The Life Cycle Assessment of Cyanide Containers in Ghana*

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Abstract

As a precious metal gold has been valued by humanity from time immemorial. Today gold is turned into gold bars forming the basis of the World's international monetary system. When complexed in ore gold needs to undergo metallurgical extraction processes to eliminate unwanted ions before being smelted and used as the metal. Cyanide is used during these metallurgical processes. The economy of the West African country of Ghana relies heavily on gold production for its economic sustainability. Most of the gold mining companies in Ghana have international origins and receive most of their input for gold extraction from international sources. Sodium cyanide is imported into Ghana in wooden intermediate bulk containers for further distribution to the mining companies. A life cycle assessment was completed to determine the burden that this packaging, which includes the wooden intermediate bulk container, a polyethylene liner and a polypropylene liner places on the environment when they are disposed. The International Organisation of Standardisation (ISO) 14040 management standard was used as a methodological framework in which the goal and scope was defined, a life cycle inventory and life cycle impact assessment was conducted. This enabled the most important issues to be identified. In the final phase consistency, completeness and sensitivity tests were completed and the results interpreted.

1 Introduction

Gold, a precious metal has been valued by humanity from time immemorial. It has been used for example, as adornment in the form of jewellery, an external indication of wealth and has been buried with Egyptian mummies for use in the afterworld. Today gold is turned into gold bars and these form the basis of the World's monetary system, and are traded internationally (Habashi, n.d.). The economy of countries such as South Africa boomed on the discovery of gold. In Ghana (the former Gold Coast) mining of gold started playing a major role in the twentieth century.

Ghana boasts a wealth of natural resources, the most notable of these being cocoa and gold (World Atlas, 2009). The trade in gold is an essential part of the history of Ghana and can be traced as far back as 1471, when Ghana supplied 10 percent of the world's gold (Briggs, 1998). Industrial trading of gold contributes to 25% of the Ghanaian GDP, of which the export of gold totals 5.7 per cent (Intute, 2009; World Atlas, 2009).

Gold is unstable and is found complexed in gold-bearing ores in one of two oxidation states aurous (Au^{+1}) or auric (Au^{+3}), or as the native metal (nuggets). As a nugget it can be panned out and then smelted for purification, but when complexed, gold needs to undergo metallurgical extraction processes to eliminate unwanted complexed ions (Habashi, n.d.; Lorösch, 2001). As technology and machinery developed so did the methods of extracting gold from low-grade ore. The most common methods include amalgamation, chlorination and cyanidation. Generally during cyanidation sodium cyanide is used as lixiviant. Gold is produced in Ghana using sodium cyanide in the recovery process (Lorösch, 2001).

Sodium cyanide is a toxic chemical that is classified as a dangerous chemical and must comply with the relevant United Nations (UN) legislation pertaining to the storage, transportation and disposal thereof. The International Cyanide Management Institute (ICMI) has produced a set of standards and practices defined in the International Cyanide Management Code (ICMC) which details a holistic approach to cyanide handling in the gold mining industry (ICMI, 2005). Participation in the ICMC is voluntary but is encouraged by the government of Ghana.

The sodium cyanide used in Ghana is manufactured in Australia or North America and is imported in wooden Intermediate Bulk Containers (IBCs) to be distributed to mining companies. According to the required UN standards sodium cyanide is sealed inside two liners (polyethylene and polypropylene) (UN Guidelines Part 7, n.d.) from which it is emptied into sodium cyanide mixing tanks before being used. The waste IBCs are then disposed of by incineration or are returned to Australia for reuse. All liners are incinerated in Ghana.

This paper follows a Life Cycle Assessment (LCA) approach, as proposed by ISO 14040 to assess the impact that the IBCs and liners have on the Ghanaian environment. The objective of the project was to determine the origin of the IBC, to quantify the num-

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ber of IBC's imported to Ghana annually, to evaluate methods of disposal of the IBC and its liners and the effect, thereof, on the environment, to identify which category in terms of human health, ecosystem quality and resources is impacted on the most by the different life cycles and to ascertain whether transportation within Ghana has a noteworthy effect on the environment.

2 Methods

A case study approach was employed to obtain data from all the identified cases in Ghana. These were made up of the sodium cyanide suppliers, the agents responsible for clearance formalities and transportation and the sodium cyanide manufacturers located outside Ghana. The method used to complete the study was the procedural framework for LCAs as proposed by ISO 14000 and described in the ISO 14040-14043 standards. UNEP, (2009) defines LCA as an objective process to evaluate the environmental burdens associated with a product, process or activity by identifying energy and materials used and waste released to the environment, and it is used to evaluate and implement opportunities to bring about environmental improvements.

The LCA tool makes use of four main steps as presented in Figure 1 namely goal and scope definition, life cycle inventory analysis, life cycle impact assessment and the interpretation of the results.

2.1 Goal and Scope Definition

A LCA commences with the definition of the goal and scope of study. It states why the LCA is being conducted and describes the system being studied (Clements, 1996). The goal of this study was to ***assess the life cycle of IBC's of sodium cyanide, as used by the Gold Mining Sector in Ghana.*** By assessing the life cycle of the IBCs imported into Ghana, based on the objectives as specified above, the impact of the emissions on the environment (whether on human health, ecosystem quality or resources) is identified. The intention of the study was to provide information to an academic audience, the sodium cyanide manufacturers and the sodium cyanide users. It could also possibly be used to research and develop alternative methods for the transportation of cyanide into Ghana. Data required to complete the study consisted of primary and secondary data.

