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SUSTAINABILITY IN PELLETIZING IRON ORE THROUGH THE INDUSTRIAL ECOLOGY AND CLEANER PRODUCTION PROGRAM

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ABSTRACT

This study aims to analyze the practices of a pelletizing iron ore industry with respect to adoption of pollution prevention measures, suggested by applying the concepts of Cleaner Production and Material Flow Analysis. The technical procedure adopted was the case study, the data collection was done through direct observation, with field research and literature review. The main results were obtained from analysis of company reports available to the public, but require a more detailed quantification of data. The study concludes that the identification of environmental opportunities is possible through the proposed implementation of Cleaner Production program, which provides better results when combined with the precepts of the industrial ecology tool, the Material Flow Analysis.

Keywords: environment management; cleaner production in pelletizing iron ore process; material flow analysis.

1. INTRODUCTION

Exports have been the great lever of domestic production of iron ore in Brazil. The main reason is the Chinese imports that have become the major importer of Brazilian iron ore since 2002. China, that in 2001 bought 20.3 million tons (megatons), started buying in 2007 a total of 89.0 Mt, an increase of 338% in these amazing 6 years (BRAZIL, 2009).

The steel industry in China continued to grow and the country increased by 11% imports of iron ore and concentrates. Diversification of Chinese imports, with the encouragement of South Africa, did not alter the dependence this country has of its major suppliers, Australia and Brazil. China imported from these countries in 2011, 64% of its iron ore needs, without significant variation in the previous year (SAMARCO, 2012).

Brazilian exports of primary goods Iron in 2010 reached 311 million tons (IBRAM, 2011).

But along with economic growth there it is necessary to think about how to ensure the current production with a look at future needs, and most importantly, how to do this taking into account the social and environmental aspects, such as establishing the doctrine of sustainability.

Being the mining activity one of the most polluting in the world, what one intends in this work is offering opportunities to minimize environmental impacts, through proposals for a production scheduling-oriented concept of Cleaner Production, which finds backed on Material Flow Analysis, to facilitate its implementation.

Thus, based on this objective, the section 2 presents the methodological aspects that contributed to arrive to search results; then in section 3 is presented a survey of the relevant literature to the concepts of Cleaner Production and in section 4, the Flow Analysis Material; in section 5 is shown the contribution of this research, the case study, and also to characterize the activity of the company under review; in section 6 is explored the Material Flow Analysis from the perspective of Cleaner Production; in section 7 is made to interpret the data obtained and the conclusions of the research, and finally section 8 presents the conclusions.

2. METHOD

2.1. Subjects or Participants

The object of this paper is devoted to an industrial unit of pelletizing iron ore in Brazil, identified here with fictitious name Iron SA, and the methodological procedures used were based on the constraints of the research of an exploratory nature, as Gil (1999) defines its presence when it is developed in order to provide an overview about the fact determined.

The private company is a joint venture between two big international companies, operates an integrated project comprising mining, beneficiation and concentration of iron ore of low grade, as well as movement of the ore concentrate by pipeline, linking the two operating units of the Company. In industrial unit under review, pelletizing processes occur - processing the ore concentrate into pellets, its flagship product, and production flow for marine terminal itself.

With an installed production capacity of around 22.5 million tons, the production is substantially sold in foreign markets. In 2011, Iron SA sold 99% of steel production for 19 countries in the Americas, Asia, Africa and Europe. Although the Chinese market still represents a large part of sales of Iron SA, the trend is the increased presence of its products in the Americas, the Middle East and North Africa.

2.2. Apparatus

The case study is highlighted in this work, considering that the focus of research interest is focused on current phenomena, analyzed within the context of real business object of the study. For Gil (1999), the case study involves the profound and exhaustive study of one or a few objects in a way that allows its broad and detailed knowledge.

Exploratory research is supported by field research, the importance of which is defended by Dane (1990), whereby it is as a label that can be assigned to a collection of research methods involving direct observation of occurrences of natural events. Because this was an exploratory study, the function of your goal is to generate knowledge and practical application directed to the solution of specific problems (CERVO; BERVIAN, 2002). Andrade (2002) also highlights some of the primary exploratory research purposes, such as providing more information on the subject that will investigate, facilitate the

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delineation of research topic, guide the setting of objectives and the formulation of hypotheses, or discover a new type of focus on the subject.

