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IDENTIFICATION OF IMPACTS TO HUMAN HEALTH AND THE ENVIRONMENT IN THE PROCESS OF BLENDING WASTE FOR CO-PROCESSING

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ABSTRACT

Blending is an activity intended for processing and preparing waste in the form of blends that are destined for co-processing in cement industries. This study aimed to identify the impacts generated in the various stages of blending. Through Life Cycle Assessment, impacts were estimated on an average production profile of 30,650 t/year of blends. The system boundary approach was “gate to gate” and the functional unit 1 t of blends. The impact assessment methodologies employed were ReCiPe and Impact 2002+. The results show that by the ReCiPe method, Human Toxicity was responsible for 53% of the total impact, caused by the emission of metals such as selenium, manganese, arsenic, and barium. For the Impact 2002+ method, Inorganic Inhalables had the highest total impact (51.8%) caused mainly by nitrogen oxides. It is concluded that the blending has a greater impact on human health, especially on the health of workers who suffer from higher exposure. It is recommended that the environmental and labor control agencies reevaluate the activity, prioritizing process automation studies, epidemiological studies, and continuing the investigation of the impacts of burning the blends in the clinker kilns in a “cradle to gate” approach.

Keywords: Hazardous waste; Toxicity; Toxic substances; Health impacts; Environmental impacts.

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1. INTRODUCTION

The co-processing technique has been used worldwide in order to reduce fossil fuel and raw material consumption in cement manufacturing. It is the use of waste from industrial activities, such as tires and even urban solid waste, as alternative fuels, and raw materials (Lamas *et al.*, 2013, p. 201).

The reduced use of fuels from non-renewable sources due to the use of alternative waste has provided environmental benefits to the cement industry, such as the reduction of greenhouse gas emissions and energy maximization (Georgiopoulou and Lyberatos, 2018, p. 224).

The opportunities to use urban and industrial waste in cement manufacturing must be objectively evaluated (Güereca and Juárez-López, 2015, p. 741). To be used as fuel and raw material for clinker production, the waste must be pre-treated before being burned.

Tukker (1999, p. 341) used life cycle assessment (LCA) to compare different forms of waste co-incineration in cement production and raised two concerns: (i) the input of contaminated waste can lead to high concentrations of metals in cement; and (ii) the lack of proof that cement kilns do not generate additional dioxin emissions. Therefore, the findings of this study recommended the requirement of the precautionary principle when waste of different compositions is used as a substitute for traditional fuel.

Al-Dadi *et al.* (2014, p. 1103) investigated the environmental impact at some cement plants in Saudi Arabia and found radiological impact as a result of the concentrations of uranium isotopes found in soil samples.

Huang *et al.* (2012, p. 13031) warned of excessive heavy metal emissions in China due to uncontrolled use of waste co-processing in furnaces. In Japan, such a problem is reduced thanks to a mature waste sorting and management system (Li *et al.*, 2015, p. 123).

The literature on the subject has noted differences in pretreatment processes between developed and developing countries. In most European cases, the risks in waste preparation for co-processing are minimized through process automation (Milanez *et al.,* 2009, p. 2146).

Stafford *et al.* (2016, p. 1293) conducted a case study on the impacts on cement production of a Brazilian plant and stated that there are still few scientific studies developed on environmental and human health impacts of coprocessing in the cement industry.

In Brazil, many of the waste preparation activities in co-processing are still performed with the support of manual labor by employees (Milanez *et al.*, 2009, p. 2146). This activity is known as blending, the purpose of which is to remove moisture from the waste and give fluidity to the material when added to the clinker kiln (Rocha *et al.*, 2011, p. 3).

In blending, the residues are mixed in such a way as to acquire properties similar to commonly used fuels, in order to meet legislation; one of them is the calorific content. This waste cocktail, in solid or liquid form, is generically called blend, and serves as an alternative fuel to replace traditional fuels - such as petroleum coke - or the raw materials and additives - gypsum, iron oxide, aluminum oxide - used in cement production (CONAMA Resolution No. 499, 2020, p. 50).

The number of blending plants in Brazil is currently nineteen, and 47% are located in the Southeast (Santos, 2020, p. 87). It should be noted that, in addition to serving the cement sector, the blending activity provides direct support to various branches of industry and commerce, which find in this activity a continuous flow for the treatment and final disposal of their hazardous or non-hazardous waste that has been contaminated.

Per the National Classification of Economic Activities - CNAE, blending encompasses two codes: 38.22-0-00 - Treatment and disposal of hazardous waste; and 38.22-1-00 - Treatment and disposal of non-hazardous waste (Brazilian Institute of Geography and Statistics [IBGE], 2019). The Risk Classification by Regulatory Norm 4 of the Labor Department of the Ministry of Economy (NR-4) assigns risk grade 3 for both codes (Ordinance No. 3214, 1978, p. 10423). According to the Polluting Activities Classification Manual MN-050.R-5 of the Rio de Janeiro State Environment Council (CONEMA-RJ, 2011, p. 58), the blending activity has the polluting potential classified as medium.

