Sustainability Reporting in the Gold Mining Industry: The Need for Continual Improvement

Gavin M. Mudd
Department of Civil Engineering, Monash University

Keywords: Gold mining, sustainability reporting, greenhouse emissions, eco-efficiency.

ABSTRACT

Gold mining in Australia and globally has a long and variable history. In recent years, due to ongoing public concern over long-term environmental impacts, the mining industry globally has been moving towards a more sustainable framework, presented as the 'Mining, Minerals and Sustainable Development' (MMSD) framework at the Johannesburg Earth Summit in 2002. There are a number of fundamental issues and concerns with assessing the sustainability of mining. These include long-term declines in ore grades, increasing waste rock from larger open cut mining, and more complex ores being processed. The impact of these trends on the resource intensity, or 'environmental' cost, of gold production is of major concern as it could lead to an increase in energy, water and reagent consumption and greenhouse emissions per unit gold produced. Many of these aspects are now routinely reported in corporate sustainability performance reports, commonly based on the 'Global Reporting Initiative' (GRI) protocol. In Australia additional reporting is also done under the National Pollutant Inventory (NPI). This paper compiles and assesses the long-term trends in gold mining in the context of its resource intensity, based on data in sustainability reports. It therefore presents a unique case study of quantifying the 'environmental' cost of the gold mining sector (and mining generally), and provides a strategic insight into the current state of sustainability reporting and areas for future improvement.

1. INTRODUCTION

The modern mining industry is increasingly moving towards annual reporting of their sustainability performance, now commonly done in conjunction with financial reporting.

Sustainability reporting practice by the mining industry has evolved rapidly over the past decade from internally developed protocols by major mining companies to increasing use of the UN protocol called the 'Global Reporting Initiative' (GRI 2006). In addition, Australia has the statutory 'National Pollutant Inventory' (NPI 2001), which requires compulsory reporting of emissions to the environment of listed pollutants or contaminants.

A number of critical questions therefore arise:

- how broad is the adoption of the GRI and NPI by the gold mining industry?
- do the current indicators of the GRI and NPI allow a systematic assessment of the sustainability performance of the modern gold mining industry?
- how can the GRI in particular be improved to facilitate more accurate sustainability reporting?

This paper presents a broad study of sustainability metrics and reporting by the global gold mining industry and respective companies.

2. METHOD: QUANTIFYING SUSTAINABILITY

The relevance of sustainability concepts to mining is perhaps not immediately obvious – since minerals and metals are commonly perceived to be finite and non-renewable resources. In reality, however, most mines presently in operation dwarf their historic cousins – often considerably. There has been little quantitative attention has been given to this area. There are a range of resource and environmental issues which need to be considered when assessing the sustainability (or otherwise) of gold mining (eg. IIED and WBCSD 2002):

- extent of known, recoverable economic resources;
- ore grades of ore mined (g/t Au);
- mining technique – underground or open cut (or solution mining);
- processing and mineral production;
- total solid waste burden – especially waste rock and tailings;
- quality and quantity of surface water and groundwater resources consumed and/or impacted;
- pollutant emissions, especially gases such as carbon dioxide (CO_2) and sulfur dioxide (SO_2);
- minesite rehabilitation and closure, especially long-term monitoring;
- energy inputs, including the quantity but also the source and types of energy (eg. fossil fuels).

This list is instructive only – more comprehensive lists are found in various technical literature (eg. GRI 2006). With respect to sustainability, the reporting and integrating of social and economic aspects with the various aspects above remains a key challenge. Data has been compiled from sustainability reporting by various gold mining companies around the world. This paper focuses on environmental and resource aspects only, presenting a brief summary of findings to date. Further details are given in Mudd (2007).

3. RESULTS

3.1 World Gold Production and Ore Grades

World gold production over the past 160 years appears in Figure 1. The gold ore grades for hard rock mining for some countries are shown in Figure 2, including the price of gold in both dollars of the day and 1998 US dollars. The effects of the California gold rush in 1849, followed by the gold rushes in Australia in 1851 and South Africa in 1884 are evident. The development of new cyanide milling technology (carbon-in-pulp, CIP) and the 1970s rise in the price of gold led to expanded production from ~1980 onwards.