2.3. Procedure

A qualitative descriptive study was done through literature that, according to Lakatos and Marconi (1991), seeks to explain a problem from theoretical references in published documents. The literature search to identify and analyze the existing cultural or scientific contributions on a particular subject, theme or issue. It covers all the literature ever published on the topic of study, and the main sources of quantitative data were obtained from the Annual Sustainability Report and Management Report and Financial Statements of the company.

Aiming which demonstrate the company's practices regarding pollution prevention, data collection was done through direct observation during field visits to the company's industrial unit. From here it was possible to establish a proposal for implementation of the program of Cleaner Production in the process of pelletizing iron ore for export, backed environmental tool in the Material Flow Analysis.

2.4. Cleaner Production Program

The need to reduce production costs, increase efficiency and competitiveness of these companies is in line with the adoption and deployment of Cleaner Production, which also contributes to the reduction of fines and penalties for pollution; facilitates access to lines credit; improves the health and safety of the worker; improves the company's image with consumers, suppliers and government; improves relationships with environmental agencies and the community, in addition to providing greater customer satisfaction (UNEP, 2002).

The practice of using cleaner production leads to the development and deployment of Clean Technologies in production processes. To introduce cleaner production techniques in a production process can be used several strategies in order targets environmental, economic and technological.

The National Center for Clean Technologies (CNTL), the office in Brazil resulting of joint efforts of the United Nations Industrial Development Organization (UNIDO) and the

ISSN: 2236-269X
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United Nations Environment Programme (UNEP), the prioritization of these goals is set in each company, through its employees and its policy-based management. Thus, depending on the case, you can have the economic point of awareness as to the definition and evaluation of adaptation of a production process and minimization of environmental impacts going to be a consequence, or conversely, environmental factors and aspects will be priority economic will become result (CNTL, 2002).

According to the booklet of CNTL (2002), the priority of Cleaner Production (Figure 1) is at the top (left) Flowchart: avoid the generation of waste and emissions (level 1). Waste that can not be avoided should preferably be reintegrated into the production process of the company (level 2). In their absence, recycling measures outside the company can be used (level 3).

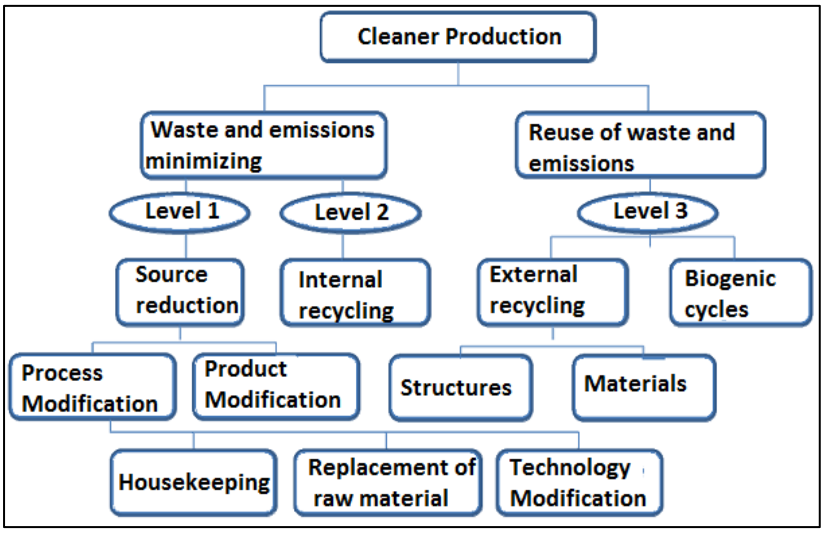

Figure 1. Escope of work of Cleaner Production. Data from CNTL (2012).

Domingues and Paulino (2009) define as housekeeping changes to internal processes using creativity, at low cost, without requiring significant technological changes and practices that address the prevention or minimization of waste, effluents and emissions; proper operation of equipment and better internal organization.

Costa (2002) points out that the basic idea of the Cleaner Production is based on the recognition that the control of pollutants after they have been generated, a technique known as end-of-pipe, is more expensive than pollution prevention. The control end-of-pipe means the installation of equipment such as filters, precipitators, scrubbers, for the

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case of atmospheric emissions as collect and clean the exhaust gases at various stages of the steelmaking process, but then require treatment of wastewater from the "washing" of the equipment, as well as the proper disposal of solid waste.

