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Environmental Impacts Assessment of the Cleaning of Plant Off-gas in the recovery process of PGM at the Anglo American Platinum LTD, South Africa

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Abstract

The cleaning of off-gas in the process of producing platinum group metals and the conversion of highly concentrated Sulphur dioxide (SO_2) to sulfuric acid (H_2SO_4) are crucial in the current discussions for attempting to reduce emissions in the entire process of mining platinum metals in South Africa. Emissions of SO_2 gas into the atmosphere became a concern lately in the production of PGM which are seen as metals to contribute to clean and renewable energy technology. SO_2 emissions are measured in terms of tons per day in the production process of PGM. This fact brought forth more considerations in reengineering process of handling and cleaning of off-gas in plant operations. This paper further examined solutions provided in terms of processes and resources used to handle and clean off-gas as well as convert SO_2 to H_2SO_4. Life cycle inventory tools were used for consideration, environmental impact assessment on emissions and new conclusions drawn from results obtained which showed emissions from resources used as well.

Keywords

Platinum Group Metals, Plant Off-gas Cleaning Process, Environmental Impacts Assessment,

1. Introduction

The South African Bushveld complex is the largest economic potential of platinum group metals (PGM) resources ever discovered in the world estimated at about 80% of the world's reserves. Anglo American Platinum, the world's largest PGM producer, operates in the Western limbs of the Bushveld Complex exploiting the world's largest known igneous complex that extends over 65,000km^2 and reaches a depth of about 7km (Mabiza, 2013).

In 2008, the overall restructuring operations of factories in the Anglo American Platinum was completed. The restructuring operations consisted of aligning newly owned mines with the new strategies put in place by the company to improve production, management, safety and environmental protection by reducing pollution and meet regulations. Sulphur dioxide (SO_2) emissions were identified the most noticed airborne pollution to be addressed in the recovery process of platinum group metals. Owing to its Precious Metals Refinery (PMR) and Base Metal Refining (BMR) units, the Anglo American Platinum shares ownership of some private mines, acquired by joint-venture agreements or other arrangements, the purchase of concentrates produced by private miners and enabling the company to maintain production up to 2,464 million ounces of PGM in 2009 compared 2,645 million ounces of production in 2008, an unwelcome occurrence in recent years (Anglo Platinum Limited, 2009). In addition, Anglo Platinum American also acquired a 17.5% stake in Johnson Matthey, a global leading producer of platinum electrocatalysts. Furthermore, through the first investment in its Platinum Group Metals Development Fund (PGMD Fund).

2. Operational process for PGM recovery

2.1 Mining

An average concentration of PGM of about five grams (5g) can be found in one metric ton (1,000kg) of mined ore which can be sent directly to the Precious Metals Refinery (PMR) unit. The rest of the mined ore undergoes ore concentration operations. Precious metals are completely recovered from the mined ore (Jones, 2006).

2.2 Ore concentration

The concentration unit is used mainly for the separation of valuable contents to rocks and sand. Ores undergo crushing, milling, and wet-screening to obtain pumpable slurry which bears the precious metals. Separation occurs in flotation cells where the reagents (chemicals) are added to aerate slugs carrying high-grade collected PGM (Anglo Platinum Limited, 2009). An approximate composition of a metric ton received at the ore concentration unit of Waterval is given in Table 1 below.

Table 1: Analysis of the concentrate at the Waterval ore concentration unit. Source: (Jones, 2006)

	Al_2O_3 %	CaO %	Co %	Cr_2O_3 %	Cu %	FeO %	MgO %	Ni %	S %	SiO_2 %	PGM g/t	Total %
Anglo American Platinum Waterval	*3.2*	*4.7*	*0.08*	*0.80*	*2.1*	*20*	*15*	*3.6*	*9*	*34*	*143*	*92*

The composition of the above concentrate (Table 1), are required, precious metals (PGM plus gold) and metals (nickel (Ni), copper (Cu) and cobalt sulphate ($CoSO_4$)) (Anglo Platinum Limited, 2003).

2.3 Smelting

Smelting is a part of the process intended to recover precious metals from the concentrate slug by use of furnaces. A simplified smelter process flow schematic at the Waterval is given in Figure 2 below.

