Sustainability Reporting and the Platinum Group Metals: A Global Mining Industry Leader?

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Platinum group metals (pgms) are increasingly used in a wide variety of important environmentally-related technologies (for example, catalytic converters), most of which are expected to grow in demand as the world develops. Over the past decade, the global mining industry has embraced the need to incorporate sustainable development into projects and governance, resulting in a major surge in the use of annual sustainability reporting to demonstrate such performance. The majority of global pgms production is in South Africa, and this paper assesses and analyses the sustainability reporting by the pgms sector. The approach to sustainability reporting is discussed, including an assessment of the extent and detail of reporting by pgms companies, as well as examining the data reported and its relationship to key production aspects such as ore grade and project scale. By analysing trends in water and energy consumption and greenhouse gas emissions, especially in terms of per unit pgms production, critical issues such as life cycle costs can be ascertained. Whilst sustainability includes social, economic and environmental aspects, this paper focuses on environmental aspects only. Overall, the pgms sector certainly appears to be a global leader in the breadth and depth of sustainability reporting, with the continuing evolution providing a valuable basis to understand the major issues facing the industry and allow strategic planning for the future.

1. Introduction

The pgms possess a range of unique chemical and physical properties. They are increasingly finding important uses in a variety of environmentally-related and specialty technologies, such as chemical process catalysts (especially oil refineries), catalytic converters for vehicle exhaust control, fuel cells, electronic components, and a variety of medical uses, amongst others. Given the need to expand almost all of these uses to meet environmental and technological challenges this century, demand growth for pgms can reasonably be expected to be sustained long into the future.

The mining of pgm ores is through conventional underground or open cut techniques. The next stage is grinding and gravity-based separation, followed by flotation to produce a pgm-rich concentrate. The run-of-mine ore grades are typically several grams per tonne (g t^{-1}), while concentrates are some 100s of g t^{-1} (1). Concentrate is then smelted to produce a pgm-rich nickel-copper matte, with the pgms extracted and purified at a precious metals refinery (including Ni-Cu byproducts). The processing is therefore more analogous to base metals rather than gold, which relies on cyanide leaching and hydrometallurgy. Smelting of concentrates from Ni-Cu mining can also be a moderate source of pgms (for example in Russia and Canada). Further details on pgm ore processing are given by Vermaak (1) and Cabri (2), with a detailed review of resources and production presented by Mudd (3).

Global production of pgms is dominated by South Africa due to their large resources in the Bushveld Complex, while other countries such as Russia, Canada, Zimbabwe and the United States play a lesser but important role. Historical production by country is shown in **Figure 1** (4). In South Africa, pgms are produced from the Platreef, Merensky and Upper Group 2 (UG2) reefs in the igneous Bushveld Complex (3).

The global economic reserves are estimated by the United States Geological Survey (USGS) at 66,000 t pgms (5), compared to 2009 production of ~465 t pgms and cumulative production from 1900 to 2008 of ~12,900 t pgms. A recent detailed compilation of reported reserves and resources by project shows ~88,800 t pgms (3). Given the trend of maintaining and expanding economic resources (6), the primary issues for the foreseeable future will not be remaining resources but the complex environmental, economic and social conditions which affect production.

This paper presents a review of the pgms industry, focussing on sustainability reporting and major environmental costs such as water, energy and greenhouse gas emissions (GGEs). The paper presents a distinctive case study for a group of metals which are unique in being largely concentrated in one region of the Earth and pose some intriguing and difficult sustainability issues for the future – yet these challenges also present significant opportunities. The pgm sector is arguably a world leader in the area of sustainability reporting in the mining industry.

2. Assessing the Sustainability of Platinum Group Metals

2.1 Overview

In the past decade, there has been strong growth in annual environmental or sustainability reporting by numerous mining companies (7–10), including many South African and especially pgm companies. In general, sustainability reports cover the environ-

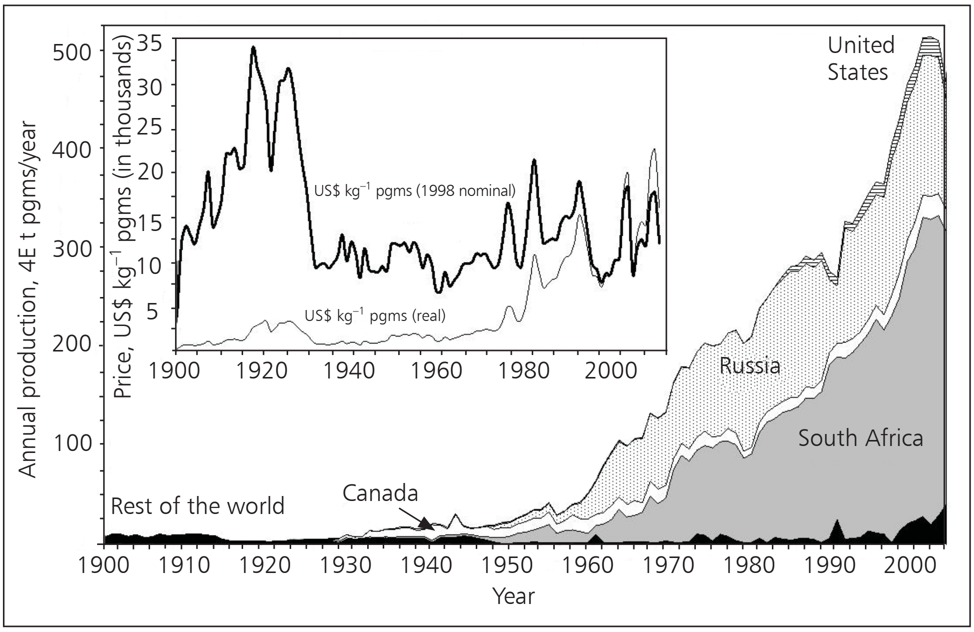

Fig. 1. Historical global production of pgms by country, including nominal and real price data inset (data updated from (4))

mental, economic and social performance of a company alongside statutory financial reporting. The compilation and analysis of the reported data can provide critical insights into a given mining sector, as well as valuable data for broader analyses of other mineral commodities. This section briefly describes the sustainability context and challenges for mining, and outlines the methodology adopted in this study.

2.2 Sustainability and Mining

At first glance, applying the principles of sustainability to mining is seemingly a simple oxymoron – since mining means to extract a resource which is finite and 'non-renewable'. The nature of mining is therefore widely considered to be unsustainable, since it is depleting a stock (or 'natural capital'). The paradox, however, is that the global mining industry is now larger than ever in history, producing minerals and metals at a rate which dwarfs previous generations of mines (11).

While there is evidence to suggest that many mineral commodities have shown growth in known economic resources over recent decades in some countries (for example, Australia (11)) as growing demand has encouraged exploration and developments in extraction technology – it is increasingly clear that the historical patterns of discovery and development of mineral resources cannot simply be assumed to continue unaltered into the future. The primary constraints may vary from social and governance issues in one region, to water or energy resources in another, or GGEs globally.

The application of sustainability principles to mining is therefore complex. The global mining industry, as part of their contribution to the Johannesburg Earth Summit convened by the UN in 2002, released a major report on mining and sustainability. The 'Mining, Minerals and Sustainable Development' (MMSD) report (12) was a major shift from arguing the historical case of growing resources over time, to a position where mining can contribute to sustainable development – even if a mining project is only a relatively short to medium term endeavour compared to other industries which are more perpetual in nature (for example, agriculture or tourism).