Costa (2002) explains that the control-end tube one polluting substance (such as powders exhaust emissions, for example) having been generated may result in a change from one substance to another half, without, however, eliminate the problem (liquid effluent generated from the gas washing controlled). Therefore, the fact that the control will not be fully effective, besides involving equipment and high cost operations led to the shift in focus to combat pollution. The important thing is to find ways to prevent or minimize the generation of polluting substance.

The rising cost of production inputs, the tightening of environmental regulations regarding waste disposal and environmental awareness of citizens are factors that lead industries to seek strategies for pollution prevention.

But the productive organizations face difficulties in maintenance and use of equipment and it is not always economically viable to purchase raw materials and supplies best quality, to meet the established principles of Cleaner Production.

According to research conducted by Costa (2002), technologies for abatement of air pollutants are classified into two major groups: Control of Pollution (CP) and Pollution Prevention (PP). The technologies consist primarily of CP system control atmospheric emissions, and techniques are based on end-of-pipe, will not be treated here. In the case of PP technologies, Costa (2002) lists a number available for all production steps and can be classified as:

- Changes in technology, including new equipment, automation and layout change;
- Change or reduction of inputs, including materials and energy (energy efficiency measures);
- Operational procedures and maintenance;
- Recycling internal.

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Thus, Oliveira Filho (2001) defines Cleaner Production as a technology strategy that requires permanent and continuous actions to conserve energy and integrated feedstock, replacing non-renewable resources with renewable and eliminate toxic substances, reducing waste and pollution resulting products and production processes.

2.5. The Analysis Flow Material

According Bartelmus (2002), Material Flow Analysis (MFA) was developed initially for specific commodities, the U.S. Bureau of Mines in the 70s, and generalized nationally by American Wuppertal Institute for Climate, Environment and Energy, as a tool to evaluate the environmental sustainability of growth and development of an economy. The purpose of a Material Flow Analysis is to monitor and quantify the flow of materials in a defined situation and for a defined period of time (BARRET et al, 2002).

For Bringezu and Moriguchi (2002), AFM is based on the paradigm of common industrial metabolism, concept firstly proposed by Ayres (1992) as the integrated set of physical processes that convert raw materials, energy and labor into finished products, energy and waste. Yet for Bringezu and Moriguchi (2002), the vision paradigm of a sustainable industrial system is characterized by physical exchanges minimized and consistent between human society and the environment, with the cycles of material internal flows driven by renewable energy.

Yet according to the authors above, the materials that are extracted by economic activities, but who do not normally serve as input for the production or consumption activities (such as the mining of mining) are called hidden flows or "ecological rucksacks". Bartelmus (2002) uses the AFM with the objective to evaluate the use and movement of materials through a key indicator, the Total Material Required (TMR) and various derivatives indicators, such as the Direct Material Input (DMI), measures the input of materials used in the economy, economic value and used for production and consumption activities (equals domestic extraction plus imports), the Domestic Processed Outputs (DPOs) or domestic processed outputs (own translation), representing the total mass of material which has been used in the domestic economy before flowing into the environment, and Total Domestic Output (TDO) equals the sum of DPO and disposal of

http://www.ijmp.jor.br v. 4, n. 1, January – June 2013.
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unused domestic extraction. The schematic flow of material in a large savings can be seen in Figure 2, below.