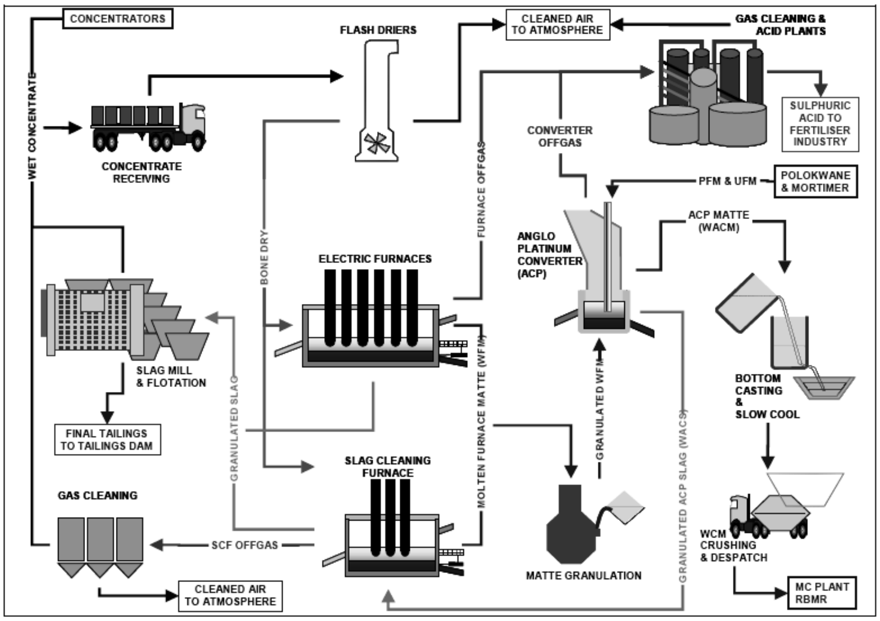


Figure 2: Simplified Smelter Process Flow Schematic at Waterval. Source: (Jacobs, 2006)

At an average temperature near to 1500°C, depending on the composition of the concentrate sulphide gangue mineral, a composition of silicate slag and oxide is separated from the inorganic sulphide matte and discarded. Matte then includes base and noble metals. According to Jacobs (2006), the analysis of the composition of furnace matte is as shown in Table 2, in which the iron (Fe) 41% and (S) 27%, both not needed, are still prevailing. In general this is the composition of the matte at this stage of the PGM recovery, in which 95% of the total of the slag is discarded. Smelters have a feed rate ranging from 25 to 54T / h.

Table 2: Furnace matte analysis at the Waterval Anglo platinum smelter. Source: (Jones, 2006)

	Co%	**Cr %**	**Cu%**	**Fe%**	**Ni%**	**S%**	**PGMg/t**	**Total%**
Anglo Platinum Waterval	***0.5***	***0.5***	***9***	***41***	***17***	***27***	***640***	***95***

Subsequently, at elevated temperatures the concentrate melts further and splits into two liquids phases; a lighter molten matte and slag rich in iron, having a density of about 2.7 to 3.3, is separated under the gravity from the molten matte, being denser, with a density of about 4.8 to 5.3 and rich in nickel and copper sulphides and in precious and base metals (Jones, 2006). The lighter molten matte is discarded and undergoes milling and cleaning of slag for possible recovery of PGM, and the molten matte is finally conveyed and discarded to the tailings dam (Figure 2).

2.4 The Furnace Matte Converting Process

The converter is designed to further separate the precious metals and base metals from the granulated matte. Because of its rich composition in iron (41%) and in Sulphur (27%) (Table 4), the granulated furnace matte undergoes a converting process in an attempt to completely remove Fe and S. This happens by blowing oxygen-enriched air through the top-submerged lance converter where the oxygen reacts with the furnace matte at high temperatures ranging around 1300°C. The blown oxygen-enriched air can then oxidise Fe and S into iron oxide slag (FeO_2) and sulphur dioxide gas (SO_2) respectively. The iron in the matte can be cut down from 40% to around 3.5%. The converter can accommodate around 14,000t of furnace matte per month, an average of 459t per day, since 2006 (Jacobs, 2006). Due to considerable amounts of the oxygen-enriched air which are blown into the converter, a typical minimum production of 4% of a highly concentrated SO_2 composes the off-gases that leave the converter toward gas cleaning and acid plants (Jones, 2006). An estimated average of 14.4 tonnes of SO_2 emissions occurs daily at Waterval smelters and refineries and some fugitive SO_2 emissions from the mouth of smelters; these are emitted to the air from a stack (Anglo platinum, 2009).