Sustainability is commonly defined as ensuring the ability of current generations to meet their needs without compromising the ability of future generations to meet their needs (i.e. the Brundtland 1987 definition (13)). In the context of mining, this can be taken to include the availability of resources and a productive environment at former mining or milling sites. The context for sustainable development and mining can therefore be taken back to first principles as balancing the potential environmental, social and economic risks. Further discussion of sustainability and mining are given in (7, 11).

2.3 Sustainability Reporting

An increasingly popular way of demonstrating performance against sustainability objectives is through sustainability reporting. This involves reporting and discussing all aspects of performance for a given year, covering social, economic and environmental aspects. Some mining companies, such as WMC Resources Ltd (now part of BHP Billiton Ltd) and Placer Dome Inc (now part of Barrick Gold Corp), began releasing annual environmental reports in the mid-1990s and these evolved into broader sustainability reports by 2000. Since the 2002 Johannesburg Earth Summit and the release of the MMSD report, numerous mining companies now report sustainability alongside statutory financial performance.

Early methods for reporting used internal company schemes. Due to the need to ensure consistency across companies, industry sectors or other organisations, the Global Reporting Initiative (GRI) was established in 1997 to develop protocols and promote and enhance sustainability reporting. The third edition was released in 2006 (14), with a pilot mining sector supplement in 2005 and the final mining sector supplement released early in 2010 (15). The GRI protocol is now the most common sustainability reporting tool used by mining companies (9).

The GRI itself is voluntary, and can be applied in whole or in part. There are five main sections of reporting, including economic, environmental, labour practices, human rights and social aspects. The qualitative and quantitative indicators used for each area are either core or voluntary. There are 30 environmental indicators in total (16), with some of the most significant examples including:

- EN3/EN4 – direct/indirect energy consumption by primary energy source (core);
- EN8 – total water withdrawal by source (core);
- EN9 – water sources significantly affected by withdrawal of water (voluntary);
- EN10 – percentage and total volume of water recycled and reused (voluntary);
- EN16 – total direct and indirect greenhouse gas emissions by weight (core);
- EN21 – total water discharge by quality and destination (core);

- EN22 – total weight of waste by type and disposal method (core).

Overall, the emergence of and continuing improvement in sustainability reporting is providing a valuable basis to assess the environmental sustainability aspects of mining. PGM companies in South Africa are certainly at the forefront in this regard, with Anglo American Platinum perhaps showing the best quality reporting of data and analysis (9).

2.4 Quantifying Sustainability and the Platinum Group Metals

The availability of growing data sets on wastes, energy, water and GGEs from sustainability reporting can be easily combined with normal production statistics from financial performance. In this way it is possible to link aspects such as energy, GGEs and water costs with ore grade, annual throughput or project configuration, providing some useful benchmarks to compare individual site operations and also enable the environmental implications to be understood as pgm production continues to grow to meet rising demand.

The 'sustainability metrics' used in this study are unit consumption of energy or water per unit pgm production (GJ kg^{-1} pgm or m^3 kg^{-1} pgm) with respect to ore grade measured for the four elements platinum, palladium, rhodium and gold (4E g t^{-1}), unit consumption of water or energy per tonne of ore milled (m^3 t^{-1} ore or GJ t^{-1} ore) with respect to mill throughput (Mt ore $year^{-1}$), and unit output of GGEs in carbon dioxide equivalents per unit pgm production (t CO_2e kg^{-1} pgm).

3. Results

3.1 Extent of Sustainability Reporting and GRI Indicators

There are fourteen primary pgm companies, with numerous more at the exploration stage (mostly concentrated in South Africa), plus four diversified mining companies operating Ni-Cu-pgm projects. Of these companies, six of the pgm and all of the Ni-Cu-pgm companies produce an annual sustainability report, with all companies using the GRI as their reporting basis. The extent of reporting against GRI indicators for these ten companies for 2009 is compiled in **Table I**. For the table, a score of 0 was noted where no information or data is provided, 1 was given for qualitative information or a brief discussion of this indicator, and 2 was given where the data and information is fully compliant with the GRI indicator, giving a maximum score of 60. Although there are many possible assessment approaches (for example, (17)), this system was considered effective to allow a comparison of reporting performance between companies as well as for critical indicators.

The total scores in **Table I** range from 10 (representing poor reporting performance) to 43 (representing fairly strong reporting performance). Only the energy indicators (EN3 and EN4) were assigned a perfect score for all ten companies. All other indicators varied widely. A major issue which is perhaps not immediately obvious is the lack of site data given by some companies, mainly the larger diversified companies. In order for any data to be materially useful, individual site data is best and should be reported. This is common practice for production.

The two top companies for sustainability reporting were Anglo American Platinum and Vale Inco. These are clearly the leaders in this area for the pgms sector. Anglo American Platinum's first report was published in 2002 (to coincide with the Johannesburg 2002 Earth Summit), and the content and presentation has continued to evolve over subsequent years. In general, Anglo American Platinum released site data up until year 2007, with the 2008 and 2009 reports giving group totals only (the site data was provided upon request to the present author (18)). Their group energy consumption for 2009 is shown in **Figure 2** (19), including the split between mining, milling, smelting and refining as well as sources of energy for each major stage and GGEs by energy source. This is an excellent approach, and allows a quick and substantive interpretation of energy consumption and sources, as well as links to GGEs. Furthermore, in their 2006 and 2007 reports, Anglo American Platinum presented mining, milling and smelting data by site, as well as including site-specific energy intensity targets, shown in **Figure 3** (20). This level of detail allows detailed analyses of energy performance, although the 2008 and 2009 reports stopped reporting in this manner. In contrast, Vale Inco have always reported by group totals and, although this allows comparison for Vale's performance year-on-year, this does not facilitate direct cross-sector evaluation of pgms production (as shown later in this paper). As a reporting model, therefore, Anglo American Platinum's provides greater depth to facilitate analysis of key factors, trends and issues.

By comparison, Lonmin scored much lower in **Table I.** However an example of their data is given in **Figure 4** (21), showing declining total energy consumption but increasing unit energy consumption.

Table I

Sustainability Reporting by GRI Metric (2009 Data)