At the outset the functional unit of the study requires identification. The functional unit describes the function or the process being studied so that there is a common unit for comparison between all the alternatives (Curran, 2006). The functional units for this study are the wooden IBC, polyethylene and polypropylene liners. The IBC was further divided into IBC reused and IBC incinerated to enable comparisons between these alternatives to be made (Table 1).

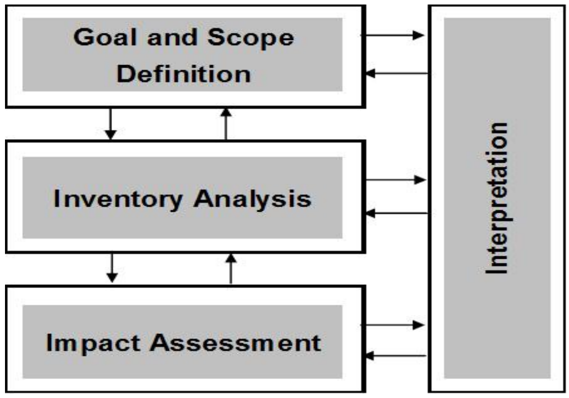

Fig. 1 The Phases of LCA according to ISO 14040 (Adapted from DEAT, 2004)

As part of the scope definition the boundary of the study was demarcated. The system boundary defines the breadth of the study and is the interface between the product and service and the environmental impacts. The ultimate system boundary is between the technological system and the receiving environment. All upstream and downstream inputs and outputs of the systems should ideally be followed; this will include the flows between the environment and the technological system (Tillman *et al.*, 1994). The main boundaries related to the type of LCA being conducted (retrospective) and to the geographical area involved (Ghana). The manufacture of IBCs and liners fall outside the scope of this study because they are not produced in Ghana.

2.2 Life Cycle Inventory

According to Clements (1996), the inventory analysis of the LCA is a series of processes and systems tied together in their common purpose of creating the product. Inventory analysis is the listing of these processes and systems, their boundaries, and the potential impact of each process and system.

The Life Cycle Inventory (LCI) was initiated with the drawing of a flow diagram in which the boundaries for each of the liners and the IBC were clearly demarcated. The data was collected within this boundary by making use of questionnaires, observations, interviews and desktop studies and these data were entered into the Simapro 7.1 software to generate an inventory list, using the Eco-indicator 99 methodology. A two per cent cut-off, in which emissions contributing two per cent or less to the emissions were discounted, was used to summarise the data. Inventory tables (Table 1) were generated from this list. These inventory tables served as input for the Life Cycle Impact Assessment (LCIA).

Table 1: Summary of Inputs and Outputs for the Functional Units

Inputs/Outputs	Unit	IBC Reused	IBC Incinerated	Polyethylene Liner Incinerated	Polypropylene Liner Incinerated
Emissions to air					
Cadmium	kg	1.37×10^{2}	4.65×10^{2}	4.76×10^{2}	1.04×10^{3}
Carbon dioxide	Mt	-1.92×10^{1}	-6.54×10^{1}	2.24	4.96
Carbon dioxide, biogenic	kg	1.15×10^{10}	3.92×10^{10}	1.16×10^{5}	2.08×10^{5}
Carbon dioxide, fossil	kg	1.98×10^{8}	6.16×10^{8}	2.40×10^{9}	4.06×10^{9}
Carbon-14	kBq	3.08×10^{7}	1.05×10^{8}	6.39×10^{6}	1.58×10^{7}
Chromium	kg	9.97×10^{3}	3.40×10^{4}	3.07×10^{2}	6.78×10^{2}
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	kg	3.91×10^{2}	1.33×10^{3}	8.54×10^{1}	2.12×10^{2}
Methane	kg	6.67×10^{6}	2.27×10^{7}	8.23×10^{6}	1.71×10^{7}
Methane, bromotrifluoro-, Halon 1301	kg	1.56×10^{2}	5.33×10^{2}	5.47×10^{2}	1.13×10^{3}
Nickel	kg	3.56×10^{3}	1.21×10^{4}	1.01×10^{4}	2.21×10^{4}
Nitrogen oxides	kg	1.81×10^{7}	6.12×10^{7}	5.81×10^{6}	7.16×10^{7}
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	5.39×10^{6}	1.82×10^{7}	1.08×10^{7}	8.13×10^{7}
Particulates, < 10 µm (stationary)	kg	7.88×10^{6}	2.68×10^{7}	1.02×10^{6}	2.23×10^{6}
Radon-222	kBq	2.58×10^{12}	8.78×10^{12}	5.63×10^{11}	1.40×10^{12}
Sulphur oxides	kg	1.61×10^{7}	5.48×10^{7}	1.60×10^{7}	3.55×10^{7}
Zinc	kg	1.68×10^{4}	5.72×10^{4}	1.07×10^{3}	2.36×10^{3}
Emissions to water					
Arsenic, ion	kg	5.24×10^{3}	1.78×10^{4}	1.96×10^{3}	3.65×10^{3}
Cadmium, ion	kg	2.42×10^{2}	8.20×10^{2}	3.84×10^{2}	6.91×10^{2}
Cesium-137	kBq	2.25×10^{7}	7.68×10^{7}	4.89×10^{6}	1.21×10^{7}
Raw material inputs/outputs					
Copper, in ground	kg	7.96×10^{5}	2.71×10^{6}	1.19×10^{5}	2.90×10^{5}
Gas, natural, 35 MJ per m3, in ground	m^3	3.61×10^{8}	1.23×10^{9}	2.06×10^{7}	5.11×10^{7}
Land use II-III	km^2a	1.77×10^{2}	6.04×10^{2}	3.94×10^{1}	9.73×10^{1}
Land use III-IV	km^2a	1.35×10^{1}	4.59×10^{1}	2.02	4.28
Nickel, 1.98% in silicates, 1.04% in crude ore, in ground	kg	1.61×10^{5}	5.49×10^{5}	1.83×10^{4}	3.58×10^{4}
Oil, crude, 42.6 MJ per kg, in ground	kg	4.02×10^{8}	1.37×10^{9}	1.41×10^{9}	2.90×10^{9}