2.5 Converter matte and slag analyses

The converter matte analysis in Table 3 shows the increase of concentration in base and precious metals when concentrations of Fe and S have been cut. After leaving the converter the matte can be processed by crushing and milling in order to separate base metals from the precious metals at the magnetic concentration plant (MCP). BMR is a process based on magnetic concentrate leaching and leaching electro-wining methods of producing Nickel, Copper and Cobalt sulphate; while PMR is based on dissolving and processing pure metal products, PGM and Gold.

Table 3: Converter matte analysis at the Waterval Anglo platinum converter Source: (Jones, 2006)

	Co %	**Cu %**	**Fe %**	**Ni %**	**S %**	**PGM g/t**	**Total%**
Anglo Platinum Waterval	***0.5***	***26***	***2.9***	***47***	***21***	***2100***	***97***

The following Table 4 shows the converter slag analysis. The converter slag is sent back to the furnace slag (auxiliary smelter) to attempt the recovery of any possible PGM concentration within the slag.

Table 4: Converter slag analysis at the Waterval Anglo platinum converter. Source: (Jones, 2006)

	Al_2O_3 %	**CaO%**	**Co%**	**Cr_2O_3%**	**Cu%**	**FeO%**	**MgO%**	**Ni%**	**S%**	**SiO_2%**	**Total%**
Anglo Platinum Waterval	***0.7***	***0.4***	***0.45***	***0.4***	***1.17***	***63***	***1.1***	***2.25***	***2.4***	***27***	***99***

3. The Off-gas Handling Processes

3.1 The Cleaning of Off-gas and the Conversion of Highly Concentrated SO_2 at the Contact Plant

According to Jones (2006), the converter off-gases containing a highly concentrated SO_2 are subjected to a jet solid scrubbing and to a gas cleaning process at the gas cleaning section. The main acid-plant blower can thereafter draft the off-gases through a gas conditioning section where they are diluted with air or the off-gas from electric furnace to obtain a diluted gas containing 10% of SO_2. The diluted gas is first mixed with 65% Sulphuric acid (H_2SO_4) then with 92% H_2SO_4 to reduce the moisture content to less than 77mg/Am^3. The conversion of the SO_2 in the diluted gas to Sulphur trioxide (SO_3) can be processed in the tower plant, at the contact plant. Through four passes consisted of vanadium pentoxide (V_2O_5) catalyst, SO_2 is converted to SO_3 in rates of 69% of SO_2 by the first pass in a hot heat exchange of 435°C. A total of 92.8% of SO_2 is converted by the second pass at a temperature raised to 503°C. An overall of 97.2% of SO_2:SO_3 conversion is attained by the third pass again cooled to 435°C. At the fourth pass, the overall conversion SO_2:SO_3 reaches approximately 99.91% and this happens at 447°C. The tail gas, cooled, goes to the final absorption tower where it is absorbed in 98.5% H_2SO_4 and passed through candle mist acid droplets and mist eliminators. Finally the residual tail gas is released to the atmosphere by means of a stack at less than 100ppm SO_2 concentration (Jones, 2006). The main reason for the SO_2-SO_3 transformation is the absolute avoidance of the air pollution by SO_2 pollution. SO_2-SO_3 transformation is a target to comply with regulations (Sichone, 2009). The tail gas released into the air is a composition with a low concentration in SO_2 of less than 100 parts per million (<100ppm); this means also only 100 molecules of SO_2 may be found in the composition of one million (1,000,000) molecules of the tail gas (Anglo Platinum, 2009). Due to the high rate of SO_2-SO_3 transformation, an important amount of H_2SO_4 can be collected at the acid plant proportionally to the capacity to handle the intermittent supply of the highly concentrated SO_2. The SO_2 is then transformed into H_2SO_4 (Figure 4) (Rodney, 2004).