Company	Site/Group	EN1	EN2	EN3	EN4	EN5	EN6	EN7	EN8	EN9	EN10	EN11	EN12	EN13	EN14	EN15	EN16	EN17	EN18	EN19	EN20	EN21	EN22	EN23	EN24	EN25	EN26	EN27	EN28	EN29	EN30	Total
Anglo American Platinum	Group	2	0	2	2	1	1	1	2	1	2	2	2	2	2	2	2	2	0	0	1	1	2	1	2	1	1	2	0	0	1	**40**
Impala Platinum	Site	0	0	2	2	2	1	2	2	1	2	2	1	1	1	1	2	0	0	2	1	0	2	0	0	0	0	0	2	0	0	**29**
Northam Platinum[a]	Site	2	2	2	2	0	1	0	2	0	2	2	2	0	1	2	2	0	0	0	1	0	0	2	0	0	0	0	2	0	1	**28**
Lonmin	Group[b]	0	0	2	2	0	0	1	1	0	0	2	2	0	1	2	2	0	0	0	1	0	2	1	2	1	0	0	2	0	2	**26**
Aquarius Platinum	Site	0	0	2	2	0	0	0	2	0	1	2	1	0	0	0	2	2	0	0	0	0	0	1	0	0	0	0	0	2	2	**19**
Eastern Platinum[a]	Site	2	0	2	2	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	**10**
Vale Inco	Group	2	1	2	2	0	0	0	2	0	2	2	2	2	2	2	2	1	2	2	1	1	2	2	2	0	1	2	2	0	2	**43**
Norilsk Nickel	Group[b]	2	2	2	2	2	2	2	2	1	2	1	0	0	1	2	0	0	0	0	2	2	2	0	0	1	1	2	0	0	2	**35**
BHP Billiton	Group	0	0	2	2	0	0	0	2	0	2	2	0	0	1	0	2	2	0	2	2	1	1	1	0	0	0	0	1	0	0	**23**
African Rainbow Minerals	Site	0	0	2	2	0	0	0	1	0	2	0	1	0	2	1	0	0	0	0	0	0	2	1	1	1	1	0	1	0	0	**18**
Number of 0's		**5**	**7**	**0**	**0**	**7**	**6**	**6**	**0**	**6**	**1**	**2**	**3**	**7**	**2**	**3**	**3**	**6**	**9**	**7**	**3**	**6**	**3**	**3**	**6**	**6**	**6**	**7**	**3**	**9**	**4**	
Number of 1's		**0**	**1**	**0**	**0**	**1**	**3**	**2**	**3**	**4**	**2**	**1**	**3**	**1**	**5**	**2**	**0**	**1**	**0**	**0**	**5**	**3**	**1**	**5**	**1**	**4**	**4**	**0**	**3**	**0**	**2**	
Number of 2's		**5**	**2**	**10**	**10**	**2**	**1**	**2**	**7**	**0**	**7**	**7**	**4**	**2**	**3**	**5**	**7**	**3**	**1**	**3**	**2**	**1**	**6**	**2**	**3**	**0**	**0**	**3**	**4**	**1**	**4**	
Average score		**1.0**	**0.5**	**2.0**	**2.0**	**0.5**	**0.5**	**0.6**	**1.7**	**0.4**	**1.6**	**1.5**	**1.1**	**0.5**	**1.1**	**1.2**	**1.4**	**0.7**	**0.2**	**0.6**	**0.9**	**0.5**	**1.3**	**0.9**	**0.7**	**0.4**	**0.4**	**0.6**	**1.1**	**0.2**	**1.0**	**27.1**

[a] *Single sites only, hence site is the same as group*

[b] *Lonmin and Norilsk Nickel generally report as a group (for example, energy, water), but do provide some data by site (for example, CO_2)*

Note: Companies who do not produce sustainability reports (or major sustainability sections in annual corporate reporting) are Platinum Australia, Platmin, North American Palladium and Stillwater Mining Company. Xstrata Alloys last released a sustainability report for 2007, which predominantly covers their South African chrome and vanadium operations and only has group data. Although Xstrata took over the Eland pgm project in late 2007, it appears that the group data does not include Eland

Notes to Table I[a]

Term	Definition
EN1	Materials used by weight or volume (core)
EN2	Percentage of materials used that are recycled input materials (core)
EN3	Direct energy consumption by primary energy source (core)
EN4	Indirect energy consumption by primary source (core)
EN5	Energy saved due to conservation and efficiency improvements (voluntary)
EN6	Initiatives to provide energy-efficient or renewable energy-based products and services, and reductions in energy requirements as a result of these initiatives (voluntary)
EN7	Initiatives to reduce indirect energy consumption and reductions achieved (voluntary)
EN8	Total water withdrawal by source (core)
EN9	Water sources significantly affected by withdrawal of water (voluntary)
EN10	Percentage and total volume of water recycled and reused (voluntary)
EN11	Location and size of land owned, leased, managed in, or adjacent to, protected areas and areas of high biodiversity value outside protected areas (core)
EN12	Description of significant impacts of activities, products, and services on biodiversity in protected areas and areas of high biodiversity value outside protected areas (core)
EN13	Habitats protected or restored (voluntary)
EN14	Strategies, current actions and future plans for managing impacts on biodiversity (voluntary)
EN15	Number of International Union for Conservation of Nature (IUCN) Red List species and national conservation list species with habitats in areas affected by operations, by level of extinction risk (voluntary)

(Continued)

Notes to Table I[a] (Continued)

Term	Definition
EN16	Total direct and indirect greenhouse gas emissions by weight (core)
EN17	Other relevant indirect greenhouse gas emissions by weight (core)
EN18	Initiatives to reduce greenhouse gas emissions and reductions achieved (voluntary)
EN19	Emissions of ozone-depleting substances by weight (core)
EN20	NOx, SOx, and other significant air emissions by type and weight (core)
EN21	Total water discharge by quality and destination (core)
EN22	Total weight of waste by type and disposal method (core)
EN23	Total number and volume of significant spills (core)
EN24	Weight of transported, imported, exported or treated waste deemed hazardous under the terms of the Basel Convention Annex I, II, III, and VIII, and percentage of transported waste shipped internationally (voluntary)
EN25	Identity, size, protected status, and biodiversity value of water bodies and related habitats significantly affected by the reporting organisation's discharges of water and runoff (voluntary)
EN26	Initiatives to mitigate environmental impacts of products and services, and extent of impact mitigation (core)
EN27	Percentage of products sold and their packaging materials that are reclaimed by category (core)
EN28	Monetary value of significant fines and total number of non-monetary sanctions for non-compliance with environmental laws and regulations (core)
EN29	Significant environmental impacts of transporting products and other goods and materials used for the organisation's operations, and transporting members of the workforce (voluntary)
EN30	Total environmental protection expenditures and investments by type (voluntary)

[a]*From (16)*

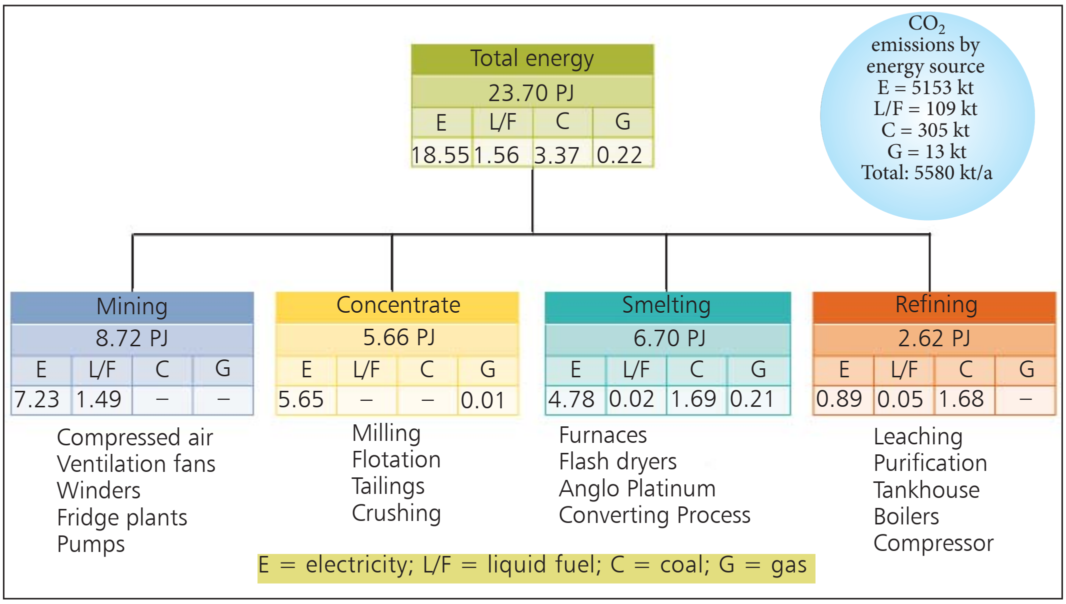

Fig. 2. Energy sources and consumption by production stage and greenhouse gas emissions by source for 2009 by Anglo American Platinum (19)