2.3 Life Cycle Impact Assessment

During the Life Cycle Impact Assessment (LCIA) the impacts identified during the LCI phase are evaluated. This evaluation includes all potential human health and environmental impacts (Curran, 2006). In this step, the effects of material consumption and environmental releases identified during the LCI were calculated.

The steps to be included in the LCIA were decided upon and included the mandatory elements (categorisation, classification, characterisation) and some obligatory elements (normalisation, grouping and weighting). The Eco-Indicator 99 (EI99) method found in the Simapro 7.1 software was used to continue with the LCIA.

1. **Categorisation of Impacts** – the data collected in the LCI was placed in a damage category according to its effect on the environment (*e.g.* resources, human health and ecosystem quality).

2. **Classification** – the LCI results were assigned to the impact categories within each damage category as specified below (e.g. classifying carbon dioxide emissions to potential climate change which then form part of ecosystem quality damage category).

a) Human Health
- Carcinogens
- Respiratory organics
- Respiratory inorganics
- Climate Change
- Ozone Layer
- Radiation

b) Ecosystem Quality
- Acidification/Eutrophication
- Ecotoxicity
- Land use

c) Resources
- Minerals
- Fossil Fuels

3. **Characterisation** – Following the definition of the impact categories, the LCI results were allocated to these 11 categories. These LCI impacts were modelled within impact categories using science-based conversion factors within the Simapro 7.1 software (e.g. modelling the potential impact of carbon dioxide and methane on climate change). Impact indicators allow LCI results to be compared within each damage category for conclusions to be com-

pared within each damage category for conclusions to be drawn as to which impact category has the largest effect on the environment.

4. **Normalisation** – During normalisation a dimensionless indicator value was calculated. The value allowed the potential impacts to be expressed in such a way that comparison within each damage category was possible (Pré, 2008). These values were generated using the Eco-indicator method in Simapro 7.1.

5. **Grouping** – In this step EI99 calculated the overall impact to each damage category by adding the calculated values from each impact category. This was presented as the damage assessment in Simapro 7.1. These damage categories show the total damage caused by each life cycle to each damage category (Goedkoop *et al*., 2008a).

6. **Weighting** – During weighting the indicator results were converted in the software and aggregated across the impact categories using a 40:40:20 (Human Health: Ecosystem quality: Resources) ratio (Goedkoop and Spriensma, 2001). Weighting resulted in a single data point that emphasised the most important potential impacts.

2.4 Interpretation

During interpretation the results from the four different life cycles were interpreted and the relevant issues were identified. Checks on the completeness, sensitivity and consistency were conducted in order to evaluate the data collected.

3 Results

All results were generated by using Simapro 7.1 software which makes use of a variety of methods. The method elected for use in this LCA was Eco-indicator 99, which is based on European emission standards because no standard exists for Ghana.

3.1 Categorisation and Classification

The software classified the selected inputs and outputs into damage and impact categories and specified the relevant compartment in which an impact could be expected (Table 2).

Table 2 Classification of Selected Input/Outputs from the Life Cycle Inventory

Damage Category	Impact Category	Compartment	Input/Output
Human Health	Carcinogens	Air	Cadmium Ion
	Carcinogens	Water	Arsenic Ion
	Carcinogens	Water	Cadmium
	Respiratory organics	Air	NMVOC, non-methane volatile organic compounds, unspecified origin
	Respiratory inorganics	Air	Nitrogen oxides
	Respiratory inorganics	Air	Particulates, < 10 µm (stationary)
	Respiratory inorganics	Air	Sulphur oxides
	Climate change	Air	Carbon dioxide
	Climate change	Air	Carbon dioxide, biogenic
	Climate change	Air	Carbon dioxide, fossil
	Climate change	Air	Methane
	Ozone layer	Air	Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114
	Ozone layer	Air	Methane, bromotrifluoro-, Halon 1301
	Radiation	Air	Carbon-14
	Radiation	Air	Radon-222
	Radiation	Water	Cesium-137
Ecosystem Quality	Acidification/ Eutrophication	Air	Nitrogen oxide
	Acidification/ Eutrophication	Air	Sulphur oxides
	Ecotoxicity	Air	Chromium
	Ecotoxicity	Air	Nickel
	Ecotoxicity	Air	Zinc
	Land use	Raw Materials	Cesium-137
	Land use	Raw Materials	Land use II-III
	Land use	Water	Land use II-IV
Resources	Fossil fuels	Raw Materials	Gas, natural, 35 MJ/m^3, in ground
	Fossil fuels	Raw Materials	Oil, crude, 42.6 MJ/kg, in ground
	Minerals	Raw Materials	Copper, in ground
	Minerals	Raw Materials	Nickel, 1.98% in silicates, 1.04% in crude ore, in ground

3.2 Characterisation

Following the categorisation all results were characterised. This resulted in a list of values assigned to each impact category. This list is shown in Table 3.