3.2 The Conversion of Weakly Concentrated SO_2

The weakly concentrated SO_2 is handled as well. This produces a weak sulphuric acid solution. The cleaning section continuously drafts electric furnace off-gas and off-gases across the plant which are collected at the pre-quench and post-quench towers to remove most of the solids that are carried away by the flow of gases. Oxygen from air and caustic soda are added to scrub out particulate matters in the off gas stream, casting them out into a tailings dam where they are all discarded variously as weak sulphuric acid, sodium salt, and slurry of dust. The cleaned off-gas is thereafter carried to the gas conditioning area where the removal of moisture occurs. The dried off-gas is directed into the de-nitration section whereby large amounts of nitrogen oxides (NO_X) are absorbed as well as SO_2 in part. Further absorption of NOX occurs when the off-gas stream is passed through a balancing vessel NO:NO_2 in ratio 1:1. The off-gas with the remaining SO_2 is then ducted into the acid generation plant where it is absorbed to produce a strengthened (nitrosyl) sulphuric acid (HNO_5S). The off-gas is finally sent to the contact plant (Figure 4) to remove the residual NO_X and SO_2 gases where the tail gas results in less than 10 part per million of SO_2 (10ppm SO_2) and 100 ppm NO_X (Jones, 2006). In general, platinum mining companies are constrained to meet the compliance on SO_2 emissions in a limit rate of 25 tonnes per day enforced by the regulation; otherwise monetary penalties follow for non-compliance. Figure 3 following describes the trend of the Anglo Platinum Waterval smelter endeavours to aligning its SO_2 and NO_X emissions with the permitted rates since 2003-2010.

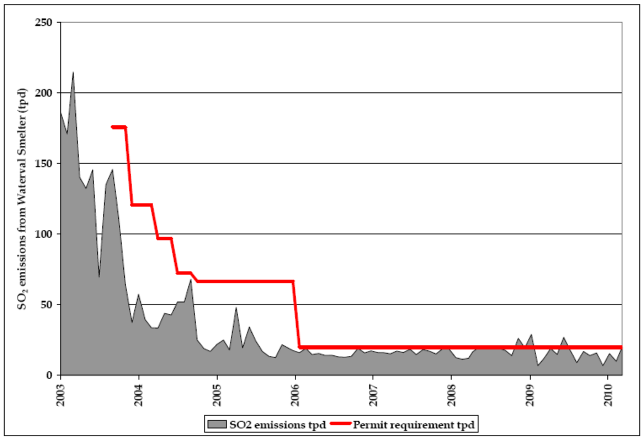


Figure 3: Decrease in SO_2 emissions at the Waterval Smelter; Source: (Hundermark et al., 2011)

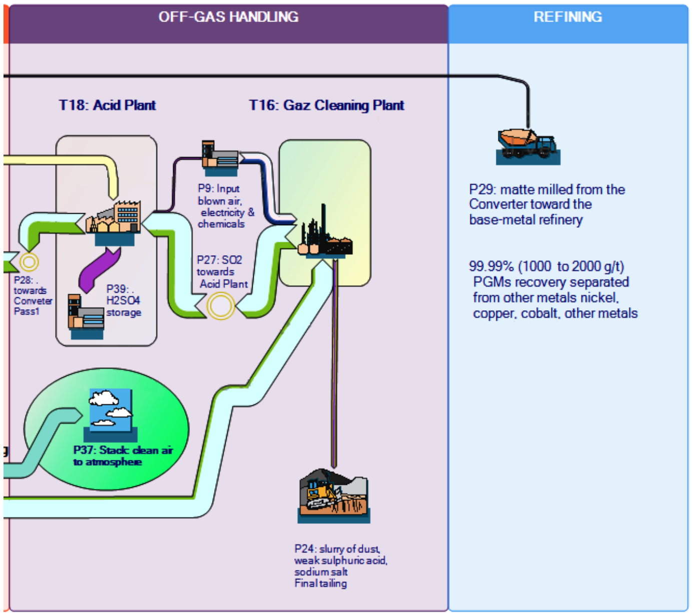
Afterward the crushed converter matte is milled and sent in the magnetic concentration plant (MCP) whereby the precious metals fraction is separated magnetically. This is pressure leached to yield a solid final concentrate that is sent to a precious metals refinery (PMR). Base metal-rich non-magnetic solids and leach solution are processed further in the base metal refinery (BMR). PMR is based on the dissolution using hydrochloric acid and chlorine gas whereby

PGM are sequentially separated and purified to yield platinum, palladium, iridium, ruthenium and gold. Osmium is precipitated as a salt. BMR is based on magnetic concentrate leaching and leaching electro-wining methods of producing nickel, copper and cobalt sulphate (Anglo American Platinum, 2011).