Energy intensity per operation	2006	2007	Target 2007
Mines (GJ t^{-1} broken)			
Rustenburg section	0.27	0.32	0.27
Amandelbult section	0.28	0.30	0.29
Union section	0.34	0.31	0.34
Lebowa	0.33	0.48	0.32
Bafokeng-Rasimone	0.23	0.25	0.24
Twickenham	–	0.08	*
PPRust	0.02	0.02	0.04
Concentrators (GJ t^{-1} milled)			
Rustenburg section	0.15	0.17	0.15
Amandelbult section	0.16	0.14	0.16
Union section	0.12	0.14	0.12
Lebowa	0.15	0.16	0.14
Bafokeng-Rasimone	0.15	0.16	0.15
Mototolo	–	0.17	*
PPRust	0.21	0.25	0.22
Western limb tailings retreatment	0.09	0.09	0.09
Processing plants			
Waterval smelter (GJ t^{-1} converter matte produced)	91.63	94.47	89.00
Polokwane smelter (GJ t^{-1} funace matte produced)	28.58	31.67	30.00
Mortimer smelter (GJ t^{-1} furnace matte produced)	50.54	39.69	53.50
RBMR (GJ t^{-1} base metals produced)	58.94	61.12	59.40
PMR (GJ oz^{-1} pgms and gold)	0.15	0.16	0.18

* No target set

PPRust = Potgietersrust Platinums; RBMR = Rustenburg Base Metals Refiners; PMR = Precious Metal Refiners

Fig. 3. Site-specific energy consumption and targets by production stage for 2007 by Anglo American Platinum (20)

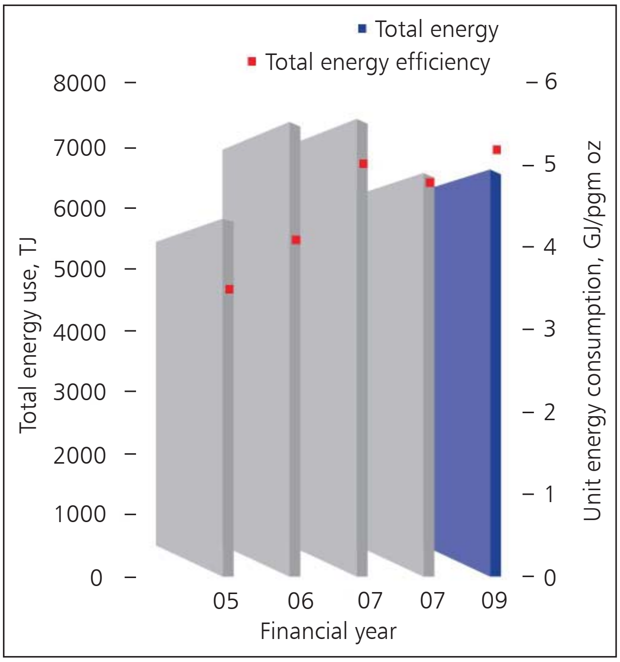

Fig. 4. Energy by total and unit consumption (labelled as 'energy efficiency') for 2009 by Lonmin (21)

3.2 Sustainability Metrics

The compiled sustainability metrics are given in **Table II**, divided by mines and companies where possible.

3.2.1 Water Metrics

The graphs of unit water costs *versus* throughput or over time, shown in **Figure 5**, do not show strong evidence of water efficiency gains for most projects. That is, larger project scales do not necessarily lead to higher water efficiency, a common belief in the mining industry. Ore grade does not appear to be a factor in unit water efficiency. Over time, most projects have shown somewhat stagnant water efficiency, with only Bokoni showing strong reductions in total water consumption and unit water costs over time, which also appear to be sustained. Some projects are showing the reverse, however, such as Northam with significantly increasing water costs over time.

3.2.2 Energy Metrics

The various graphs for energy in **Figure 6** show no substantive evidence for improved unit energy efficiency at higher throughputs, despite the common perception in the mining industry. There does appear to be a minor negative scale effect for unit energy consumption for stand-alone mine-concentrator-smelter projects with low throughputs (i.e. smaller scales entail higher unit energy costs). Ore grade does appear to be a significant factor for unit energy consumption (correlation coefficient 49.9%, **Figure 6**). No project studied has shown long term energy efficiency improvements over time, with most showing relatively stable or slightly increasing trends. The Bokoni and Northam projects, however, show substantive increases in energy costs over the past few years – despite both maintaining similar production levels and ore grades.

The low energy cost for mining at Mogalakwena (24.4 MJ t^{-1} rock) is due to this being an open cut mine, while the deep Northam underground mine (~2 km) has the highest mining energy consumption (1414 MJ t^{-1} rock). The data in **Table II** also show that indirect energy (electricity) is the dominant energy input overall, with the majority of energy being used by underground mining. This would be due to the narrow mining techniques used, requiring large areas of development for small returns in ore compared to underground bulk mining techniques. Although a relatively small percentage of Bushveld ore is derived from open cut mines, many pgm producers have planned expansions to incorporate open cut mines in the future. There is a clear energy trade-off between underground and open cut mining (i.e. MJ t^{-1} rock) and the amount of solid wastes produced, since open cut mining produces large volumes of waste rock (see **Section 3.2.4**).

Table II

Sustainability Metrics for PGM Projects and Companies[a]

Mine & concentrator only	Mining, MJ t^{-1} rock	Milling, MJ t^{-1} ore	Energy, GJ kg^{-1} pgm	Energy, MJ t^{-1} ore	Water, m^3 kg^{-1} pgm	Water, m^3 t^{-1} ore	CO_2e emissions, t CO_2e kg^{-1} pgm
Bafokeng-Rasimone	261.5 [3]	166.2 [3]	117.0 [8]	418.3 [8]	228.1 [8]	0.809 [8]	29.9 [8]
Bokoni	572.2 [4]	140.9 [4]	164.1 [7]	605.8 [7]	385.4 [7]	1.397 [7]	39.9 [7]
Mogalakwena	24.4 [5]	156.7 [5]	190.1 [8]	460.8 [8]	297.6 [8]	0.697 [8]	29.9 [8]
Tumela-Dishaba	365.5 [5]	140.1 [5]	112.6 [8]	480.2 [8]	212.5 [8]	0.919 [8]	28.4 [8]
Rustenburg Group[b]	294.8 [5]	166.7 [5]	123.0 [8]	436.3 [8]	213.0 [8]	0.755 [8]	31.1 [8]
Union	288.9 [5]	118.4 [5]	191.6 [8]	523.9 [8]	236.4 [8]	0.656 [8]	44.4 [8]
Twickenham	-	-	28.5 [1]	890.0 [1]	420.1 [3]	1.665 [3]	16.2 [3]
Mototolo JV	-	-	70.1 [3]	242.5 [3]	174.0 [3]	0.575 [3]	18.9 [3]
Kroondal JV	-	-	103.1 [3]	206.3 [3]	460.7 [1]	0.933 [1]	27.8 [3]
Marikana JV	-	-	217.2 [3]	410.7 [3]	92.2 [1]	0.175 [1]	36.5 [3]
Everest	-	-	130.5 [3]	260.3 [3]	162.6 [1]	0.386 [1]	92.4 [3]
Marula	-	-	109.4 [5]	403.9 [5]	581.2 [5]	2.154 [5]	-
Mimosa	-	-	109.8 [5]	305.4 [5]	720.3 [5]	1.988 [5]	51.2 [1]
Modikwa JV	-	-	10.7 [1]	40.6 [1]	135.4 [1]	0.513 [1]	2.7 [1]
Two Rivers	-	-	40.5 [1]	99.2 [1]	205.6 [1]	0.504 [1]	5.3 [1]
Crocodile River	-	-	162.7 [3]	403.0 [3]	1086.4 [1]	2.328 [1]	34.5 [3]