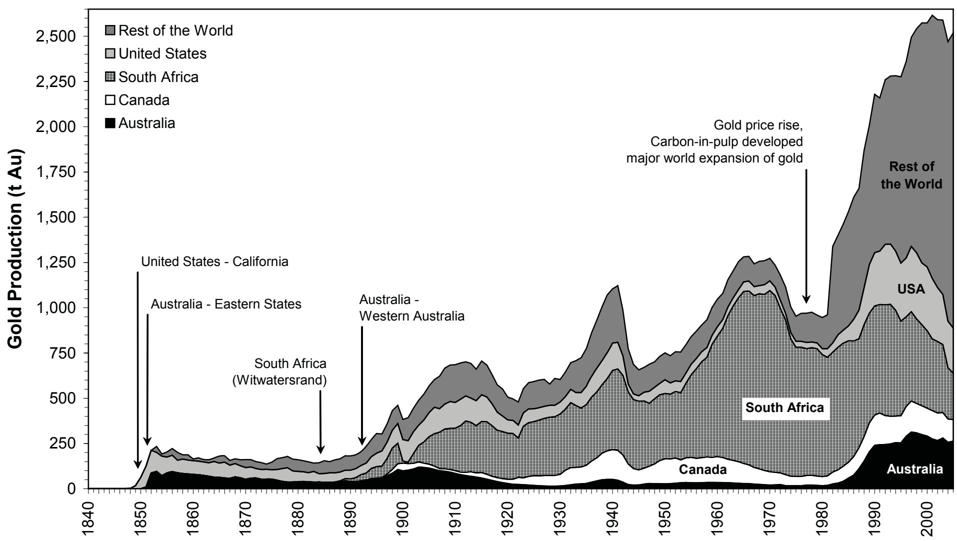

Figure 1. World gold production over time by country

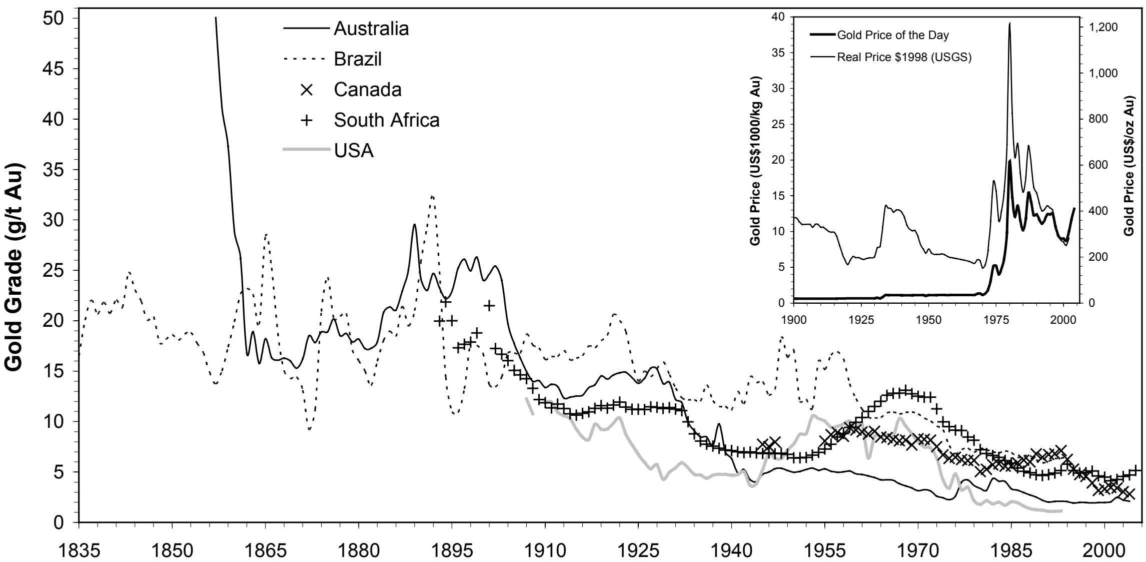

Figure 2. Average gold ore grades over time by country and gold price

3.2 Energy Consumption

The supply and consumption of energy is often a key factor in the economic viability of gold mines (diesel is particularly important, with natural gas use increasing). The available data for energy consumption between 1991 and 2006 are shown in Figure 3, including a power regression of all data points; data over time are reported in Table 1.