In this activity, workers work under precarious safety conditions, when performing the management of hazardous waste, leaving them exposed to multiple toxic substances, inhalation of gases and vapors with strong unpleasant odor, in addition to direct contact with liquids, oils, and chemicals, such as paints and solvents, coolant, and engine oils. Many of these risks are increased by the existence of broken drums and packages without proper identification (Milanez *et al.*, 2009, p. 2148).

Among the toxic compounds present in paint sludge, the organic solvents stand out, as they are highly flammable, toxic, and have a strong odor. The main substances that represent this group are benzene, toluene, xylene, and cyclohexane (volatile organic compounds - VOCs). Most VOCs are central nervous system depressants, irritate the eyes, skin, and respiratory tract, and cause nausea and allergic reactions (Milan, 2017, p. 68).

The indiscriminate burning of used lubricant oil without prior demethanizing treatment generates significant metallic oxide emissions, besides other toxic gases, such as dioxin and sulfur oxides (Milan, 2017, p. 63).

Junior and Braga (2009, p. 2010) found a process of illness among cement plant workers who handled the waste before it was co-incinerated in the cement kilns. They highlight symptoms such as: discomfort to the unpleasant odor, headache, nausea, burning eyes, breathing problems, skin contamination, itching, dizziness, and even fainting.

The toxicity is related to the inherent characteristics of the substance - in this case, waste - under the interference of the work process, and may result in greater or lesser impact on the worker's health (Junior and Braga, 2009, p. 2010).

The alternative found was to remove the blending activities from inside the cement plants, transferring them to specific homogenization and mixing plants, which became known in Brazil as *blendeiras* (blenders). However, the several irregularities were still being verified, with important impacts to human health, even affecting the neighboring population due to the unpleasant odors exhaled (Milanez *et al*., p. 2149).

Santos (2020, p. 116) studied the health problems of the neighboring populations in the blending activities in Magé - RJ and found complaints about unpleasant smells in most of the people surveyed, in addition to discomforts, such as frequent headaches (22.8%), eye irritation (18.2%), and hoarseness (18.2%). In all age groups, the most recurrent symptoms are cough on waking up and cough during the day and night, especially in the children interviewed (71, 4%) and in the elderly (50%).

Thus, this paper sought to close this gap by assessing in more detail the cause and potential health and environmental impacts of the blending stages, including knowledge on the residues used, their toxic potential, and the identification of the most significant environmental aspects linked to the set of processes characteristic of this activity.

2. METHODS

Rocha *et al*. (2011, p. 6) mention that co-processing is a broad field of investigation for Life Cycle Assessment (LCA) and recommend that each type of co-processed waste should be subject to study, since its physical and chemical characteristics can alter the results.

The LCA method has as its main references the technical standards NBR ISO 14040 (2006) and 14044 (2006), which seek to assess the environmental impacts of a product or service from its inception to its final disposal (from cradle to grave). This technique comprises four steps: objective and scope definition; life cycle inventory analysis; impact assessment; and interpretation.

Objective and scope definition

The study objectives and scope (system boundaries), the Lifecycle Impact Assessment (LIA) methods and the functional unit are established as appropriate (Spiro and Stigliani, 2009, p. 326).

Life cycle inventory analysis (LCI)

Inputs are quantified using mass, energy, and output balances; emissions are released to air, soil, and water at all process steps included in the system boundaries (Spiro and Stigliani, 2009, p. 326).

Impact assessment

Quantitative and/or qualitative analysis used to identify, characterize, and evaluate the potential impacts of interventions identified in the LCI analysis (Spiro and Stigliani, 2009, p. 326).

Interpretation

Results verification against the scope. In this phase, the contribution of processes and elementary flows to the result is often evaluated (Ugaya, 2013, p. 290).

3. OBJECTIVE AND SCOPE

This study aimed to identify the impacts generated in the blending stages. The impacts were analyzed in the fourteen steps identified. The functional unit chosen was one ton of blend produced, that is, the product of blending.

For the purposes of delimiting the system boundary, only the preparation of the blends in their various stages was considered, i.e., a "gate-to-gate" approach. This study did not compute the impact of the transport of these wastes to the blender, nor the consumption of the blend in the clinker kilns of the cement plants.

Two methods of lifecycle impact assessment were chosen, ReCiPe Midpoint (E) v1.04 World ReCiPe E and Impact 2002+ v2.06. In the first methodology, all categories were considered, aiming for a comprehensive analysis. In the second method, four categories linked to human health were chosen, aiming for a deeper understanding of the main indicator substances and their possible adverse effects.

Lifecycle Inventory

LCI was initially built in the National Portal of Environmental Licensing of the Ministry of Environment with the search for enterprises that performed the blending activity outside the physical space of cement plants. To this end, the expression "waste blending" was typed in the field intended for the search of the economic activity. Two blending firms located in the Metropolitan Region of the State of Rio de Janeiro that supply blends to the cement pole located in the municipality of Cantagalo - RJ (Ministério do Meio Ambiente [MMA], 2019) were chosen.

From there, on the portal of the state environmental agency, which licensed these plants, in possession of the administrative process numbers, various documents were accessed, such as authorizations for the movement and treatment of hazardous waste, inspection reports, opinions for issuing licenses, contaminated area reports, and environmental audits (State Environmental Institute [INEA], 2019).