(Continued)

Table II (Continued)

Mine, concentrator, smelter and refinery (full refined production)	Mining, MJ t^{-1} rock	Milling, MJ t^{-1} ore	Energy, GJ kg^{-1} pgm	Energy, MJ t^{-1} ore	Water, m^3 kg^{-1} pgm	Water, m^3 t^{-1} ore	CO_2e emissions, t CO_2e kg^{-1} pgm
Northam	1414.5 [6]	546.9 [6]	230.1 [6]	1961.4 [6]	1804.2 [6]	15.639 [6]	60.0 [6]
Zimplats	-	-	222.6 [5]	645.7 [5]	617.4 [5]	1.776 [5]	-
Implats	-	-	269.5 [7]	1022.0 [7]	624.4 [5]	2.324 [5]	54.5 [7]
Lonmin	-	-	175.1 [8]	492.6 [8]	269.3 [8]	0.761 [8]	41.7 [8]
Company/group totals	**Direct energy fraction, %**	**Indirect energy fraction, %**	**Energy, GJ kg^{-1} pgm**	**Energy, MJ t^{-1} ore**	**Water, m^3 kg^{-1} pgm**	**Water, m^3 t^{-1} ore**	**CO_2e emissions, t CO_2e kg^{-1} pgm**
Impala Platinum	35.9 [7]	64.1 [7]	269.5 [7]	1022.0 [7]	624.4 [5]	2.324 [5]	54.5 [7]
Lonmin	20.0 [6]	80.0 [6]	175.1 [8]	491.6 [8]	269.3 [8]	0.761 [8]	41.7 [8]
Northam Platinum	8.0 [6]	92.0 [6]	-	-	-	-	-
Anglo American Platinum	23.3 [5]	76.7 [5]					

[a] *Average values; number of years of data in brackets*

[b] *Former name used for consistency with older reporting (Rustenburg Group includes the Bathopele, Khomanani, Thembelani, Khuseleka and Siphumelele mines and Rustenburg mill)*

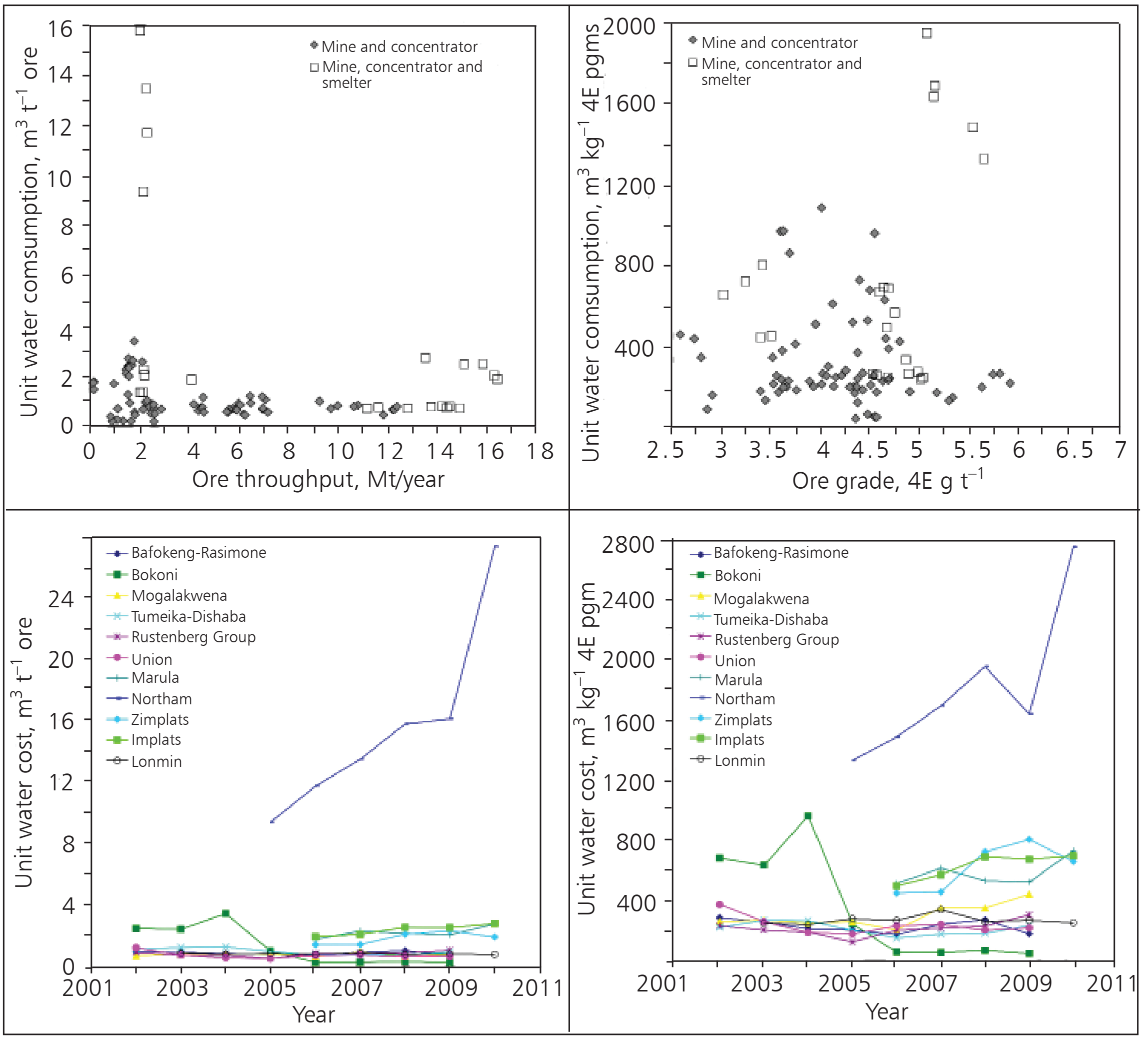

Fig. 5. Water intensity metrics – ore processing versus ore throughput (top left); production versus ore grade (top right); ore processing over time (bottom left); production over time (bottom right)

3.2.3 Greenhouse Gas Emissions Metrics

A moderate relationship is suggested between ore grade and unit GGEs (correlation coefficient 28.6%, **Figure 7**), while the correlation between unit energy and unit emissions, surprisingly, yields a correlation coefficient of 39.1% (**Figure 8**) – despite South Africa's electricity supply being dominated by coal (89.7%) with a small proportion of hydroelectricity (5.0%) (22). The variability could be due to different estimation methods used by companies, although given the dominance of electricity this should not be the case (recalculation of GGEs based on reported energy consumption also produces consistent results). Most of the values which appear to be unusual (or outliers) are mines which have only reported one or two years of data, or where site activities or conditions were atypical (such as sites undergoing expansions or values reported during the electricity crisis) resulting in lower production and higher metrics. Unit GGEs over time show a slight but gradually increasing trend for all projects included in **Figure 7**, which could also affect the correlation between energy and emissions intensity.