4. Inventory Assessment over off-gas handling process

The following Figure 4 portrays the process at the off-gas handling unit, the gas cleaning plant where off-gases are cleaned, the double absorption acid plant where SO_3 is absorbed by H2SO4, the tailings dam where weak sulphuric acid solution, sodium salt and slurry of dust are discarded and the (exhaust) stack where the off-gas bearing weak SO_2 and NO_X is vented to the atmosphere.

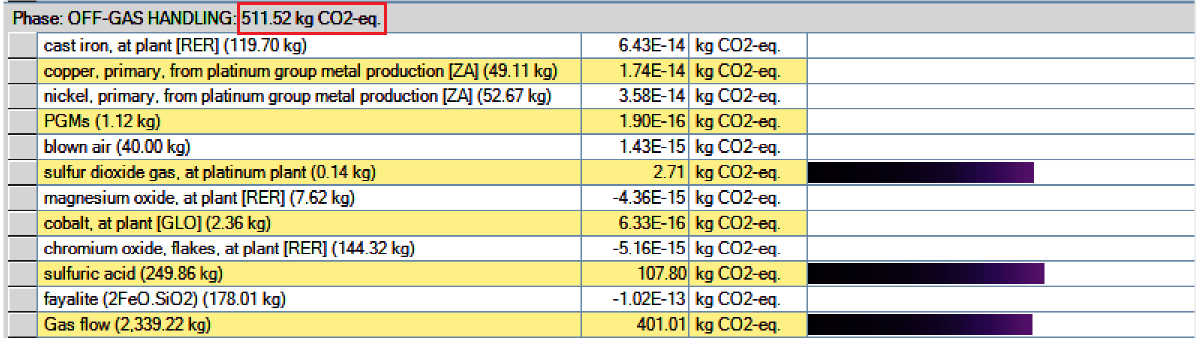
4.1 Life Cycle Inventory of the flow-material in off-gas handling phase



|Figure 4: ACP gas cleaning process and acid plant processing at Waterval smelter. (Developed using Umberto software)

4.2 Equivalent Carbon Dioxide

Table 5: Equivalent carbon dioxide to the off-gas handling process



Phase: OFF-GAS HANDLING: 511.52 kg CO2-eq.			
cast iron, at plant [RER] (119.70 kg)	6.43E-14	kg CO2-eq.	
copper, primary, from platinum group metal production [ZA] (49.11 kg)	1.74E-14	kg CO2-eq.	
nickel, primary, from platinum group metal production [ZA] (52.67 kg)	3.58E-14	kg CO2-eq.	
PGMs (1.12 kg)	1.90E-16	kg CO2-eq.	
blown air (40.00 kg)	1.43E-15	kg CO2-eq.	
sulfur dioxide gas, at platinum plant (0.14 kg)	2.71	kg CO2-eq.	▆
magnesium oxide, at plant [RER] (7.62 kg)	-4.36E-15	kg CO2-eq.	
cobalt, at plant [GLO] (2.36 kg)	6.33E-16	kg CO2-eq.	
chromium oxide, flakes, at plant [RER] (144.32 kg)	-5.16E-15	kg CO2-eq.	
sulfuric acid (249.86 kg)	107.80	kg CO2-eq.	▆
fayalite (2FeO.SiO2) (178.01 kg)	-1.02E-13	kg CO2-eq.	
Gas flow (2,339.22 kg)	401.01	kg CO2-eq.	▆

The Table 5 above shows three constituents identified as source of emissions in the phase with quantified CO_2-eq emissions. Other constituents have no emissions related to this phase but rather involved as parts of the overall recovery process of PGM. In addition the three CO_2-eq emissions may be justified as emanating from energy-mix with 88% from coal burning power generation used by electric units in the phase and use of chemicals. The Table 5 also presents emissions over a typical composition of one tonne (1t) of ore mined and added resources. A total amount of equivalent carbon dioxide of about 511.52kgCO_2-eq is associated with the process. The masses displayed in the column “product” together with the designated constituents, are apparent weights which are in relation to the molecular masses of these constituents. They are the total masses of the constituents in the entire life cycle analysis of the assessed PGM recovery cradle, the mining, to gate, the off-gas handling process. The column "share", however depicts, by a length, the amount of CO_2-eq emissions emitted by each constituent in this phase (Table 5).