From Table 3 it is observed that each of the four life cycles contribute to the degradation of the environment to different degrees, however no conclusive interpretations can be made as to which life cycle impacts on the environment the most. To illustrate this point, it can be seen in the category carcinogens that all four life cycles have a negative impact, that IBC incinerated has the highest impact and the polyethylene liner has the lowest impact.

Within each impact category the same type of information can be deduced when consulting Table 3. Figure 2 presents these characterisation results graphically.

3.3 Normalisation

Normalisation is used after characterization to enable the reader to identify the damage category most impacted on by studying the length of the bars in the graph (y-axis). The normalisation values are presented graphically in Fig. 3. The taller bar represents the impact category most affected by the life cycle. This is brought about by making these impact categories dimensionless by dividing or multiplying by a reference value. The reference value used in the study is the one most often used; which is the average yearly environmental load in a country or continent divided by the number of inhabitants. As no values were available for Ghana the values were calculated using European emission standards (Goedkoop and Spriensma, 2001; Goedkoop *et al*., 2008b).

Figure 3 shows that fossil fuels, respiratory inorganics, and climate change are, in order of magnitude, the three impact categories that are affected the most by the four life cycles, whether positive or negative. This is illustrated by the length of the bars in the graph. The other eight impact categories are all affected to a lesser extent with land use being affected the most by IBC incinerated in these remaining categories.

In summary, it appears that the life cycle of the IBC and liners impact the most on fossil fuels in the resources category, followed by respiratory inorganics which affects human health and then climate change which forms part of ecosystem quality (Fig. 3). These damage categories and classifications (impact categories) are generated in the Simapro 7.1 software.

Table 3 Characterisation of separated liners and IBC

Impact category	Unit	Life Cycle IBC Reused	Life Cycle IBC Incinerated	Life Cycle Polyethylene Liner	Life Cycle Polypropylene Liner
Carcinogens	DALY	3.99×10^2	1.36×10^3	2.32×10^2	4.51×10^2
Resp. organics	DALY	8.05	2.72×10^1	1.90×10^1	1.06×10^2
Resp. inorganics	DALY	5.64×10^3	1.91×10^4	1.79×10^3	9.17×10^3
Climate change	DALY	-1.52×10^3	-5.18×10^3	1.01×10^3	1.97×10^3
Radiation	DALY	7.35×10^1	2.50×10^2	1.60×10^1	3.96×10^1
Ozone layer	DALY	2.41	8.22	7.64	1.44×10^1
Ecotoxicity	PAF*m^2yr	1.37×10^9	4.66×10^9	9.62×10^8	2.15×10^9
Acidification/ Eutrophication	PDF*m^2yr	1.31×10^8	4.42×10^8	5.00×10^7	4.46×10^8
Land use	PDF*m^2yr	3.51×10^8	1.20×10^9	2.47×10^7	5.94×10^7
Minerals	MJ surplus	3.90×10^7	1.33×10^8	7.29×10^6	1.68×10^7
Fossil fuels	MJ surplus	4.84×10^9	1.64×10^{10}	8.82×10^9	1.82×10^{10}

3.4 Grouping

The damage assessment as used in Eco-indicator 99 is a grouping procedure. Figure 4 is a graphical representation of the damage that the life cycles of the IBC and the liners have on the different damage categories of the environment. The categories illustrated in this figure are human health, ecosystem quality and resources but can be expanded to show the damage on each impact category.

All three damage categories, consisting of the sum of all the relevant impact categories, have four bars of different lengths. These bars represent the life cycles of the functional units investigated. Each of these bars represent the sum (y-axis) of all the classified results (impact category values) in that damage category and are scaled to 100% to assist with interpretation.

By consulting Figure 4 (the lengths of the green bars in each category), it becomes clear that the incinerated IBC has the largest impact overall, followed by the polypropylene liner, as these bars are the longest in all three categories. The positive impact that climate change has as observed in Figure 3, is outweighed by all the other negative impacts in this category. These positive effects (climate change) are subtracted from the negative effects causing a lower overall negative impact. It is not obvious whether the reused IBC or the polyethylene liner has the largest impact by just consulting the graph however, when the percentages from each category of these life cycles are added it appears as though the polyethylene liner has (=80%) a smaller impact than the reused IBC (=90%).

3.5 Weighting

The final step conducted in this LCIA was that of weighting and was presented as an impact assessment in the Simapro 7.1 software. Figure 5 summarises the impacts for each impact category in each separate life cycle as a single score to enable interpretation "at a glance."

The unit on the y-axis is gigapoints (GPt = 1 x10^9 points). The annual emission of one average European inhabitant amounts to approximately 1 000 points. From this the burden of the product is able to be calculated and is represented as people equivalents (Goedkoop and Spriensma, 2001).