Since there is some evidence for major pgm producers showing declining ore grades over the past decade (3, 4), the implication is that unit GGEs will increase further if no action is taken. It is worth noting that some companies are now responsible for GGEs of the order of several millions of tonnes per year – and if development and production continue to grow

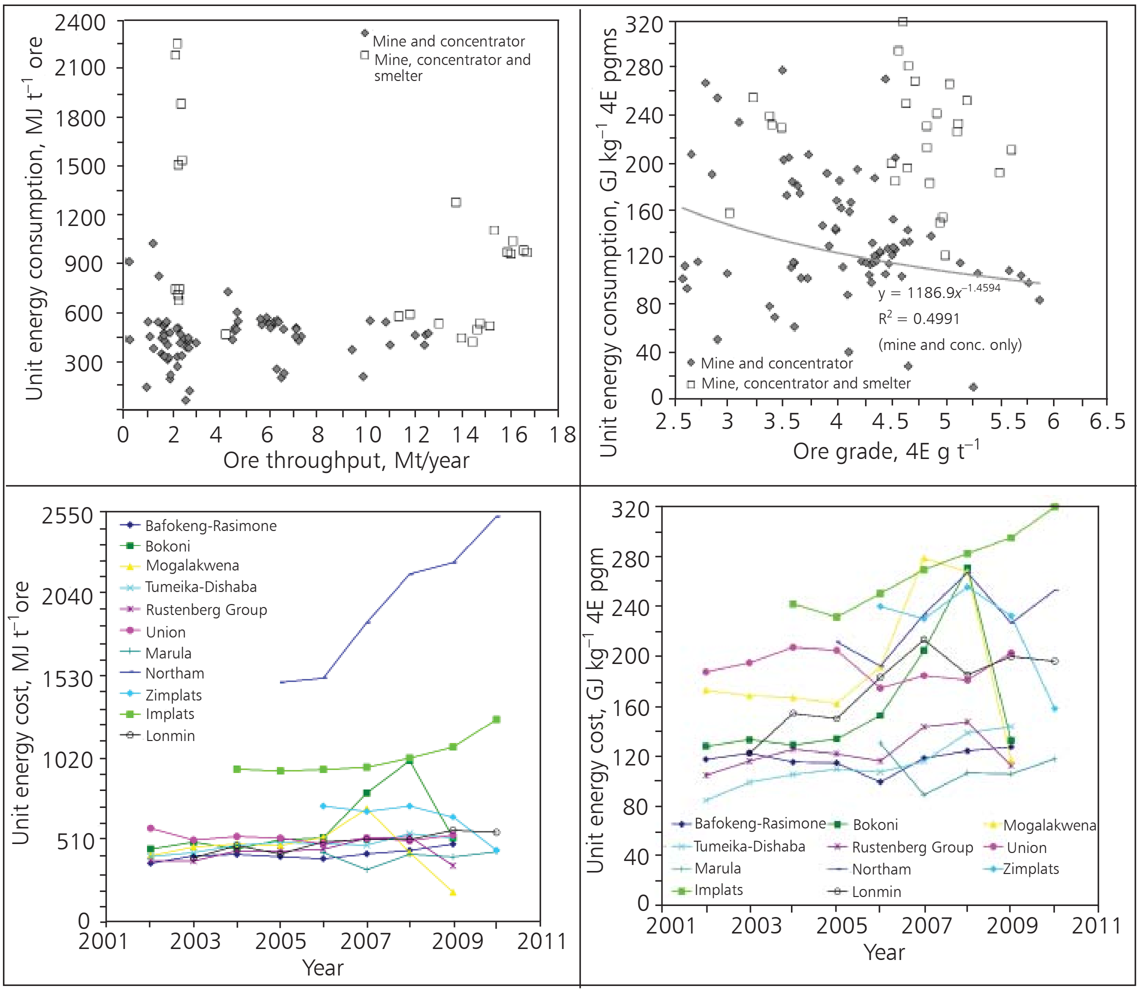

Fig. 6. Energy intensity metrics – ore processing versus ore throughput (top left); production versus ore grade (top right); ore processing over time (bottom left); production over time (bottom right)

at or close to historical rates, this will lead to major increases in total emissions.

Based on the data in **Figure 7** and **Table II**, the growth in GGEs due to production increases is likely to be much greater than the possible savings due to mine, mill or smelter efficiency improvements. To date, it would appear that the energy savings achieved at most sites are relatively modest or are cancelled out by other factors such as operational issues (for example, the South African electricity crisis). By way of illustration, some Anglo American Platinum mines show variation within a typical range (for example, Bafokeng and Union), while others show a gradual increase over time (for example, Bokoni, Mogalakwena, Tumela-Dishaba and Rustenburg Group). In other words, if production doubles there is little evidence that existing mines can reduce energy consumption by half. This means that GGEs will become an increasingly important issue as pgm production grows.

One way to address this issue may be to switch energy production to renewable alternatives. If current coal-derived electricity were changed to baseload solar thermal (i.e. solar thermal plants with heat storage), this could significantly reduce the carbon intensity of pgms production – which, at present, is often trending upwards due to a variety of competing factors.

3.2.4 Mine Wastes – Waste Rock, Tailings and Smelter Slags

The majority of pgm ore is sourced by underground mining, with 2009 production data showing that for the

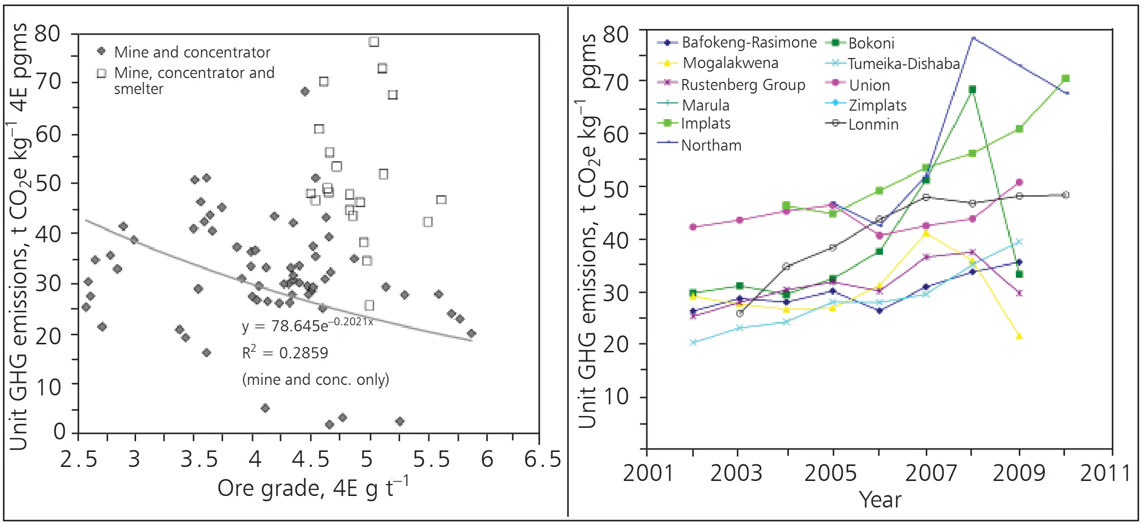

Fig. 7. Greenhouse gas emissions intensity metrics – production versus ore grade (left); production over time (right)

Bushveld, Great Dyke and Stillwater fields underground mining represents ~83.5% of the ore milled, with ~16.5% by open cut mining.