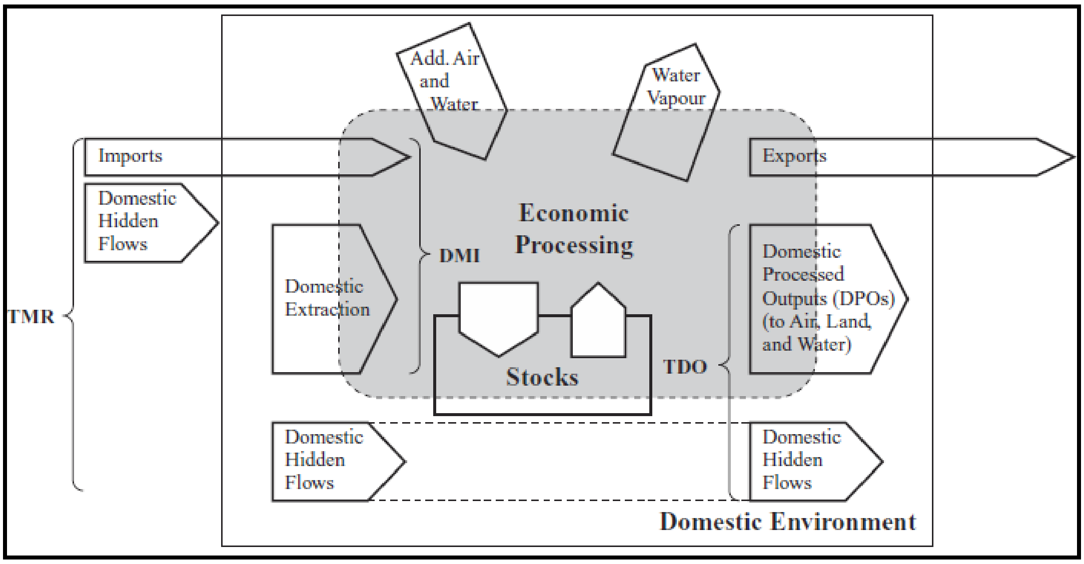

Figure 2. Flow materials of a broad economy. Based on BRINGEZU and MORIGUCHI, 2002.

Also according Bartelmus, the TMR reflects the total use of materials as a ratio of income through the economy, including its "ecological rucksacks". The scope of sustainability with such yield economic performance must occur at a level compatible with the "ecological balance" in the long run the planet.

To Bringezu and Moriguchi (2002), the services provided or the economic performance (in terms of value added or GDP) may be related to both indicators of input or output to provide efficiency measures. For example, the ratio of GDP by DMI indicates the productivity of direct materials. The GDP measures the TDO by economic performance in relation to significant losses to the environment. Set the value in relation to the inputs and outputs provides important information about the eco-efficiency of an economy. The interpretation of these measures should always consider the trends of absolute parameters. The latter are usually also provided on a per capita basis to support international comparisons.The representation of the mass balance in the production process of an ore (generic) is shown in Figure 3.

http://www.ijmp.jor.br v. 4, n. 1, January – June 2013.
ISSN: 2236-269X
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In industrial ecology, the Life Cycle Assessment (LCA) has been used as a tool responsible for review and compilation of inputs, outputs and potential environmental impacts of a product during its life cycle (SUH; HUPPES, 2005).

According to Hinz (2007), LCA is concerned with environmental preservation coupled with technological development and its function is to transform the material flows cyclically and ecological, which encompasses the process from capture of natural resources to final disposal, also considering aspects such as: recycling and reuse.