3.5.1 Life Cycle of Reused IBC

The total amount of points on the y-axis for the life cycle of the reused IBC adds up to 0.325 Gigapoints (GPt) which translates to 325 000 people equivalents. This in turn equates to the emissions of 325 000 people in one year, thus the emissions caused by the reused IBC compares to the emissions of 325 000 people in one year. For this life cycle, respiratory inorganics have the highest value, followed by fossil fuels. Climate change is positively impacted on in this life cycle.

3.5.2 Life Cycle of Incinerated IBC

Figure 5 presents the impact categories having the largest negative impact on the environment for the incinerated IBC and are arranged from highest to lowest namely; respiratory inorganics, fossil fuels, land-use, acidification/eutrophication, ecotoxicity, and carcinogens. In this scenario, climate change has a perceived positive impact on the environment,

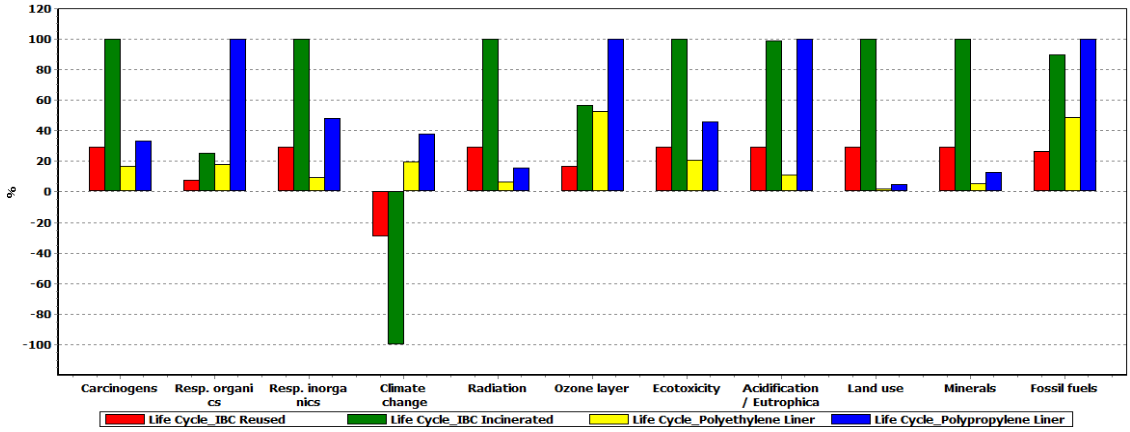

Fig. 2 Characterisation Results of Separate Life Cycles

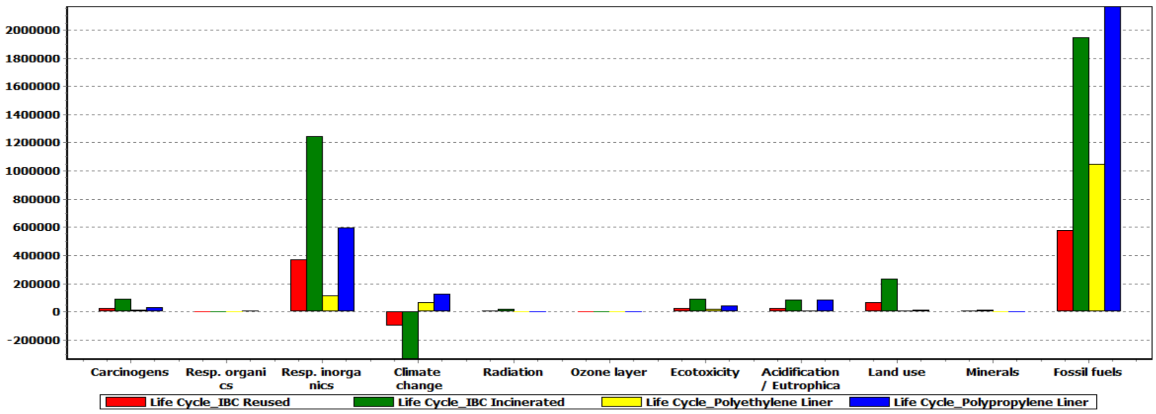

Fig. 3 Normalisation of Separate Life Cycles

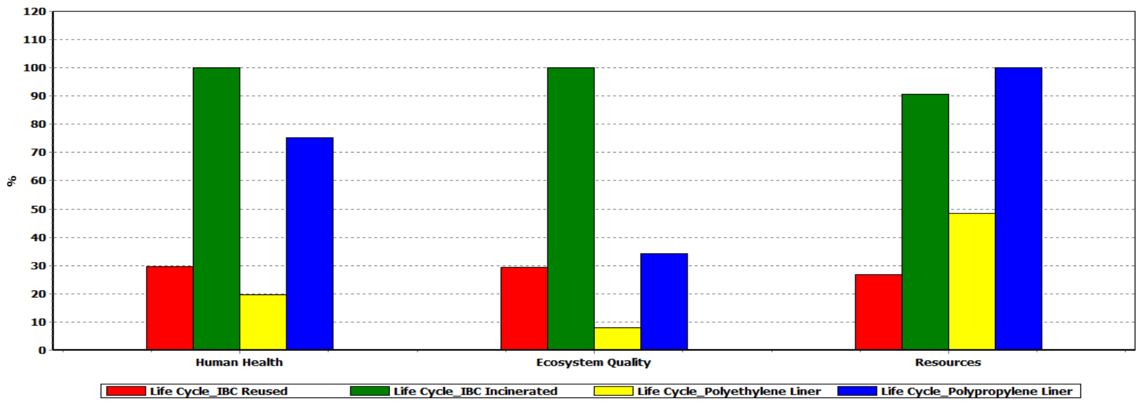

Fig. 4 Damage assessment of Separate Life Cycles

probably caused by the emission of carbon dioxide formed by the burning of biogenic sources (wood). The burden of the incinerated IBC amounts to 1.1 gigapoints (Fig. 5), which is translated to the impact caused by 1 100 000 people equivalents and thus the emissions from the incinerated IBC for this period is comparable to those that are caused by 1 100 000 people.