3.3 Water Consumption

The availability of a suitable water supply is important for any mine, though water quality for gold mining is no longer as critical since the development of CIP technology. This process can efficiently utilise hypersaline waters (eg. many gold mines in Western Australia). As there is no consistency in reporting waters of various sources or quality, the data are presented as total water consumption. There is presently little reporting of whether water comes from either fresh or recycled sources, or various levels of water quality or salinity. The available data for water consumption between 1991 and 2006 are shown in Figure 4, including a preliminary power regression of all data points; data over time are in Table 1.

3.4 Cyanide Consumption

The use of cyanide in gold mining poses environmental risks that needs to be pro-actively managed. Several tailings dam failures and cyanide transport accidents since 1995 have led to increased public scrutiny (Kumah 2006). Although many companies now publish sustainability reports, only some include cyanide consumption. The 'International Cyanide Management Code' (ICMI 2002) as well the more recent GRI Mining Supplement (GRI 2005) are voluntary and do not require compulsory reporting of cyanide consumption. The available data for cyanide consumption between 1992 and 2006 appear in Figure 5, which also includes a power regression of all data points; data over time are summarised in Table 1.

3.5 Greenhouse Emissions

Greenhouse emissions, primarily through fossil fuels use, provide a major environmental challenge for the mining industry globally but this is particularly difficult for gold mining that involves large-scale open cut operations (Dow and Minns 2004). As with water and energy, greenhouse emissions are presented as unit release per gold production with respect to ore grade as well as unit release per tonne of ore milled with respect to mill throughput. Data between 1991 and 2006 are shown in Figure 6; data over time are in Table 1.

