Gestão ambiental – avaliação de desempenho ambiental – diretrizes*, Associação Brasileira de Normas Técnicas (ABNT), Rio de Janeiro.

Campos, L.M.S. and Melo, D.A. (2008), "Indicadores de desempenho dos Sistemas de Gestão Ambiental (SGA): Uma pesquisa teórica", *Revista Produção*, Vol. 18 No. 3, pp. 540-555.

Carmelio, J.S. (2009), *Guia ABIFA de fundição*, São Paulo, available at: www.abifa.org.br/ (accessed January 21, 2010).

Cimm (2008), "A evolução do forno cubilô: equipamento é o mais utilizado no setor de fundição nacional", available at: www.cimm.com.br/portal/noticia/exibir_noticia/4628-a-evolucao-do-forno-cubilo (accessed April 17, 2015).

Dantas, J.M. (2003), *Montagem, comissionamento e operação de um sistema de recuperação de areia de fundição: Regenerador térmico – Plano de Trabalho da Fase II*, Instituto de Pesquisas Energéticas e Nucleares, São Paulo.

Delai, I. and Takahashi, S. (2011), "Sustainability measurement system: a reference model proposal", *Social Responsibility Journal*, Vol. 7 No. 3, pp. 438-471.

Donaire, D. (2000), *Gestão Ambiental na Empresa*, Atlas, São Paulo.

Fatta, D., Marneri, M., Papadopoulos, A., Savvides, Ch., Mentzis, A., Nikolaides, L. and Loizidou, M. (2004), "Industrial pollution and control measures for a foundry in Cyprus", *Journal of Cleaner Production*, Vol. 12 No. 1, pp. 29-36.

Fipa (2007), "Boletim informativo da Federação das Indústrias Portuguesas Agro-Alimentares", available at: www.fipa.pt/pdf/fipaflash95.pdf (accessed January 8, 2013).

Fore, S. and Mbohwa, C.T. (2010), "Cleaner production for environmental conscious manufacturing in the foundry industry", *Journal of Engineering, Design and Technology*, Vol. 8 No. 3, pp. 314-333.

Hunt, C.B. and Auster, E.R. (1990), "Proactive environmental management: avoiding the toxic trap", *MIT Sloan Management Review*, Vol. 31 No. 2, pp. 7-18.

Jain, P.L. (2009), *Principles of Foundry Technology*, 5th ed., Tata McGraw-Hill, New Delhi.

Jasch, C. (2000), "Environmental performance evaluation and indicators", *Journal of Cleaner Production*, Vol. 8 No. 1, pp. 79-88.

Jung, E.J., Kim, J.S. and Rhee, S.K. (2001), "The measurement of corporate performance and its application to the analysis of efficiency in oil industry", *Journal of Cleaner Production*, Vol. 9 No. 6, pp. 551-553.

Lei 12305 (2010), "Política nacional de resíduos sólidos", available at: www.planalto.gov.br/ccivil_03/_ato2007-2010/2010/lei/l12305.htm (accessed March 15, 2015).

Mastella, V.G. (2013), "Elaboração do mapa de risco para o setor de fundição da empresa metalúrgica DS Ltda", Monografia (Especialização em Engenharia de Segurança do Trabalho), Universidade do Extremo Sul Catarinense, UNESC, Criciúma.

Mukherjee, D.P. (2011), "Barriers towards cleaner production for optimizing energy use and pollution control for foundry sector in Howrah, India", *Clean Technologies and Environmental Policy*, Vol. 13 No. 1, pp. 111-123.

Pegado, C., Melo, J. and Ramos, T. (2004), "Ecoblock: Método de avaliação do desempenho ambiental", available at: http://gasa.dcea.fct.unl.pt/ecoblock/Apea%2001.doc (accessed April 12, 2015).

Perotto, E., Canziani, R., Marchesi, R. and Butelli, P. (2008), "Environmental performance, indicators and measurement uncertainty in EMS context: a case study", *Journal of Cleaner Production*, Vol. 16 No. 4, pp. 517-530.

Rao, R.V. (2013), *Decision Making in the Manufacturing Environment Using Graph Theory and Fuzzy Multiple Attribute Decision-Making Methods*, Vol. 2, S.V. National Institute of Technology, Surat.

Rebelato, M.G., Madaleno, L.L. and Rodrigues, A.M. (2013), "Proposed indicators for assessing the environmental performance of production processes of sugar-energy plants", 4th International Workshop Advances in Cleaner Production, São Paulo.

Rebelato, M.G., Rodrigues, A.M., Castaneda-Ayarza, J.A. and Zeviani, C.H. (2014), "Estructura metodológica para evaluar el desempeño ambiental de los procesos industriales en ingenios cañeros", 49ª Asamblea Anual de CLADEA, Barcelona.

Rodrigues, A.M. and Rodrigues, I.C. (2003), "O desenvolvimento econômico regional no contexto do desenvolvimento sustentável", Anais do XXIII Encontro Nacional de Engenharia de Produção (ENEGEP), Ouro Preto.

Rohrich, S.S. and Cunha, J.C. (2004), "A Proposição de uma taxonomia para análise da gestão ambiental no Brasil", *Revista de Administração Contemporânea*, Vol. 8 No. 4, pp. 81-97.

Roodchenko, S.V. and Banin, A. (2015), "MindDecider theory", personal communication, December 2.

Saaty, T.L. (1991), *Método de Análise Hierárquica*, Makron Books do Brasil Editora Ltda, Rio de Janeiro.

Searcy, C., Karapetrovic, S. and McCartney, D. (2005), "Designing sustainable development indicators analysis for a case utility", *Measuring Business Excellence*, Vol. 9 No. 2, pp. 33-41.

Seiffert, M.E.B. (2009), *ISO 14001Sistemas de gestão ambiental*, Atlas, São Paulo.

Sosa, B.S., Banda-Noriega, R.B. and Guerrero, E.M. (2013), "Industrias de fundición: Aspectos ambientales e indicadores de condición ambiental", *Revista de Metalurgia*, Vol. 49 No. 1, pp. 5-19.

Tahir, A.C. and Darton, R.C. (2010), "The process analysis method of selecting indicators to quantify the sustainability performance of a business operation", *Journal of Cleaner Production*, Vol. 18 No. 16, pp. 1598-1607.

Thoresen, J. (1999), "Environmental performance evaluation: a tool for industrial improvement", *Journal of Cleaner Production*, Vol. 7 No. 5, pp. 365-370.

Further reading

Chiaverini, V. (1986), *Tecnologia mecânica: Processos de fabricação e tratamento*, McGraw-Hill, São Paulo.

Jabbour, C.J.C. and Santos, F.C.A. (2009), "Sob os ventos da mudança climática: Desafios, oportunidades e o papel da função produção no contexto do aquecimento global", *Revista Gestão and Produção*, Vol. 16 No. 1, pp. 111-120.

Naves, R.M. (2008), "Análise hierárquica de sistema de bilhetagem eletrônica", Dissertação (mestrado), Universidade Federal do Rio de Janeiro, Rio de Janeiro.

Odum, H.T. (1996), *"Environmental Accounting: Energy and Environmental Decision-Making*, John Wiley and Sons, New York, NY.

Oliveira, A.A., Costa, J.A.F. and Neto, M.V.S. (2011), "Aplicação do método de análise hierárquica na tomada de decisão para a adoção de computação em nuvem", FGV-EAESP In: SIMPOI, São Paulo.

Shimizu, T. (2010), *Decisão nas organizações*, No. 3, Atlas, São Paulo.

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