All input and output data correspond to the records of six years (2010 to 2015) of operation at both plants. The data were recorded in spreadsheets and transformed into a single average production profile of 30,650 t/year for analysis in this study.

The survey registered the reception of class I and II residues as the main input, coming from sixty-one Brazilian industry and commerce activities, of which 90% are generated in the state of São Paulo. The contribution percentages of these sectors are as follows: ports (45.94%); oil and gas (20.48%); waste management and recycling (11.13%); electric energy (5.82%); chemical industry in general (3.47%); lubricants (3.11%); paints and varnishes (2.80%); automotive (2.11%); aviation (1.31%); and other activities smaller than 1% (3.84%).

The waste arrives to the blenders in several ways: in bulk in dump trucks, or packaged in drums, bins, containers, big bags, and various packages. A total of one hundred and seventy-five types of waste were registered to be treated; of these, 72.58% are in a solid and/or semi-solid state, and 27.42% are in a liquid state.

The distinct percentages of the waste used in the production of the solid blends are as follows: contaminated soil (39.83%); oily sludge (16.35%); grease (8.89%); chemical waste and various reagents (6.59%); contaminated sand (4.08%); paint sludge - water based (2.96%), solvent based (2.29%); STP sludge (2%); resins (1.94%); contaminated gravel (1.87%); other waste smaller than 1% (11.59%).

The liquid residues presented the following percentage distribution: lubricants (39.43%); solvents (23.54%); ethanol (9.98%); alkylbenzene sulfonate (5.33%); ethoxylated alcohols (5.25%); iron sulfate (4.25%); diesel (2, 69%); phosphoric acid (2.04%); formaldehyde (1.61%); fatty acid (1.32%); oils (1.32%); oily water (1.01%); and other liquid wastes smaller than 1% (5.23%). Also computed were structuring and chemical agents, such as maravalha (sawdust) and virgin lime, respectively, which are mixed with the waste in the blending (INEA, 2019).

The main freshwater inputs come from underground wells, and consumption is recorded from water grant registrations by the state environmental agency. The resource is used mainly for washing drums and metallic parts that come contaminated, and its effluents are captured for the liquid blends line. The cleaned metallic parts are sent to the recyclers.

All outputs were detailed in the various blending processes by averages: of atmospheric emissions measured in air filters; of sanitary and industrial effluent emissions to water; of metals emissions to soil and groundwater; in addition to the generation of waste materials forwarded to other forms of treatment and final disposal (INEA, 2019).

Table 1 presents the LCI with the main substances:

Lifecycle Impact Assessment

In both methods, first the characterization, i.e., the contribution of each impact, was performed. For this, equivalence factors are used for each raw material or emission - for example, for human toxicity, a value is used for the emitted substance that corresponds to the reference unit kg 1.4 DB eq (dichlorobenzene equivalent).

Normalization, in turn, consists in evaluating the characterization results against a benchmark, which means how much a world citizen was responsible for a given impact category in a given year. Since the SimaPro Data Server (2006) database with *ecoinvent* was also used, resulting in many entries in the inventory, a 95% mass cutoff was made, i.e., substances that contributed less than 5% to the impact under analysis were disregarded. This application occurred in both characterization and normalization. The software SimaPro v.7.2 (2010) was used for the analysis procedure.

The ReCiPe hierarchist v.1.04 methodology is summarized as a continuation of the Eco-indicator 99' and CML 2000 methods (Mendes *et al.*, 2016, p. 163). In this study, only midpoint impacts will be analyzed, with a view to reducing uncertainties.

Table 1. LCI for 1 t of blend produced

Flow	Comp.	Substance	Unit	Value
Inputs	Raw material	Water	m3	7.60E-01
		Mineral coal	t	2.50E+00
		Copper	kg	6.23E+00
		Chromium	kg	5.50E-01
		Iron	kg	9.43E+02
		Natural Gas	m3	3.00E+01
		Nickel	g	1.12E+02
		Arable, non-irrigated occupation	m2a	8.11E+02
		Occupation, built up industrial area	m2a	9.98E+00
		Occupation, construction site	m2a	1.52E+01
		Occupation, permanent harvest, intensive	m2a	5.46E+02
		Occupation, forest, intensive short cycle	m2a	2.83E+02
		Occupation, mineral extraction site	m2a	9.19E+00
		Crude oil	t	1.81E+00
		Forest transformation	m2	1.15E+00
		Rainforest transformation	m2	1.03E+01
		Forest transformation, extensive	m2	9.90E+00
		Forest transformation, int. suppression	m2	1.03E+03
		Forest transformation, int. short cycle	m2	1.08E+01
		Forest transformation, intensive	m2	1.03E+01
Outputs	Air	Carbon dioxide, fossil	kg	1.20E+04
		Methane	kg	7.90E+01
		Dichlorodifluoromethane, CFC-12	g	3.44E+01
		Chlorinated hydrocarbons	g	1.51E+02
		Selenium	mg	8.91E+02
		Nitrogen Oxides	kg	5.40E+01
		Carbon Monoxide, Biogenic	kg	7.14E+00
		NMVOCS	kg	1.09E+01
		Nitrogen Dioxide	g	5.11E+03
		Sulfur Dioxide	kg	5.55E+01
		Particulates, < 2.5 um	kg	5.38E+00
		Particulates, > 2.5 um, and < 10 um	kg	5.78E+00
		Radon-222	kBq	1.23E+06
		Carbon-14	Bq	6.02E+04
		Ammonia	kg	6.83E+00
	Water	Manganese	kg	4.10E+00
		Arsenic, ion	g	5.34E+01
		Barium	g	4.75E+02
		Phosphate	kg	1.55E+01
		Nitrate	kg	3.35E+01
		Phosphorus	g	2.56E+02
		Manganese	kg	4.13E+00
		Vanadium ion	g	1.18E+02
		Zinc ion	g	1.25E+03
		Beryllium	g	7.88E+00
		Selenium	g	2.25E+01
		Cobalt	g	1.76+02
		Nickel, ion	g	6.40E+02
	Soil	Cypermethrin	mg	2.52E+03
		Phosphorus	g	1.07E+01
		Atrazine	g	2.28E+01
		Copper	mg	-1.84E+03