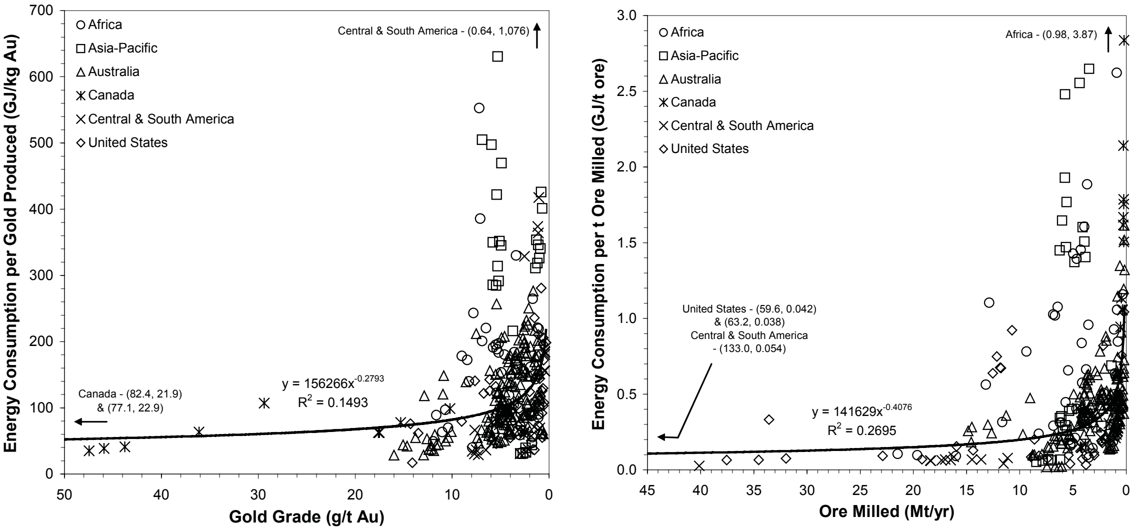

Figure 3. Energy consumption in gold mining

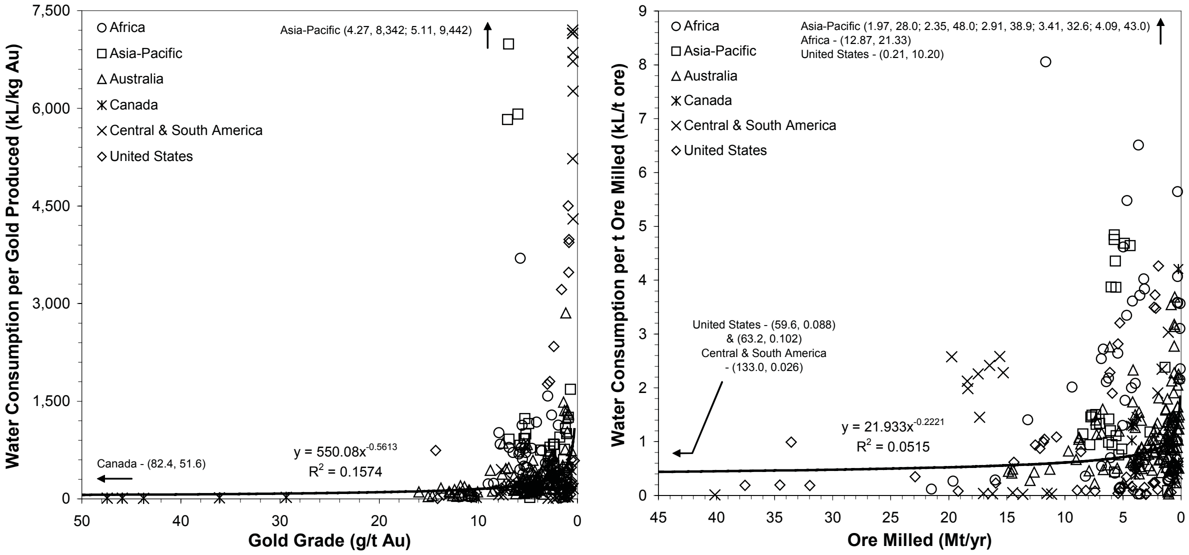

Figure 4. Water consumption in gold mining

Table 1 – Resource intensity of gold mining over time

Year	Water Consumption			Greenhouse Emissions			Energy Consumption			Cyanide Use	
	kL/ t ore	kL/ kg Au	No. Mines	kg $CO_{2\text{-}e}$/ t ore	t $CO_{2\text{-}e}$/ kg Au	No. Mines	GJ/ t ore	GJ/ kg Au	No. Mines	kg CN/ kg Au	No. Mines
1991	1.14	390	3	36.7	12.6	2	0.533	172	2	172	2
1992	0.96	335	3	38.5	13.4	2	0.516	175	2	175	2
1993	1.02	346	3	40.9	13.9	2	0.577	205	2	205	2
1994	1.16	323	3	38.8	10.7	2	0.586	162	2	162	2
1995	1.17	260	3	26.0	16.4	8	0.213	142	8	142	8
1996	0.97	224	4	29.8	15.6	10	0.230	120	10	120	10
1997	2.82	1,579	18	25.2	11.4	14	0.471	213	14	213	14
1998	2.56	1,443	29	21.4	10.3	19	0.406	193	20	193	20
1999	2.67	1,368	26	18.5	10.2	13	0.440	185	16	185	16
2000	2.67	1,281	27	22.1	10.6	19	0.446	169	20	169	20
2001	0.77	378	28	26.3	12.2	31	0.280	130	32	130	32
2002	0.74	374	26	24.8	11.8	29	0.264	123	34	123	34
2003	0.74	426	24	21.5	12.0	25	0.265	141	31	141	31
2004	1.51	725	34	23.2	11.9	40	0.336	155	43	155	43
2005	0.72	398	56	23.6	12.1	41	0.336	130	59	130	59
2006	2.87	1,783	22	5.8	3.7	4	0.648	187	22	187	22
Avg.	**1.42**	**691**		**21.7**	**11.5**		**0.311**	**143**		**141**	