5. Environmental Impact Assessment using Eco-Indicator 99 methodology

The Eco-indicator 99 method can be well thought-out as a valuable tool to determine environmental damage impacts over a manufacturing process or product life cycle. The method is applied on the result of a Life Cycle Assessment (LCA) conducted. LCA is an analytic development over a product manufactured whereby raw materials extraction and input materials through operation, to final product, waste recycle, disposal treatment, and emissions are mapped out and connected, and mass and energy balances are closed. In the case of a process of manufacture, emissions through the process are determined so as to improve the process to more environmentally sound activity. The Eco-indicator 99 method of assessment can be used to assist in making decisions that can lead to significant environmental improvements.

The Eco-indicator 99 method was a developed approach to overcome the difficulty that occurred in the weighting step of the ISO 14040 method. The eco-indicator 99 methodology therefore considers the weighting step, whereby eco-indicators, as the starting point in the assessment of environmental damage impacts (Figure 1). Weighting step consists of determining damage analysis. This is related either to damage to mineral and fossil resource extraction, damage to ecosystem quality, or damage to human health. Exposure and effect analysis can thereafter be determined from damage analysis (Pré Consultants, 2001).

5.1 Damage category Human Health

Damage to human health is expressed as DALY (Disability Adjusted Life Years). According to Pré Consultants (2001), a human is identified as a member of the present or a future generation. His health may be damaged and suffer consequences either by reducing duration of life, or by causing disabilities. Of the current state of knowledge, sources of environmental damage on human health are mainly the following:

- *Climate change*: causing respiratory and cardiovascular diseases, infectious diseases, as well as forced relocation.
- *Ionising radiation*: causing cancer.
- *Ozone layer depletion*: causing cancer and eye damages.

5.2 Damage category Ecosystem Quality

Damage to ecosystem quality is expressed as the percentage of species that are threatened or that have disappeared in a certain area due to the environmental load. The issue of analyzing ecosystems is very complex. It challenges us to assess all of the different kinds of damage relating to this. Damage to ecosystems is measured using methods such as (Pré Consultants, 2001):

- *Ecotoxicity*: is a method that determines the Potential Affected Fraction (PAF) of species with regard to toxic substances concentration.
- *Acidification and eutrophication*: are observed effects. Methods used to make these particular observations use complex biochemical mechanisms. The Eco-indicator 99 method observes these effects on plants. From these observations a probability of occurrence (POO) translates to Potential Disappeared Fraction (PDF), of specified plant species in a specified area. Not all plant species are greatly affected. The damage to modelling acidification and eutrophication refers to NO_X, SO_X and NH_3 depositions.
- *Land use*: The information gained by use of the PDF as indicator for the damage of all species can be broken down into four different categories:
    - The local effect of land occupation
    - The local effect of land conversion
    - The regional effect of land occupation
    - The regional effect of land conversion