3.5.3 Life Cycle of Polyethylene Liner

The polyethylene liner has the smallest impact on the environment according to Fig. 5. The total number of people equivalents for this life cycle is 300 000 represented by the 0.3 gigapoints, thus the impact of the polyethylene liner on the environment for 2008 equates to the emissions caused by 300 000 people. When consulting Fig. 5 it is apparent that fossil fuels have the largest impact and climate change and respiratory inorganics both have smaller negative impacts on the receiving environment.

3.5.4 Life Cycle of Polypropylene Liner

In this study, the life cycle of the polypropylene liner demonstrates that it has the second highest impact on the environment, after the incinerated IBC (Fig. 5). The people equivalents that this product has on the environment amounts to 800 000 as seen in the 0.8 gigapoints in (Fig. 5. When this life cycle is related to people it is comparable to the damage caused by 800 000 people for 2008.

4 Discussion

The interpretation phase of the LCA presents the most noteworthy issues and most noteworthy life cycle as well as the evaluation of the data for completeness, sensitivity and consistency.

4.1 Most Noteworthy Issues

During the interpretation of the results the noteworthy issues in this LCA were identified for each life cycle using the characterisation results in Table 3. Table 3 shows to what extent each emission within the life cycles impact on the individual categories, thus a contribution analysis. The impacts for each category were summarised by Simapro 7.1 into a single score (Fig. 6).

4.1.1 Human Health

In this LCA, respiratory inorganics exhibit the largest adverse effect on humans for all four life cycles (Table 3). The major constituents of the respiratory inorganics emitted into the air in these four life cycles as shown in Table 2 are:

- Nitrogen oxides (NOx).
- Stationary particulates, less than 10 micrometre (μm) in size.
- Sulphur oxides (SOx).

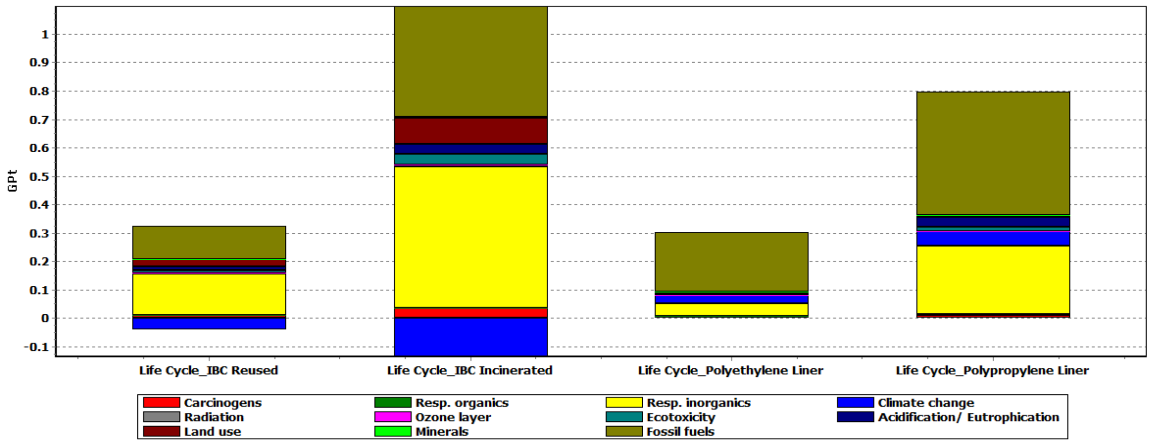

Fig. 5 Single Score Impact Assessment of the Life Cycle of IBC and Liners per Impact Category

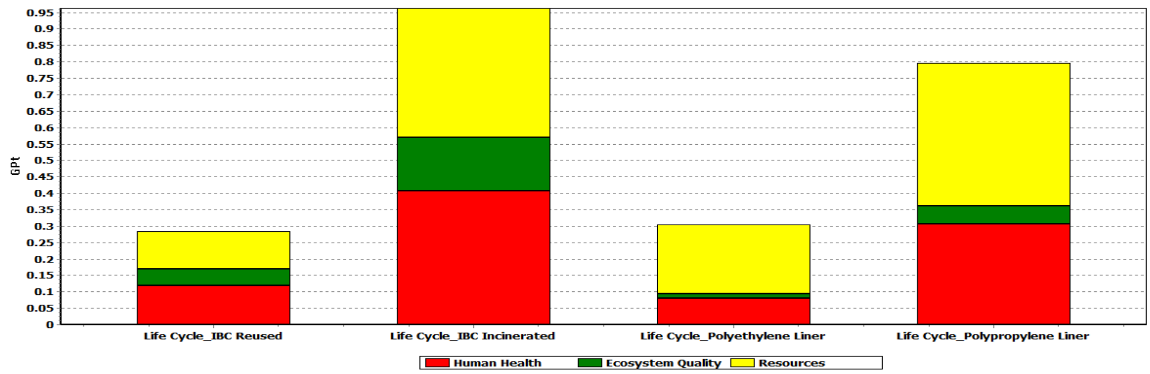

Fig. 6 Single Score Presentation of Life Cycles

4.1.2 Ecosystem Quality

The damage category, ecosystem quality, can be sub -divided into three impact categories namely; ecotoxicity, acidification/eutrophication and land use. For all four life cycles, the most noteworthy impacts were on air quality and occurred in the impact category ecotoxicity as depicted in Table 2 and Table 3. The emissions identified as the most important in the impact category ecotoxicity are:

- Chromium.
- Nickel.
- Zinc.