Source: Aguiar *et al.* (2020)

All lifecycle impact categories were studied: Climate Change (CC), Ozone Layer Depletion (DO), Photochemical Oxidant Formation (POF), Particulate Matter Formation (PMF), Terrestrial Acidification (TA), Ionizing Radiation (IR), Agricultural Land Occupation (ALO), Urban Land Occupation (ULO), Natural Land Transformation (NLT), Freshwater Eutrophication (FE), Marine Eutrophication (ME), Metal Depletion (MD), Fossil Depletion (FD), Human Toxicity (HT), Terrestrial, Freshwater and Marine Ecotoxicity (TE, FET, and MET, respectively).

Note that among the seventeen impact categories, four of them are directly linked to toxicity, referring one to human toxicity and three to ecosystem toxicity. Another important factor is that these categories can also be understood by their effect scale: global (e.g., climate), regional (e.g., ecosystems/resources), or local (e.g., health).

Impact 2002+ is a Swiss method that is combined as to the level of impact assessment (midpoint and endpoint) (Mendes *et al.*, 2016, p. 165). The categories selected were two that were related to human toxicity: carcinogenic (CRC) and non-carcinogenic (NCR), and two to respiratory effects: inhalable inorganic (II) and inhalable organic (IO), in order to get a deeper insight into the possible effects of the activity on human health.

4. RESULTS AND DISCUSSION

Description of the blending steps

The stages of the waste blending process are described below, as well as the main environmental aspects observed. The process follows two production lines: solid blends and liquid blends (Chart 1).

It is worth noting that the aforementioned production lines communicate through the use of waste and liquid emissions that arise from their respective processes (Figure 1).

Environmental impact assessment of the life cycle

Characterization

The characterization results point to human toxicity (HT) as the main impact of the blending processes, totaling 1.37E+05 kg 1,4-DB eq (Table 3). Water was the environmental compartment that received the main pollutant loads.

HT predominated in most stages, except for RCL, PAX, and CRL, and had marine ecotoxicity (MET) as the main impact, with 4.31E+03, 1.70E+02, 4.71E+01, and kg 1.4DB eq. The main substance responsible for the MET category was nickel (Ni) emissions.

It was found that the steps with the highest records of human toxicity occurred in the production line of solid blends. The steps that stood out in this category were mix and rest (MSD) and inertization (INZ), with the highest contributions, both with the same value (2.64E+04 kg 1.4-DB eq.).

The potential impacts of HT were provided mainly by the emission of selenium (Se), barium (Ba), manganese (Mn), and arsenic (As) based substances. The other substances individually had an impact of less than 5%.

Figure 2 highlights selenium (Se) with a higher emission in the mixing and resting (MSD), inerting (INZ), and screening (PNT) stages, endowed with the same value 9.81E+03 kg 1,4-DB eq. The likely sources of selenium come from wastes, such as paints, pigments, rubbers, fertilizers, and pharmaceuticals, used in the solid blends line.

Selenium, when originating from industrial wastes, dissolves when it encounters water, deposits in particles, and can be converted by the action of microorganisms into an inert, soluble form, and can also bioaccumulate in the food