The two large volume mine wastes, tailings and waste rock, both require active planning and management to prevent major environmental or social impacts such as tailings dam failures (for example, the 1974 Bafokeng tailings disaster (23), acid and metalliferous drainage or other problems (for example, dust and environmental health issues). In addition, slag wastes from smelters are important and are commonly disposed of in tailings dams at pgm mines (or slags can be reprocessed to extract residual pgms).

Given that the ratio of ore to concentrate can be anywhere from 30:1 to 50:1, this means that some 96–98% of the ore becomes tailings. Waste rock to ore ratios are typically high for open cut mining (between 5:1 and 20:1) and the reverse for underground mining (for example, Zimplats reported a ratio of 0.03:1) (24). At present, very little data exists on underground waste rock generation in the Bushveld or other mines, but the ratio could be expected to be ~0.1:1. The waste:ore ratios reported for the Mogalakwena, Kroondal and Marikana Joint Venture open cut mines range from 6.9:1 to 23.7:1, leading to waste rock ranging from 2.6 to 94.6 Mt year^{-1}. During its operation, the Ngezi open cut mine at Zimplats had a ratio of 12.5:1 (24), producing ~150 Mt of waste rock.

At present, it is rare for companies to report total mine wastes under their control and active management.

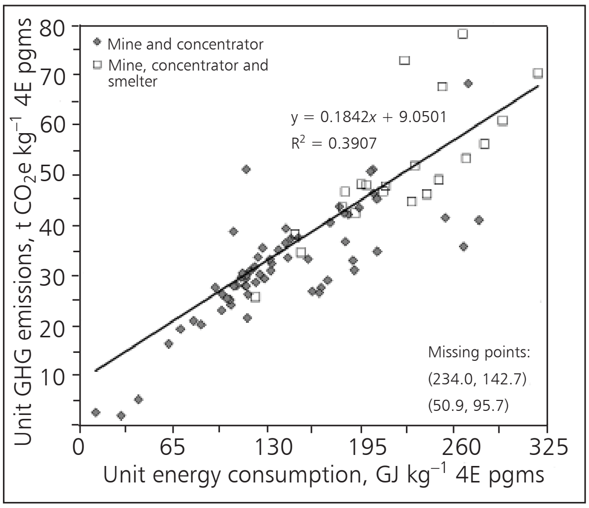

Fig. 8. Unit greenhouse gas emissions intensity versus unit energy intensity

One exception, however, is Anglo American Platinum, who reported in 2009 that their cumulative mine wastes were 839.1 Mt of tailings, 692.8 Mt of waste rock and 5.2 Mt of smelter slags (19) – demonstrating the large scale and significance of managing these wastes in the surface environment long into the future. Studies by Anglo American Platinum suggest that both Merensky and UG2 tailings have a low acid and metalliferous drainage potential, although potential drainage waters from tailings would still be high in sulfate – meaning tailings still require active environmental management to prevent impacts on water resources. In March 2008, the non-government group ActionAid claimed that there is evidence for local impacts on water resources used by surrounding communities of some Anglo American Platinum operations (especially Mogalakwena) (25). In response, Anglo American Platinum commissioned external studies to assess the extent of water resource impacts, demonstrating that the problems identified by ActionAid were not related to Anglo American Platinum operations (19).

4. Discussion

4.1 Sustainability Metrics: Historical Comparison

In 1955 the Rustenburg and Union mines processed ~1.6 Mt ore and consumed 306,000 GJ of electricity and 2,157,000 m^3 of water (26). Assuming all South African production of 11.87 t pgm in 1955 was from these mines, this gives a yield of about 7.42 g t^{-1} (an ore grade of ~9.3 g t^{-1} assuming 80% recovery) and unit energy and water costs of 25.8 GJ kg^{-1} pgm and 182 m^3 kg^{-1} pgm, respectively, plus 1.35 m^3 t^{-1} ore. Compared to recent values (**Table II**), this suggests that energy costs have increased over time but water costs have only marginally increased. The increasing energy costs are probably related to the gradually increasing depth of the mines and lower ore grades.

4.2 Sustainability Metrics: Energy

With respect to energy, the data show a moderate negative correlation between ore grade and unit energy costs – as ore grades decline the unit energy costs increase (**Figure 6**). Although average 4E ore grades in the Bushveld have not declined as dramatically as gold ores elsewhere in South Africa, the current average ore grade of ~3.9 g t^{-1}(4E) is marginally below the 2009 average ore grade of Bushveld reserves and resources of ~4.3 g t^{-1}(4E) (3). Average ore grade may decline as shallower but lower grade projects (for example, the Platreef or Great Dyke mines) are expanded or developed in preference to deeper Merensky/UG2 projects. Therefore there will be only slight pressure on energy costs from declining grades, and overall, this suggests that total energy consumption will largely be a function of pgm production. Declining grades, however, may still affect individual companies or major projects.

Unlike gold mining, energy in pgm mining and production is dominated by electricity consumption, related to the prevalence of underground mining in the Bushveld region and the more complex processing that is required for pgm extraction. The typical range for unit energy costs is presently 122–319 GJ kg^{-1} pgm, with a production-weighted average of 222 GJ kg^{-1} pgm (based on refined production only). Most projects show variable unit energy costs over time and no clear trend, although 2007 to 2009 are often the highest on record – presumably related to the South African electricity supply crisis affecting production. A recent study of gold mining (7) showed that the typical unit energy costs of gold ranged from 120 to 213 GJ kg^{-1} Au and averaged 143 GJ kg^{-1} Au. The unit energy costs for pgms are clearly higher than those for gold, but not as much as could be expected based on the differences in mining and processing.

Anglo American Platinum's data show the split in energy costs between mining, milling, smelting and refining (**Figures 2** and **3**), showing the dominance of the first three of the four major stages in pgms production. In addition, the inclusion from 2006 to 2007 of energy costs split between mining and milling is a rare example of detailed reporting in the global mining industry, and allows improved understanding of the various stages of pgm mining and production. Unfortunately, as individual smelter pgm production statistics are not reported (for example, grade and tonnes of concentrate processed to matte produced), it is not possible to provide a breakdown to unit energy costs (GJ kg^{-1} pgm) for each major stage which could then be expanded into a rigorous, process-based model of pgms production.

4.3 Sustainability Metrics: Greenhouse Gas Emissions

The unit GGEs also show a moderate negative correlation to ore grade, similarly to energy – as should be expected given the dominance of coal in South Africa's electricity mix. The typical range for unit emissions is 25.8–78.3 t CO_2e kg^{-1} pgm, with a production-weighted average of 51.2 t CO_2e kg^{-1} pgm (based on refined production only). The unit GGEs for gold typically range from 10.3 to 16.4 t CO_2e kg^{-1} Au and average 11.5 t CO_2e kg^{-1} Au (7). The significantly higher unit GGEs for pgm production are influenced by the high proportion of coal-based electricity for Bushveld projects as well as the more intense processing associated with smelting and refining.