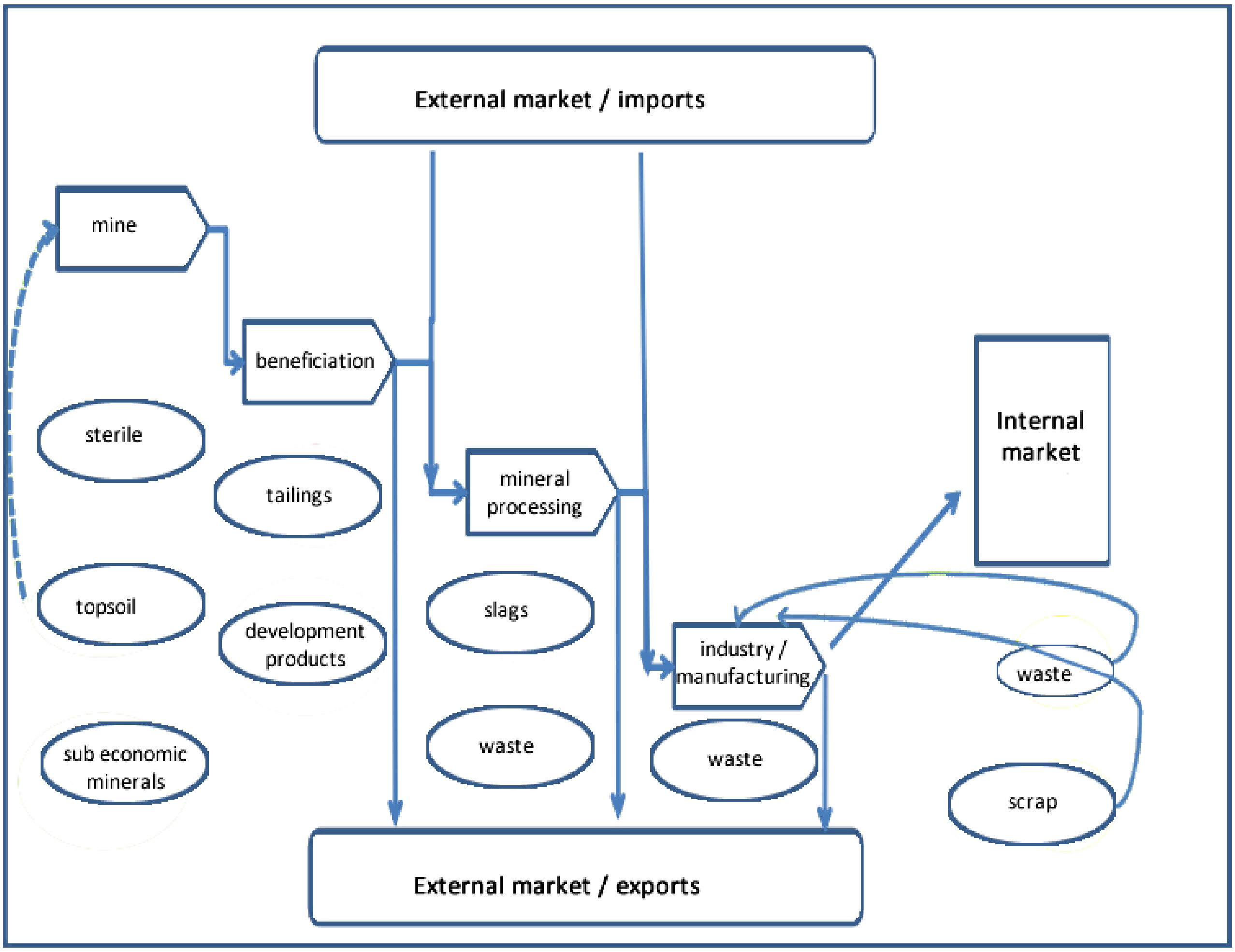

Figure 3 Generic mass balance of the ore. Data from Brazil, 2009.

The LCA tool is standardized and structured by the international standard of the International Organization for Standardization (ISO) ISO 14000, environmental management standards ISO 14040 specifically: LCA, Principles and Structure and ISO 14044: ACV, Requirements and Guidelines. Its structure consists of four interdependent

ISSN: 2236-269X
DOI: 10.14807/ijmp.v4i1.55

steps, one of the Life Cycle Inventory, which estimates the resource consumption and the amount of waste streams and emissions caused by or attributable to the life cycle of a product (ROJAS, 2010).

The Life Cycle Inventory, one of steps of LCA, keeps more similarities with the Material Flow Analysis, which appears most appropriate tool for the type of study to which this work is dedicated.

3. CASE STUDY: EXPLORING THE MATERIAL FLOW ANALYSIS FROM THE PERSPECTIVE OF CLEANER PRODUCTION

After the ore is mined, processed and concentrated, it is mixed with water and transported in the form of pulp by two pipelines, approximately 400 miles long each, up pelletizing plants, in the industrial unit under study, where the pulp is received and subjected to a process for separating solid what is and what is water.

The solid fraction is directed to the production process, where the iron ore concentrate is converted into pellets, of sizes between 8 and 16 mm in diameter. These undergo a heat treatment in acquiring desirable characteristics to the steel industry is in the process of blast furnace or direct reduction to.

The surplus production of iron ore concentrate, pellets out of specification, known as thin (sinter feed and pellet feed), are also sold. Thus, only pelletizing iron ore belongs to the scope of this work.

As in Material Flow Analysis, the inputs and outputs in the production process must be qualified and quantified to support the evaluation of Cleaner Production. This is the first step to implement a program of P + L, according to the CNTL (2003), after a detailed analysis of the flowchart allows visualization and definition of qualitative flow of raw materials, water and energy in the production process, visualization waste generation during the process, thus acting as a tool to obtain data required for the formation of a strategy of minimizing the generation of waste, effluents and emissions.