Chart 1. Description of the process steps for producing the blends

Solid /Liqu Line	Steps/Acronym	Description	Environmental Aspect
S	Debottling or Dedrumming (DSV)	Arrival and opening of containers with packaged waste. Top cuts in containers are made by workers (operational assistants). Bulk residues do not go through this stage.	Release of odors and volatile agents
S	Shredding, crushing, and grinding (PTM)	Visual inspection, manual sorting on a flat conveyor by workers and physical-chemical analysis of the solid waste, which needs pre-treatment by means of shredding, crushing, or grinding, in order to reduce its granulometry, in compliance with the quality specifications of the cement factories.	Particulate matter emissions
S	Structuring (EST)	Impregnation of the mixture with wood shavings, sawdust, or shredded materials. The humidity of the material is removed. The solid waste acquires fluidity, allowing transportability, maneuverability, homogeneity, and uniformity in the fuel injection lines in the cement kilns.	Gaseous emissions, odor release, volatile agents, and slurry.
S	Mixing and resting	The residues are sent to bays with the use of a loader, to turn and organize the material in stacks. There is residual drainage of the liquid fractions, which are captured by gutters and sent to the liquid blends line.	Gaseous emissions, liquid emissions, odor release, and volatile agents
S	Inertization (INZ)	It promotes the stabilization of the mixture, decreasing its humidity and correcting the pH by using an inerting additive, e.g.: virgin lime. It increases the temperature of the reaction, causing the water to evaporate. The mixing is done with the help of a loader. After mixing, the blend is stored in piles for the continuity of the reaction	Generation of gaseous emissions, suspended particulates (dusts), release of odors and volatile agents
S	Sieving (PNT)	Separation of the particles into different sizes using sieves with 10 mm and 50 mm mesh. Contaminated soil can be screened using 100 mm mesh. It separates the dry and fluid granulated material with a view to good operability, without generating intense clogging in the equipment's mesh. The blends are then stored in piles in the finished product storage bays.	Generation of particulate materials, release of intense odors (light and aromatic hydrocarbons present in the waste). The intensity varies depending on the blend composition and climatic conditions. This stage is perceived as one of the most significant in terms of odor emissions.
S	Loading (CRG)	The blends are shipped by dump trucks. Loading is done with the aid of a loader	Odor release
L	Receipt of liquid waste (RCL)	Liquid waste is unloaded with the help of a forklift truck. Workers assist operationally in opening the lids and rims of drums, barrels, and containers. 10% of these residues have sludge at the bottom, so they are emptied, and the solid part is destined to the solid blends line.	Odor release
L	Pumping (BOB)	Use of pneumatic pumps for emptying packages with material into the transitory blending box, referring to filtration and destined for storage in tanks for non-energetic liquid blend, energetic liquid blend, and industrial effluent. Sending finished material to tanker trucks at the CRL, which will be destined to the cement plants or to the STP. Directing liquid emissions captured in the blends lines to the liquid blends line.	Possible leakage to the ground, energy expenditure, and/or fuel consumption.
L	Direct Blending (MID)	Performed in a 20m3 container or transitory box, whose aim is to produce a mix in the calorific power range between 500 and 3,000 kcal/kg, and above 3,000 kcal/kg. Bulk volumes of 15m3 are handled, and volumes of 1m3 are handled for more reactive materials.	Adverse effects of mixing between reactive liquids. Fire hazard
L	Filtration (FLT)	Consists in removing the organic load from the liquid, decreasing the chemical oxygen demand (COD). It produces an effluent suitable for third-party wastewater treatment plants. The filtering element is wood shavings.	Generation of effluents for external treatment
L	Storage (ARM)	Allocation in specific tanks for the non-energetic liquid blend, energetic liquid blend, and industrial effluents.	Possible leakage from the tanks to the ground
L	Liquid blend loading (CRL)	Supplying tanker trucks with liquid blends destined for cement plants	Odor release and leakage
S/L	Auxiliary Processes (PAX)	Truck parking, workshops, and water and electricity supply	Effluent emissions to soil and groundwater

Source: INEA (2019)

chain. The most common signs and symptoms of high levels of urinary selenium are gastrointestinal disorders, skin discoloration, decayed teeth, hair or nail loss, nail abnormalities, and peripheral nerve changes. The International Agency for Research on Cancer (IARC) considers Se to be one of the unclassifiable substances as to its non-carcinogenicity to humans (Companhia Ambiental do Estado de São Paulo [CETESB], 2018a, p. 2).

These three blending steps also record the highest Mn emissions with the same values (5.60E+03 kg 1.4-DB eq). The sources of manganese come from various hazardous wastes from the chemical, textile, and fertilizer industries. Workers chronically exposed to aerosols and dusts containing high concentrations may experience coughs, nausea, headaches, fatigue, loss of appetite, insomnia, manganism, and lung inflammation that can lead to chemical pneumonia. Some forms are persistent in the aquatic environment and can be accumulated by organisms such as algae, mollusks, and some fish. Bioaccumulation of manganese is greatest at lower levels of the food chain (CETESB, 2018b, p. 2).

Arsenic was also prevalent in these steps with a similar value of 2.14E+03 kg 1,4-DB eq. The substance is used in the manufacture of non-ferrous alloys. Forms such as arsenic acid are used as a bleaching and whitening agent in the industry for certain products, such as glassware and bottles. In water, arsenic can be introduced by emissions from industrial effluents or via atmospheric pathways. One of the likely diffusive sources can be iron sulfate (pyrite) - which was one of the listed wastes for the production of liquid blends. The clinical signs and symptoms of acute arsenic poisoning are abdominal pain, vomiting, diarrhea, muscle redness, and weakness, followed by numbness and tingling of the extremities (CETESB, 2017a, p. 2).