4.1.3 Resources

Based on the characterisation results in Table 3, it can be deduced that within the damage category resources, the reserve of fossil fuels are impacted the most for all four life cycles followed by the mineral reserve. Within the impact category fossil fuels, the use of gas exceeds the use of oil, showing that the manufacture of the functional units impact the most on oil in the resources category. In this study the polypropylene liner has the highest impact on resources, followed by the incinerated IBC, the polyethylene liner and finally the reused IBC (Fig. 6).

4.2 Most Noteworthy Life Cycle

Figure 6 shows that the largest overall adverse impact (determined by the length of the bar) is caused by the incinerated IBC followed by the polypropylene liner, then the polyethylene liner, and finally the reused IBC.

When consulting Fig. 5 and Fig. 6, it can be seen that the life cycle having the greatest impact on the environment is the life cycle of the incinerated IBC. In Fig. 6 it is apparent that the incinerated IBC impacts the most on resources followed by human health and finally on ecosystem quality in that order. In Fig. 5 and Figure 6 it can be seen that the polypropylene liner has the highest impact on resources but has the second highest overall impact.

The impact of the reused IBC and the polyethylene liner on the environment are similar, with the polyethylene liner having a slightly higher effect overall. As with the polypropylene liner, the polyethylene liner has a relatively high impact on resources but a smaller impact on the environment.

4.3 Evaluation of Data

To establish confidence in the LCA results, an evaluation process takes place. During this process checks on completeness, sensitivity, and consistency are carried out (Curran, 2006).

4.3.1 Completeness Check

The completeness check entails the examination of the data to ascertain whether or not the data is complete. The results for each life cycle are evaluated against the goal and scope of the study (Curran, 2006; Goedkoop et al., 2008a).

The deficiencies identified in this LCA are listed below:

a) Data required for input of information pertaining to the IBC into the software for each supplier was not available due to confidentiality clauses.
b) Data required for input values for the liners was not available for each supplier due to confidentiality clauses.
c) The software used was designed for Europe and thus calculations in the software was based on European emissions as no software which made use of the Ghanaian environment could be sourced.
d) Open air burning was included as part of incineration.
e) The incinerator was powered by electricity generated in Ghana, whereas the software bases the electricity used on European grids.
f) An average mass for the sea containers were used.
g) Disposal/Reuse input values will differ from year to year as the production of gold varies.
h) Impact Categories such as noise and odour were not included in the software.
i) Emissions from incineration are not passed through a clarifier before being discharged.
j) The quality of diesel used as fuel in Ghana may differ from that used in Europe.

These deficiencies were not considered significant to adversely affect the goal and scope of the study during the completeness check.

4.3.2 Sensitivity Check

In completing a sensitivity test, the reliability of the results are evaluated to determine whether the issues identified in the completeness check will have an affect on the definition of comparative conclusions. This can be determined by using different parameters on the same life cycles to highlight the data elements that influence the results the most (Curran, 2006; Goedkoop et al., 2008a).

To generate the information, only one parameter is altered along with its dependents, all other independent parameters are kept constant. In this study, the following sensitivity testing was concluded by keeping the specified parameter constant and retesting by altering each parameter up or down with ten percent:

a) The mass of the sea-containers
b) The mass of the functional units
c) The tonnage of cyanide received for 2008 was adjusted.

The mass of the sea containers were altered by entering the true mass of a container from each sea-liner as well as the average value as used in the study.

The results obtained in this sensitivity indicate that:

a) By using the minimum and maximum values for the sea containers no real changes in emissions can be expected (all percentages are less than 1%)
b) When the masses of the IBCs and liners are altered by an increase or decrease of 10 percent the change is in the same order (± 10%)
c) If the tonnages were to increase or decrease by 10 percent a change of approximately 20 percent can be expected both ways.

When considering the above it can be assumed that the uncertainties surrounding the issues addressed should not significantly affect the results for this LCA. The information provided indicates that consumption of cyanide is the key driver for the impacts associated with the life cycle but to a greater degree than just a linear approach. For example, with the commissioning of more mines that use cyanide, the effects associated with the IBCs are expected to increase at a rate greater than the added consumption of cyanide. The increase of emissions is approximately double the increase in tonnages of cyanide used.

4.3.3 Consistency Check

The assumptions, methods, and data used throughout the LCA are tested against the goal and scope of the study for consistence during the consistency check. This check is carried out for each product and/or process evaluated and helps to increase the confidence in the final results. Some inconsistency is deemed acceptable as long as it is documented and its role in the LCA defined. The ISO standards require that the following are checked (Curran, 2006; Landu, 2006):

a) Data source

Primary and secondary nature was collected. The primary data was obtained directly from cyanide manufactures, agents and end-users by making use of questionnaires, interviews and site visits. The secondary data was available through the internet as well as literature resources such as books and journals. Other secondary data included personal communication that was forwarded via email or discussed during the interviews.