The next step for implementing P + L, according to the CNTL (2003), is drawing up the material balance, where indicators are set forth and identified the cause of the

ISSN: 2236-269X
DOI: 10.14807/ijmp.v4i1.55

generation of waste, i.e. exactly equal to that followed in the Flow Material Analysis to be made then the identification of options Cleaner Production.

After lifting the flowchart of the production process of the company, the survey is made of the quantitative data of existing environmental and production using available sources, as can be seen in Figure 4, for the case of the production process of the company under study.

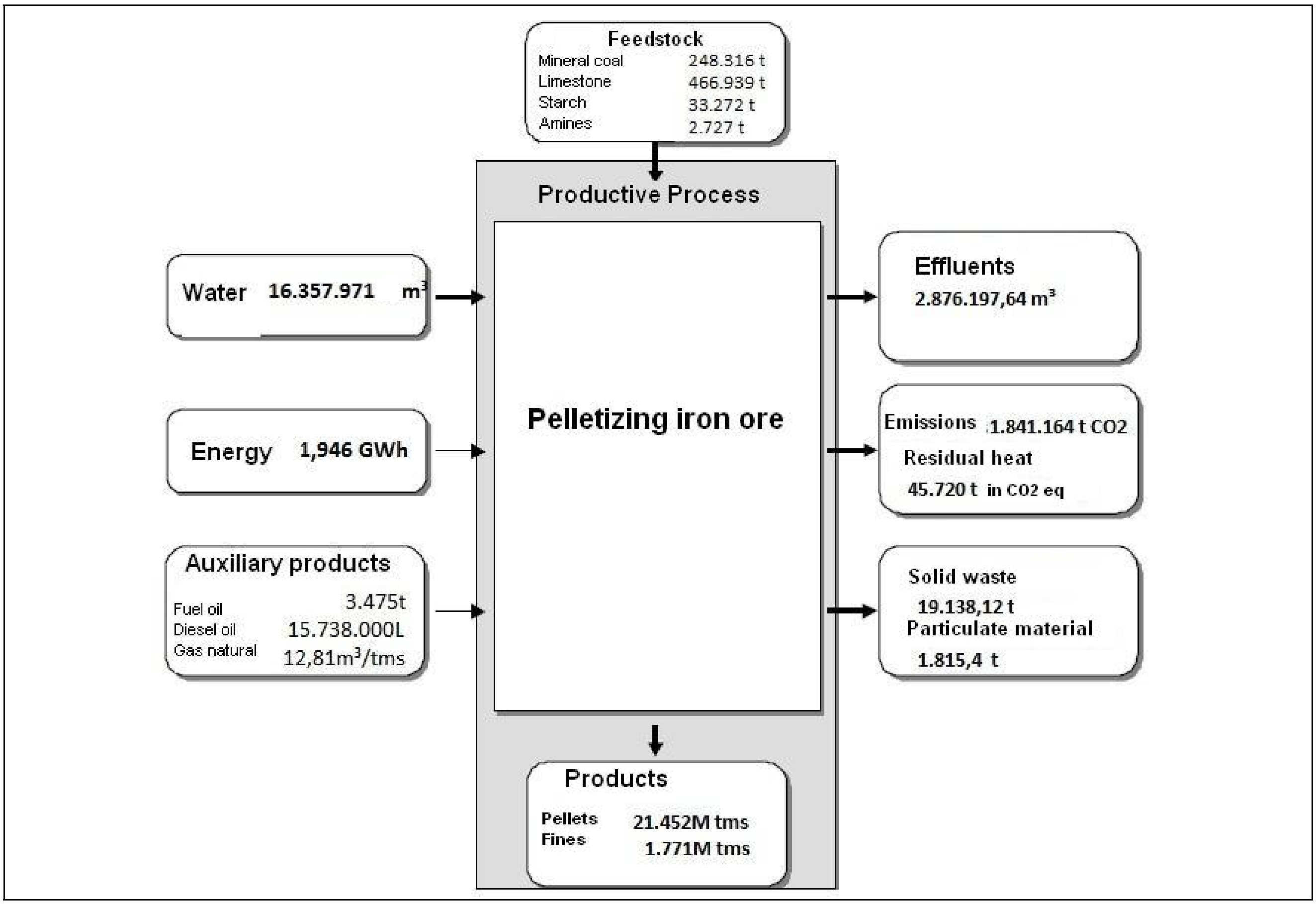

Figure 4 Qualitative and quantitative analysis of inputs and outputs of the production process of the Iron SA. Base on CNTL, 2003.