As for barium, the emissions have the same recorded value in the mixing and resting (MSD) and inerting (INZ) stages (6.36E+03 kg 1.4-DB eq). The residence time of the particles in the air depends on their size, but they end up being deposited on the ground. Anthropogenic emissions into water can occur from the discharge of industrial effluents. This substance is used in the manufacture of various types of industrial products that are also discarded in waste form, such as plastics, glass, ceramics (refractory), textiles, lubricants, and rubber (CETESB, 2017b, p. 2).

In summary, one can assign the percentage contributions of the main substances in the human toxicity (HT) category as follows: Se 37.8%, Mn 22.1%, Ba 21.5%, As 8.8%, and other substances 9.8%.

Other impact categories that stood out in blends production were marine ecotoxicity (MET) and climate change (CC), with 9.89E+04 kg 1,4-DB eq and 1.41E+04 kg CO_2 eq, respectively.

For the MET, the substances that contributed to the impact were selenium with 1.44E+04 kg 1.4-DB eq, coming from the raw materials (waste), and manganese with 6.09E+03 kg 1.4-DB eq, emitted to water. In this category, the largest contribution to the impact was from debottling (DSV), with 1.15E+04 kg 1.4-DB eq.

As for climate change (CC), the main substance emitted into the air was CO_2, with 1.05E+04 kg CO_2 eq, and the stage

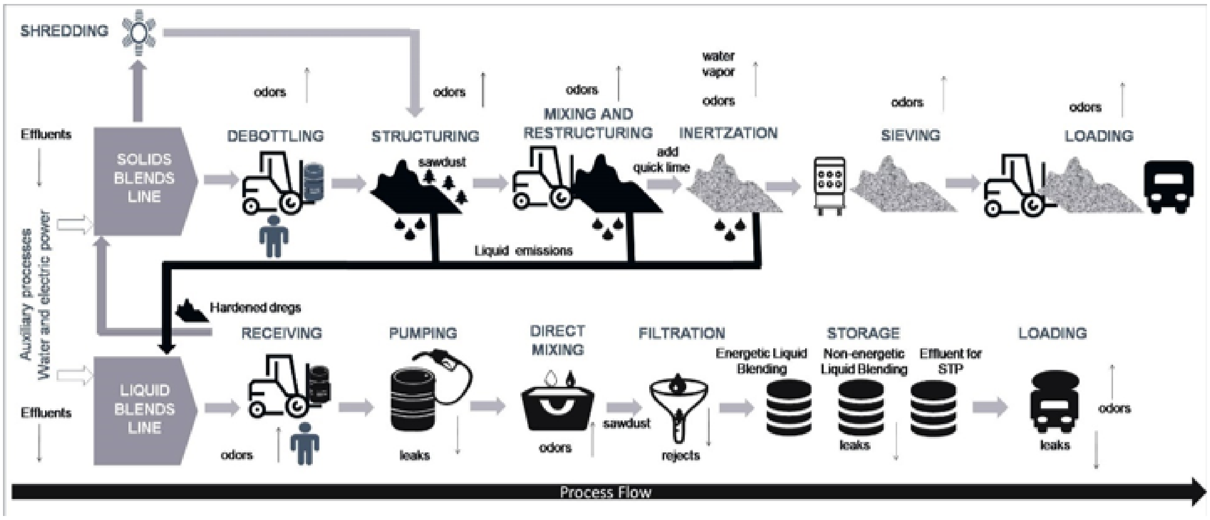

Figure 1. Blending steps with system boundary delineation

Source: Elaborated by the author (2020)

that contributed the most was storage (ARM), because it uses pumping with diesel as fuel, with 9.03E+02.

By the Impact 2002+ method, the non-carcinogenic category (NCR) was the one that stood out the most, with the total of 3.03E+03 kg C_2H_4 eq (Table 1). The main substance that accounts for 87% of the impact in this category was arsenic, emitted to soil with 2.66E+03 kg C_2H_3Cl eq. In soil, arsenic can be released from the solid phase under reducing conditions and can leach to groundwater or flow to surface water (CETESB, 2017a, p. 1).

The ARM stage was the category with the highest record, with a value of 9.74E+02 kg C_2H_3Cl eq. Note that in it, the liquid blends are already properly mixed, after being pumped to the storage structures. In this phase, some leaks of these liquids were registered into the soil (INEA, 2019).

When emitted into the soil, arsenic also appears as the leading substance, contributing 39% in the carcinogenic category (CRC). IARC (International Agency for Research on Cancer) classifies arsenic and its inorganic compounds as carcinogenic to humans (CETESB, 2017a, p. 2). The storage step (ARM) is repeated as the most significant for this impact, also with 8.75E+01 C_2H_3Cl eq.

Other substances that emerged with a significant percentage in carcinogens (CRC) were aromatic hydrocarbons (APH) and aldrin, with 28% and 25%, respectively. The main hazardous wastes containing APH in the production of the blends were petroleum and its derivatives and naphthalene. Studies of workers exposed to APHs by inhalation or over long periods of time suggest the possibility of lung and skin cancer (CETESB, 2018c, p. 3.).