The energy and GGEs intensities of Bushveld pgm production give rise to perhaps a unique situation in global mining. Due to the high proportion of electricity used per unit production, it should be possible to examine future low GGE electricity sources, including renewable energy projects like wind power, baseload solar thermal and/or photovoltaics, to progressively replace existing coal-based electricity. This would still allow electricity needs to be met but provide for a significant reduction in emissions. In contrast, gold mining is often dominated by open cut techniques, for which sustainable alternatives to diesel as an energy source appear very limited at present. Although viable energy sources in the Bushveld are outside the scope of this study, it is clear that energy efficiency as well as the choice of energy sources will be critical in determining both the energy and emissions intensities of pgms production.

4.4 Sustainability Metrics: Water

The extent of water consumption for pgms is within typical ranges for various metals (8). In terms of water consumed in milling, the range found in this study for processing pgm ore is 0.18–3.39 m^3 t^{-1} ore with one project averaging some 15.6 m^3 t^{-1} ore. The average of 1.04 m^3 t^{-1} ore (excluding the single high value) is similar to gold (1.37), copper-gold (1.22), copper (1.27), lead-zinc-silver (2.67) and nickel (1.01) ore processing (all m^3 t^{-1} ore; (8)). Almost all of these ore types undergo grinding and flotation to produce concentrates in a similar manner to pgm ore processing.

A perhaps surprising outcome is the degree to which the Bokoni project has reduced water consumption from a high of 6.07 million m^3 in 2004 to just 279,000 m^3 in 2008 (in 2009, Bokoni became a non-managed joint venture (JV) and water reporting reflects this change in ownership as a full year's data was not available in 2009 (18)). Most projects, however, have not been successful in this regard, with Anglo American Platinum's Rustenburg group increasing total consumption of water from ~3.1 million m^3 between 2002–2004 to about 6 million m^3 in 2009 despite only a marginal increase in production. The opportunity to save water would appear to be very site and project specific but remains a critical area for future sustainability in the pgm sector.

Despite the increasing reporting of water consumption by pgm companies, it remains a challenging area for sustainability reporting. Under the GRI, total water consumption (EN8) and water discharges (EN21) are core reporting indicators while impacts on water resources (EN9) and water recycling (EN10) are voluntary. Very few pgm companies report on all of these indicators in detail (see **Table I**), with most simply reporting total water consumption. As such, it has not been possible to present an account of the extent of water recycling in pgm ore processing.

The typical range for unit water consumption per unit pgms produced of 241–2743 m^3 kg^{-1} pgm, with a production weighted average of 800 m^3 kg^{-1} pgm, compares similarly to gold mining where production requires an average of 691 m^3 kg^{-1} Au (typical range 224–1783 m^3 kg^{-1} Au) (7). The differences are probably related to ore grades, the degree of water recycling and the more intensive smelting and refining processes that are required for pgms.

A major weakness in the GRI's approach to water aspects is that water quality is not considered, except for external water discharges to the environment (8). This is critical since water quality is the primary factor in determining its potential use, recyclability and impact on the environment. At present, not all pgm companies divulge data on the quality of consumed water, and there is limited information on the quality of water discharged to the environment. Anglo American Platinum's statement on water resource impacts at Mogalakwena *versus* those of ActionAid, discussed earlier, are an exception in this regard.

4.5 Sustainability Metrics: Mine Wastes

The mining industry is the largest annual producer of solid wastes globally (12, 27). The relatively low grade of pgm ores, of the order of a few grams per tonne, means that > 99.99% of the ore becomes solid waste. However, despite numerous major tailings dam failures, riverine or marine disposal of tailings, or ongoing acid and metalliferous drainage at innumerable current and former mine sites around the world (12, 27–29), the GRI still does not mandate that large volume mine wastes be fully and accurately reported. Under the main GRI protocol (14), the core indicator for solid wastes (EN22) is typically taken to refer to putrescible and/or hazardous wastes, such as those sent to landfill, recycled or treated further (for example, chemicals, oils, metals, woods, etc.) (9). The GRI mining and metals sector supplement (15) proposes that 'total amounts of overburden, rock, tailings, and sludges and their associated risks' (p. 33, indicator MM3) should be a core indicator but fails to make it an explicit requirement to report complete data. It is expected that only 'hazardous' mine wastes should be reported, effectively leaving the reporting of large volume mine wastes at the discretion of a site 'risk assessment' to judge what is 'hazardous'. This is unfortunate, since it allows an easy escape clause to avoid reporting such wastes. Based on a comprehensive survey of sustainability reporting by many major mining companies, full and accurate reporting of large volume mine wastes is a key strategic weakness across the global mining industry (9).

Within the pgms mining sector, Anglo American Platinum are certainly the leader with respect to reporting mine waste data, although all pgm companies can and need to improve their reporting in this regard. The recent controversy over the perceived water resources impacts at Mogalakwena highlights the importance of proactive management of large tonnage mine wastes, especially where these border large local communities which depend on water resources adjacent to mining projects.

4.6 Sustainability Metrics: Biodiversity

The reporting of biodiversity data and information was highly variable and often poor (indicators EN11 to EN15 and EN25). Given the public prominence of biodiversity issues, legislation and numerous international conventions or treaties and the potential impacts of mining on protected areas and threatened and endangered species, this is rather surprising. For some indicators, a review of International Union for Conservation of Nature (IUCN) information on 'Red List' species is all that is required, while other indicators simply require land tenure information and a discussion of protected or high conservation areas relative to land uses and management plans.

The best example of detailed biodiversity reporting was by Vale Inco, who scored perfectly for indicators EN11 to EN15. Vale Inco provide detailed biodiversity data, descriptions of their operations relevant to specific regions or biodiversity values, and detailed discussions of management plans. It is perhaps no coincidence that Vale Inco has been at the forefront of these challenges in their home country Brazil, home of the Amazon rainforest, compared to other companies which are in established agricultural and/or mining provinces where biodiversity issues have not historically been as prominent.

5. Conclusions

This paper has reviewed the ongoing development of sustainability reporting by the pgms mining sector, focussing in particular on the technical basis for environmental aspects and the trends in the reported data. Given the strong expected growth in the long-term demand for pgms to meet the needs of environmental and other technologies, it is critical to understand the existing factors which govern environmental aspects such as carbon intensity, water costs and energy consumption – otherwise known as unit metrics. At present, there appears to be significant upward pressure on these unit metrics, such as t CO_2 kg^{-1} pgms or GJ kg^{-1} pgms, due to a variety of complex factors. For example, both the ongoing South African electricity crisis and the current global financial crisis have impacted on production, commonly placing upward pressure on unit metrics. The high proportion of coal in South Africa's electricity mix is also a crucial factor in the high carbon intensity of pgms, since most pgm ore is sourced from underground mining and is electricity intensive.

In general, the breadth and extent of sustainability reporting by the pgms mining sector is improving over time, especially as companies become more familiar with reporting protocols such as the GRI, as well as the ability to link such reporting to operational performance and targets. Based on the present review, best practice in sustainability reporting involves detailed and complete site data as well as coverage of all GRI indicators, even where only qualitative information is required.

In summary, this paper provides an important insight into sustainability reporting and the pgms sector, which is certainly a global leader in this regard compared to other major mining sectors, allowing a valuable insight into the links between unit metrics, such as carbon intensity, and the issues facing the pgm mining industry such as the choice of electricity source, the development of deeper mines and the challenges of changing ore types and grades.

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across the pgm sector is warmly recognised, as they continue to provide a leading example of sustainability leadership and reporting in the global mining sector. Long may this continue and improve!

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