The annual analysis of qualitative and quantitative inputs and outputs of the production process of Ferro SA (above) have elaborated the tables below, necessary to compose the environmental diagnosis.

In Table 1, the cost presented related to raw materials, it was considered the value (most significant) to acquire iron ore from third parties, since the company has its own operating mine ore, and the purchase takes place in casual occasions . The cost of the

ISSN: 2236-269X
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water is unknown due to not declared in any of the reports of the company that served of basis for this research.

Table 1 Table of raw materials, inputs and auxiliary. Base on CNTL, 2003

	Quantity	Cost
Energy	1,946 GWh	US$ 20,4 millions
Feedstock	751.254 t	US$ 121,7 millions
Water	16.357.971 m³	unknow
Auxiliary	304,04M m³/3.475t	US$ 1.360.610

Still on the data in Table 1, the cost related to "auxiliary" was considered the total of raw materials, consumables and changes in finished goods and work in process inventories recognized in cost of sales of the Company.

Among the auxiliary materials, for purposes of calculating the total natural gas defendant appealed to the given volume traded in the year 2011 of exercise Iron SA, which was a total of 22.506 tons of dried metric (tdm) of iron ore. Thus, based on qualitative and quantitative analysis of inputs and outputs of the production process of the company (Figure 4), we arrived at a total of 288.3 million cubic meters of natural gas required in the pelletizing operation. This value combined with the diesel fuel used in the production (constant in Figure 3) gives the amount of volume at 304.04 M inputs in m³ (the amount of fuel oil is provided beside in the table).

In Table 2, the cost of products (sinter feed and pellet feed) is not considered, since they are sold as surplus production (which is essentially based on pellets) and are reversed in profit for the Company. In the amount of effluent, approximately 2.9 million cubic meters, it is being considered only the effluents from the pelletizing operation (one cannot ignore the importance of wastewater generation during beneficiation of iron ore, but this phase does not belong to the scope of this work).

Table 2 Table of byproducts, waste, effluents and emissions. Base on CNTL, 2003

	Quantity	Cost
Byproduct	1.771M tdm	Not present
Waste	19.138,12t	Σ = US$ 175 millions
Effluents	2.876.197,64M m³	
Emissions	1.841.164t in CO_2 eq*	

ISSN: 2236-269X
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Even with regard to Table 2, the cost that relates to waste, effluents and emissions, is considered in the budget of the total investment planned for the year 2012 exercise in the treatment of these components, as presented in the Management Report and Financial Statements of Iron SA.

4. RESULTS

With the information from the environmental diagnosis, the next step to implement a program of Cleaner Production, according to the CNTL (2003), is to select among all the activities and operations of the focus work. This information is analyzed considering the legal regulations, the amount of waste generated, the toxicity of the waste, and the costs involved.

As an approach in this work, it was decided to focus on issues that relate to air emissions at the plant of S. Ferro A. in particular the emission of greenhouse gases, the ability to cause warming of the globe, which implies several consequences harmful to the planet, especially the occurrence of climate change.

The Brazilian Law, CONAMA Resolution n. 436/2011, Annex XIII establishes emission limits for air pollutants generated in the pelletizing plant iron ore, whose kiln exhaust system is touted as emission source punctual, being allowed up to 70 mg/Nm3 for Particulate Matter, 700 mg/Nm3 for SO2 and 700 mg/Nm3 for NOx (MMA, 2011). Seeking to meet the demands that the previous law, the main type measure Pollution Prevention (PP), to reduce greenhouse gas emissions, the Iron S. A. promoted the substitution of fuel oil by natural gas as an energy source in pelletizing furnaces, the initiative also resulted in cost savings (CEPEMAR, 2009).