Aldrin is a synthetic organochlorine compound classified as persistent organic pollutant (POP) compounds, and have been widely used as a pesticide in corn and cotton crops. IARC classifies dieldrin and aldrin metabolized to dieldrin as probable human carcinogens (CETESB, 2018d, p. 2). It is worth remembering that many contaminated cotton fabrics, cloths, rags, and personal protective equipment (PPE) uniforms are used in the blends.

The main substance found in category II was NOx, with a total value of 6.41E+00 kg 2.5 PM eq, corresponding to 40% of the impact. NOx are formed during combustion processes, for which vehicles are the main responsible (CETESB, 2020). In these stages, wheel loaders are used to transport and stir up the waste mixture. People with asthma and chronic lung conditions are more susceptible to the impacts of NOx on lung function (Ribeiro & Assunção, 2002, p. 130). Mixing and resting (MSD) and inerting (INZ) were the most significant categories of NOx emission, with 1.28E+00 kg 2.5 PM eq.

In the IO category non-methane volatile organic compounds (NMVOCs) were the most prominent, with a total of 6.17E+00 kg C_2H_4 eq, or 71% contribution to the impact in the category. The most significant step was sieving (PNT), with 1.10E+00 kg C_2H_4 eq.

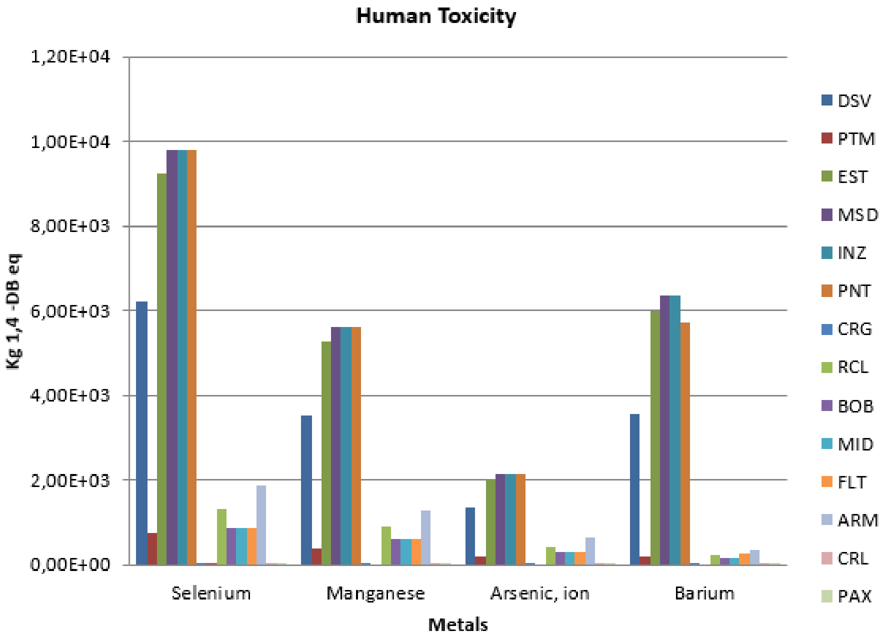

Figure 2. Emissions of metals in the blending steps of the HT category

Source: Own authorship (2020)

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NMVOCs are emitted into the atmosphere from numerous sources, such as solvents and various production processes. NMVOCs contribute to the formation of tropospheric ozone and groups of species, such as benzene, that are harmful to human health (European Environment Agency [EEA], 2015, p. 1).

The solvents are part of the composition of both the liquid and solid blends - through paint sludge - and the emissions are enhanced by revolving the material.

All the results of the impact characterization can be seen in the supplement to this article.

Standardization

By the ReCiPe method, human toxicity (HT) showed a total value of 1.39E+02, corresponding to 53% of the total blending impacts. Toxicity was prevalent in all processes. Mixing and resting (MSD) and inerting (INZ) continued as the most impactful steps regarding human toxicity, with the same value (2.69E+01), followed by screening (PNT) with a value of 2.63E+01 (Figure 3).

Next, the marine ecotoxicity (MET) category contributed 20% of the total blending impact. The mixing and resting (MSD) and inerting (INZ) steps were also the most significant in this category, with the identical values of 9.59E+00.

Subsequently, the freshwater eutrophication (FE) and terrestrial ecotoxicity (TE) categories accounted for 11% and 4% of the blending impacts, respectively. The most significant steps for these categories were mixing and resting (MSD), inerting (INZ), and sieving (PNT), with the same values 5.23E+00 and 2.24E+00, respectively. The main substance that caused the FE was phosphates from various sludges also found in the mineral fractions of contaminated soils, and some wastes from agricultural activities, such as fertilizers. Note that standardization gave this category the third highest blending impact.

In FET, the most relevant substance for 40% of this impact was nickel (Ni) emitted directly into this compartment. The main sources are pigment residues. In the hydrosphere, this element tends to precipitate with organic material and reach the sediment. In significant amounts, it is not bioaccumulable in organisms. When ingested accidentally, it can cause stomach pains and blood changes in humans (CETESB, 2018e, p. 2). The other impact categories added together account for only 11% of the total impact on blending processes.