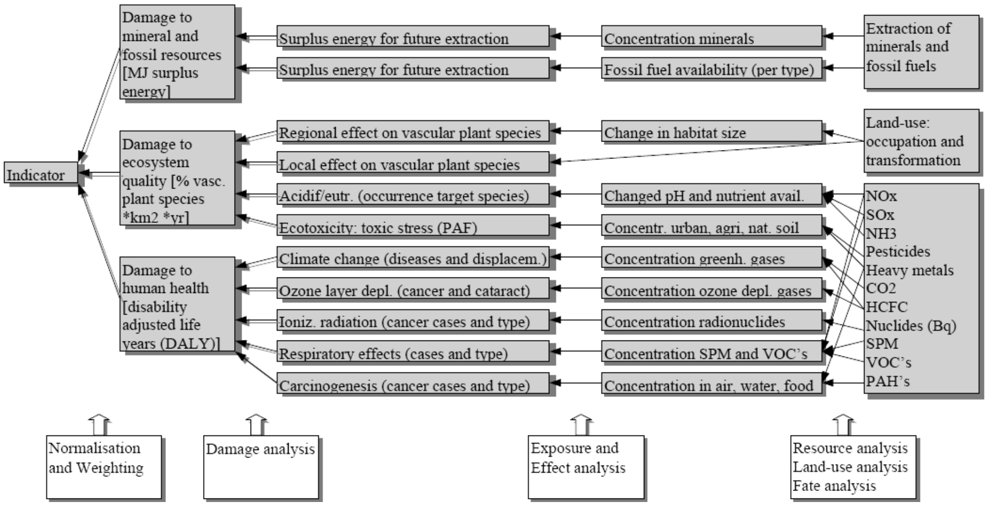


Figure 1. Graphical presentation of the Eco-indicator 99 methodology; Source: (Pré Consultants, 2000)

5.3 Damage Category Resources

The Eco-indicator 99 methodology deals effectively with damage resources relating to minerals and fossil fuels. Silvicultural and agricultural biotic resources, mining of resources such as gravel and sand, are perceived as effects, basically being covered by land use.

5.4 Damage Category Units and Normalization

Eco-indicator 99 methodology suggests three simplified categories of damage, namely: damage to human health, damage to ecosystem quality and damage to resource extraction. All the three damage categories have different units. A suggested normalisation of units is defined as a set of dimensionless weighting factors which unifies the three damage categories into a single dimensionless scale (Pré Consultants, 2001).

5.5 Modelling Uncertainties

According to Pré Consultants (2001), the main types of uncertainty considered are both operational and fundamental. The operational uncertainty deals with technical uncertainties in the data. The fundamental uncertainty, the most important for eco-indicator 99 methodology, is based on the correctness the methods developed. Factors modelling uncertainties to damage cannot be expressed as a range, given that a model assumption is correct or not. In order to cope with the fundamental uncertainties, three perspectives were proposed. The three perspectives are defined as follows:

- Egalitarian (E)
  Egalitarian is a long time perspective in which even a minimum indication which is scientifically based, justifies inclusion.
- Individualist (I)
  Individualist is a short time perspective in which only proven effects are included.
- Hierarchist (H)
  Hierarchist is a balanced time perspective in which consensus among scientist determines inclusion of effects.

Hypothetically, the combination of any couple perspective-normalisation set is possible; but the most relevant are the following (Pré Consultants, 2001):

- The Hierarchist damage model and normalisation, or H perspective with the average weighting (H,A). This is considered as default combination.
- The egalitarian damage model and normalisation, or E perspective with the egalitarian weighting (E,E).
- The individualist damage model and normalisation, or I perspective with the individualist weighting (I,I).
- A fourth theoretical version can be made of the Hierarchist damage model and normalisation with the Hierarchist weighting (H,H).

5.6 Evaluation of Environmental Impact Assessment

Table 6. Environmental Impact Assessment (EIA) Form for the recovery of PGM from mining to off-gas handling phase

Product or process **The recovery of PGM from mining to off-gas handling phase**	*Project* **Environmental Impact Assessment of the recovery process of PGM. (Primary data aligned with the Anglo American Platinum 2011 Annual Report)**
Date	*Author* **Junior Mabiza**

Inputs to the Production Phase (Materials, Processes, energy)

Material or process	**Amount / 36547kt ore milled**	**Indicator (weighted damage factor) = (damage factor** x **normalisation) ÷ weight** (Pré Consultants,2000) (Pré Consultants,2001)	**Exposure & Type of damage factor**	**Result (Impact)**
Energy from electricity purchased, produced from coal	19049 E+9 KJ	42.95E-05	Damage to Resources caused by extraction of fossil fuels (H,A)	8.18 E+9
Land conversion in industrial area (PDF* x m^2 per yr.): Land acquired for mining and relate activities in 2011	202.51 E+2 Ha	1.68E-03	Damage to Ecosystem quality causing Potential Disappeared Fraction of Species per m^2 per year (E,E)	34.02 E+0
Sub Total [mPt]				8.18 E+9