Even with regard to atmospheric emissions, is accented generation of particulate matter, as can be confirmed by qualitative and quantitative analysis of inputs and outputs of the production process of pelletizing the company in question (Figure 4). However, in this regard, are observed more actions for the Control of Pollution (CP), one of them is the

*It is a metric measure used to compare the emissions from various greenhouse gases (GHGs) based on global warming potential of each. Represents the result of multiplying the tons of GHG emitted by its global warming potential. For example, the global warming potential of methane gas is 21 times higher than the potential of CO2. So, tell us that the CO2 equivalent of methane equals 21 (IPAM, 2013).

http://www.ijmp.jor.br v. 4, n. 1, January – June 2013.
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wind fence (about wind, our translation), a structure about 30 meters high which acts as a screen that involves all the stockyard. This device reduces the incidence of wind, minimizing the susceptibility of Entrainment of particles that may be emitted to the environment.

Figure 5 Wind fence (photo of the author's field visit)

Another measure adopted as CP to improve the environmental quality of the site is the enclosure of the towers of transfers in the courtyard of pellets (Figure 6), because detachment of dust kicks in (transfer between conveyor belts).

Figure 6 Cloistered tower of Transferring (photo of the author's field visit)

The dust collector, venturi-type, is also a dust collecting device installed in the towers transfer, which are the places where there are drop pellets in transposing the direction of flow of the product. There are suction points in kicks (where there is detachment of powder pellets), and the air with airborne dust is collected and is directed to

http://www.ijmp.jor.br v. 4, n. 1, January – June 2013.
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the gas scrubber, which sprinkles water for cleaning. The powder is then separated from the wastewater system and that subsequently goes to the clarifier.

Figure 7 Dust collector (photo of the author's field visit)

As for technology shares under the Control of Pollution, the Iron S. A. invested with the installation of Electrostatic Precipitators, equal to that shown in Figure 8, with the aim of reducing particulate emissions from pellet plants, so that they reach an adequate performance to environmental requirements.

Figure 8 Electrostatic Precipitator in Iron SA (photo of the author's field visit)

Another technological resource control air pollution caused by the dispersion of particulate matter in the air bag filters are used in other areas of the production process of the Iron S. A. but in a smaller dimension, which mechanism is explained by Cavalcanti (2012) which consists in that particles are separated from the exhaust gas through a

http://www.ijmp.jor.br v. 4, n. 1, January – June 2013.
ISSN: 2236-269X
DOI: 10.14807/ijmp.v4i1.55

porous material, allowing high removal efficiencies, its power consumption is high and can operate only a limited range of temperature and humidity of the gases.

Finally, when iron ore, in pellets form, are arranged in stacks in the yard ore, and it is the applicated a polymer, the suppressor powder diluted in water adheres to the surface of the pellet forming a film that prevents dust particles from detaching and issued the environment by wind.

5. DISCUSSION

The main results were obtained from analysis of company reports available to the public via the world wide web. Based on them we observe that the company Ferro S. A., guided by economic strategy applies, even if informally, some of the recommendations of the Cleaner Production program to promote technological change, change or reduction of inputs and internal recycling, especially as it is for the reuse of water in your production process.

However, it is possible to verify that there is still waste in the utilization of iron ore mainly in powder form during the production process and the emphasis is still in control, and not for the prevention of pollution. In an attempt to solve the problem, most investments, seen in section 7, is still done in the control end of pipe, one conducted after the waste is generated.

However, what is observed is that most of these investments would be better spent if it were based on a more detailed analysis of the Material Flow of the process under study. Thus follows the line of recommendation Brigenzu and Moriguchi (2002) when they say that this analysis is increasingly used to provide the basis for measures of political, strategic and environmental, and evaluate the effectiveness of such measures.

It is noteworthy that the inferences developed in this work were based on data provided exclusively through the company's own statements, contained in its reports for accountability to society, and that lack of a more detailed quantification of data, rendering it impossible to check these values, as observed in the preparation of Table 1, which showed no data regarding the acquisition cost of the water required to feed the production process.

ISSN: 2236-269X
DOI: 10.14807/ijmp.v4i1.55

Despite the field visit, it is understood that a closer relationship with the company could bring more information that is not found in reports, thus enabling the application of tools to analyze environmental management as coherently as possible with the reality of industrial dynamics studied.

Another factor that makes the limited studies and applications of these tools coincides with the line of reasoning of Rojas (2010), states that it is unknown when the publication of a database containing information of emissions, pollutants and / or waste generated in different industrial activities in Brazil.

Finally, it is believed that the Cleaner Production program when integrated with Industrial Ecology, allow to achieve the purpose of monitoring progress towards sustainability can be improved continuously.

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