In the Impact 2002+ method, it is noted that inorganic inhalables category (II) obtained the highest score, 1.55E+00, corresponding to 51.8% of the total blending impacts, related only to human health, followed by non-carcinogenic (NCR) with 39.7% and carcinogenic (CRC) with 8.35%. The blending processes with the highest scores in category II were mix and rest (MSD) and inertization (INZ), with 2.91E-01, with NOx remaining the most representative substance in this impact category, with a value of 6.31E-01, equivalent to 40% for class II waste.

5. CONCLUSIONS

Based on the studied LIA methods, it is concluded that the impact of the blending activity has greater scope on a local scale, with greater damage to human health.

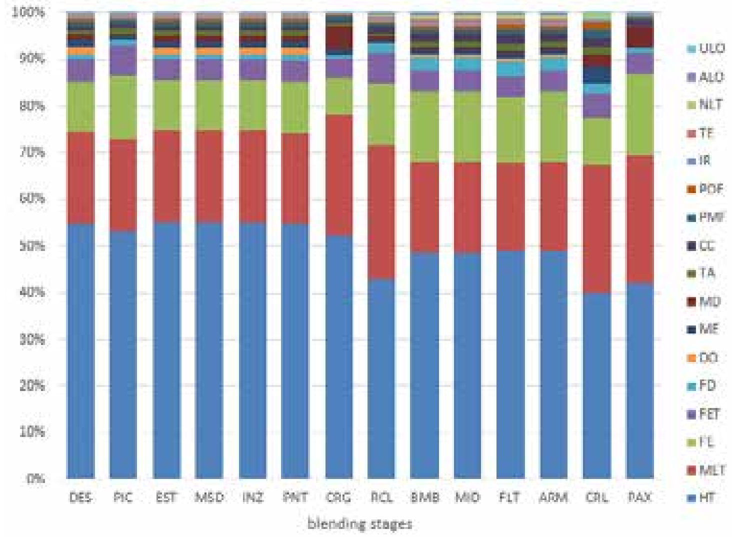

Figure 3. Percentage of impacts in the blending stages. ReCiPe method

Source: Own authorship (2020)

The ReCiPe method has shown that human toxicity is the main impact of blending, meaning a series of health risks through occupational exposure, and can reach the surrounding population, mainly by the emission of Se, Mn, Ba, and As into the water.

However, the toxic and synergistic potential of the remaining substances should not be disregarded, despite their low percentages of contribution to the impact (<5%), because the diversity of toxic wastes used is quite wide.

Among the blending processes studied, the stages blend and rest (MSD) and inertization (INZ) were those where human toxicity had the highest score, explained by the practice of stirring the mass of mixed hazardous waste, potentiating the emission of toxic fumes and odors, liquid emissions, and the addition of structuring and inerting agents to the blend.

Complementarily, by the Impact 2002+ method, the characterization indicated the non-carcinogenic category (NCR) as the main impact (40%), confirming the participation of arsenic as one of the main substances contributing to the health impact. It is worth noting the carcinogenic potential of arsenic, which is also presented as the main substance in the carcinogenic category (CRC).

The OI category presented as the main substances the non-methane volatile organic compounds (NMVOCs), which can be an indicator group of the unpleasant smells that reach the activity's surroundings and are exhaled by the waste substances of this group, such as hydrocarbons, present in several hazardous wastes, like the oil sludge.

By standardization, the main impact was category II (51.8%), the main cause being the emission of NOx into the air, caused by the use of diesel vehicles, followed by particulate emissions from the revolving of the material in the blending. The non-carcinogenic (NCR) and carcinogenic (CRC) categories accounted for 39.8% and 8.36% of the impacts, respectively. In addition to the various imminent risks to human health, the marine ecotoxicity (MET) and freshwater eutrophication (FE) categories (ReCiPe method) point out the dangers of impact to the environment by emissions of metals into soil and groundwater, and phosphate into water resources.

From the accurate analysis performed, it can be reiterated that the blender's worker is the most vulnerable agent to exposure, due to the possible emergence of diseases of the respiratory tract, various pathologies due to chronic exposure, and development of cancer.

Methodologically, using life-cycle assessment (LCA), the insertion of blending into the co-processing chain raises a debate of the human health impacts on the environmental sustainability issues of industrial waste treatment in the cement production chain.

It is recommended that the various sectors of industry and commerce, the waste generators, may implement pollution prevention programs approved and monitored by the control agencies, encouraging the development of less polluting products. It is also suggested that a higher percentage of residues can be used in several recycling lines, instead of being directly and indiscriminately blended.

It is also advisable the complete re-evaluation of the blending activities by the environmental and labor control agencies, requiring the entrepreneurs to prepare studies for the automation of their processes, aiming to reduce as much as possible the direct handling of residues and the exposure of workers and the population to odors and other dangers. Epidemiological studies with the *blendeiras*' workers (blenders' workers) are also indicated, as well as LCA in the social and economic fields to complement these studies.

It is essential to continue LCA studies with a cradle-to-grave approach with the use of these blends that will be co-processed in the clinker kilns, since the burning brings greater possibilities of amplifying the impacts to the health of workers, the surrounding population, and the environment.

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