Remarks:

- PDF* refers Potential Disappeared Fraction of Species (Pré Consultants,2000)
- - * no evident record

Emissions likely occurring in PGM recovery process in the gas flow (Materials, waste, energy)

Material or process *(From the converter slag analysis. Table & The Annual report 2011)*	**Amount / 36547kt ore milled**	**Indicator**	**Exposure & Type of damage factor**	**Impact**
Dust (PM_{10}),($PM_{2.5}$) (0.20E-3Kg in 1t ore)	4.20 E+5 Kg	9.40 E-7	Airborne: respiratory effects on humans caused by inorganic substances (H,A)	39.48 E-2
NO_x	(Not measured by Anglo American)	2.20 E-7	Airborne: respiratory effects on humans caused by inorganic substances (H,A)	-
S (720E-3Kg in 1t ore)	0.26 E+5 Kg	-	Emission to soil	-
SiO_2 (8.1Kg in 1t ore)	2.96 E+5 Kg	-	Airborne: respiratory effects on humans. minimal cytotoxicity exposure from fine dust particles	-
SO_2, (Emissions due to treatment)	1.77 E+6 Kg	140.00 E-9	Airborne: respiratory effects on humans caused by inorganic substances (H, A). Damage to Ecosystem Quality by Acidification.	2.48 E-1
Tailings dam area and waste rock dump area	36.38 E+2 Ha	1.68 E-03	Damage to Ecosystem quality causing Potential Disappeared Fraction of Species per m2 per year (E,E)	6.11 E0
Sulphuric acid production		-	Good produced	
Slurry of dust weak sulphuric acid sent to tailing dams		-	Emission to soil: Landfill, acid mining drainage impact on underground water, flora, fauna	
Sodium salt sent to tailing dams		-	Emission to soil: Effects of de-icing salt on ground water characteristics, infertility of soil	
Sub Total [mPt]				297.11 E0
Total [mPt]				**8.18 E9**

6. Interpretation of results and conclusion

The Table 6, an environmental impact assessment (EIA) Form, brought about an effective understanding on environmental damage impacts which are likely occurring in the recovery process of PGM with regard to the gas flow boundaries treated at the off-gas handling unit of the plant. The EIA Form (Table 6) is composed of two sub-forms of which the first is the input resources sub-form summarizing all the input materials and processes identified with their amounts, indicators, exposure and the types of damage. The second sub-form summarizes emissions occurring after transformation processes in the ore recovery, focusing on the outcome at the off-gas handling activities with data on amounts, indicators, exposure and type of damages.

The environmental impact assessment was done, no longer on one metric ton of ore but, on an annual input of ore of about 36547 metric tons. The largest damage impact was from indirect CO_2 emissions associated with electricity purchased of 19,049 Tera-joules with an impact estimated to 8.18 E+9. Up to 88% of the South African energy supply is produced by coal-fired power generation. The mining sector can be regarded as a major contributor to the national heavy carbon footprint due to its high energy demand. Another important factor contributing to significant energy consumption is the need to supply significant volumes of clean water, besides the potable water supplied, by recycling ground and surface water treatment before and after use. The second largest damage impact estimated at 3.43 E+8 was attributed to extraction of minerals. This damage impact was not involved this work given it does not interact with the section of our interest, the off-gas handling.

The damage impact caused by SO_2 emissions which has an impact on human health and the ecosystem quality was relatively minor compared to the damage impacts to resource caused by the extraction of fossil fuels and the extraction of minerals. The damage impact caused by NOx, and SiO_2 emissions, which may likely occur as airborne emissions, might result to cytotoxicity exposure from fine dust particles on humans.

Conclusion

The cleaning of off-gas analyzed can be considered palliative in the lessening of onsite airborne SO_2 and NO_X emissions. There is however operational and indirect emissions due to the use from non-renewable energy-mix, the upstream that should be looked at, and onsite should be considered more approaches to have emissions of SiO_2, Slurry of dust, weak sulphuric acid, and Sodium salt to tailing with impacts to environment as landfill, acid mining drainage affecting ground water, flora, and fauna, all to be addressed as well.

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