The LCI data was obtained from existing databases and software developed for the Dutch Ministry of Housing, Spatial Planning and Environment and used in Simapro 7.1 (Goedkoop and Spriensma, 2001). These data were then used to generate all other information required for the analyses.

b) Data accuracy

All data obtained from the manufacturers, agents and end-users are believed to be reasonably accurate as these figures are used in the cyanide consumption balances required by the International Cyanide Management Code (ICMC). Questionnaires and interviews were also structured in such a way as to allow for cross-referencing. Personal observations confirmed the data received.

c) Data age

All primary data used in the LCA were collected for the year 2008, thus it is deemed recent. Where secondary data were used from journals originating from internet websites and from other literature, the most recent was considered relevant. Inventory data originating from the software database were from 1993 onwards.

d) Temporal representation

The use of cyanide in the extraction of gold is currently the most widely used method for gold recovery where gravity extraction methods are uneconomical. Ghana makes use of the same transportation methods that are used globally and includes sparging and transportation of the cyanide in an IBC. The delivery of liquid cyanide is used internationally as well but was not considered as it is not a viable method of cyanide transportation in Ghana. Liquid cyanide is not manufactured or transported in Ghana.

e) Geographical representation

The geographical boundary of the study was Ghana. The raw data obtained from the manufacturers, agents and end-users was within the boundary of the study and is representative of what occurs in Ghana with regards to the cyanide containers.

The LCI databases used were not representative of Ghana, but represented Europe as a whole. No LCI databases were available for Ghana during 2008/9 when the study was conducted and documented. The LCIA method used (Eco-indicator 99) also makes use of European standards. From this it can be concluded that the LCI and LCIA is not entirely representative of Ghana.

f) Technical level of the data

The data used is believed to be sound and technically acceptable for the following reasons: Most of the manufacturers, agents and end-users have been or are scheduled to be audited for ICMC compliance by an International Cyanide Management Institute (ICMI) auditor. To be awarded with a compliance certification all data are required to comply with the high standards set by the ICMI.

In terms of the above categories, the data can be considered consistent with the goal and scope of the LCA. In cases where it is not entirely consistent (geographical representation, technical level) the impact that these differences may have on the LCA is not significant.

5 Conclusions

Five objectives were identified around which the research process was designed to achieve the objectives in relation to the aim. In the text that follows each objective will be presented.

The origin of the IBC and the associated liners was identified as being outside of Ghana, indicating that resources such as raw material extraction and mineral use did not affect the Ghanaian environment in the first objective.

The second objective successfully quantified the number of IBCs and liners imported to Ghana for 2008. Furthermore it was observed that the tonnage of cyanide imported to Ghana would vary from year to year as the ore body and number of mines operating changes. This, in turn, will affect the number of IBCs and liners that will enter the country and also the emissions.

In objective three the methods of disposal and their effects on the receiving environment was evaluated. Incineration as a method of disposal appeared to have the biggest impact on the Ghanaian environment.

When related to the Ghanaian environment the respiratory inorganics emitted into the air during incineration of the IBC and its liners were the largest contributors to the deterioration of the associated environment (objective four). Outside of Ghana the use of resources were of concern.

Objective five investigated the effect of transportation on the Ghanaian environment and was successful in determining that the emissions generated by transportation had an effect on the Ghanaian environment. The objective was inconclusive in terms of the magnitude of the effect that these emissions may have, as the model was generated based on European fuel and not on the fuel used in Ghana.

In conducting this study some shortcoming were noted as well as questions that were not answered. In the following section the following recommendations can be made.

a) To conduct a more comprehensive study, the boundary should be extended so that the LCA would commence from the cradle (raw material growth and acquisition) and end at the grave (complete incineration /reuse).
b) For more accurate results, a region-specific inventory database for the Simapro 7.1 LCA software package should be compiled to accurately determine the impacts of the various constituents used or emitted in that country.
c) Further research could be conducted in developed, transition, and developing countries to compare the different ways by which cyanide is transported and the IBC's and liners are disposed of.
d) Different transportation mechanisms could be investigated for the transportation of cyanide in Ghana.
e) Avenues such as the decontamination and reuse of the wood from the IBC as building material could be explored.
f) Where possible, more data should be collected with regards to the functional units, where confidentiality clauses prevented it in this study.
g) The life cycle of the IBC incinerated and the IBC reused should not be separated as in this study but should be examined as a closed loop life cycle.
h) Fuel from Europe and that from Ghana should be both analysed for constituents and emissions on combustion.

The LCA conducted in this research project proved to be effective in identifying the impact that the IBC and the two liners have on the Ghanaian environment although the limitations experienced in the quantification of these impacts, such as the use of European databases and confidentiality clauses, cannot be discounted or underestimated. The study has also generated a base from which future research can be conducted in terms of LCAs, cyanide use, transportation and packaging.
In conducting this study it became apparent that transportation of the cyanide and incineration of its packaging in Ghana impacts negatively on a relatively pristine tropical environment. As the extraction and production of gold is an important contributor to the Ghanaian economy, mitigation and management practices should be explored and/or developed to reduce the overall impacts that this packaging has on the environment.

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