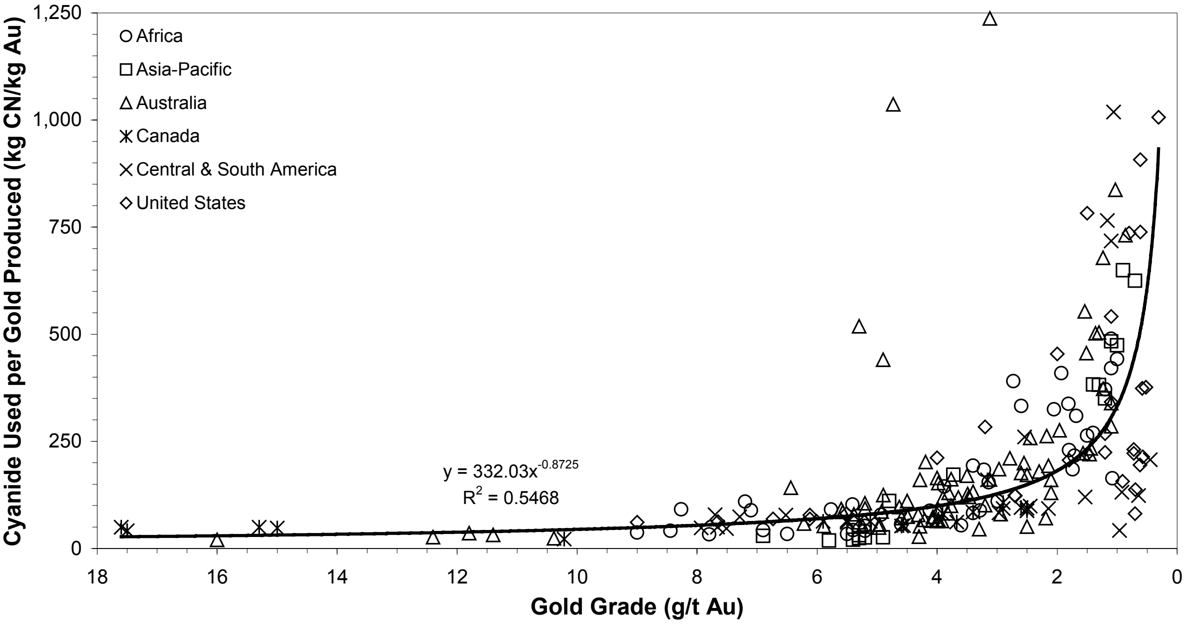

Figure 5. Cyanide consumption in gold mining

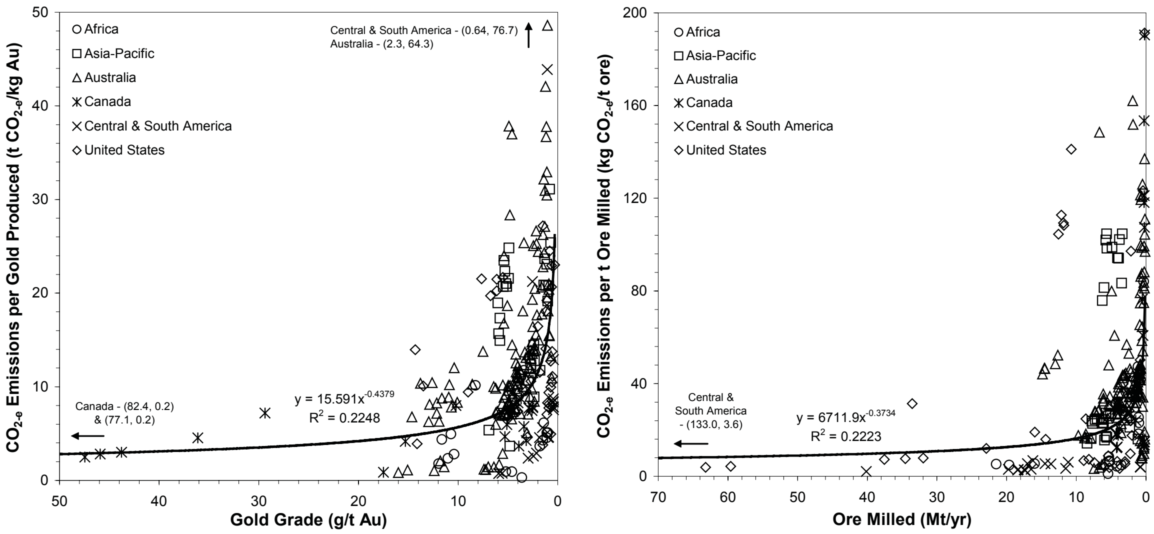

Figure 6. Greenhouse emissions from gold mining

3.6 Waste Rock

The quantity of waste rock associated with gold mining has increased dramatically since the late 1970s. This is due to the use of large scale open cut mining, especially in Western Australia, Nevada and elsewhere. There is no systematic reporting of waste rock produced, although some companies do publish details, together with ore mined and processed. The compiled data appear in Figure 7. They are the best available totals for Australia, Canada, United States and Papua New Guinea, and the ratio of waste rock-to-ore ratio (WR:O) for all mines compiled within this study.

3.7 Economic Gold Resources

The extent of economic gold resources is known for some countries over time. Ore grades are rarely presented, with the limited data given in Mudd (2007) showing long-term declines for Canada, Australia and South Africa. The data for economic resources and the ratio of resources-to-annual production are shown in Figure 8.

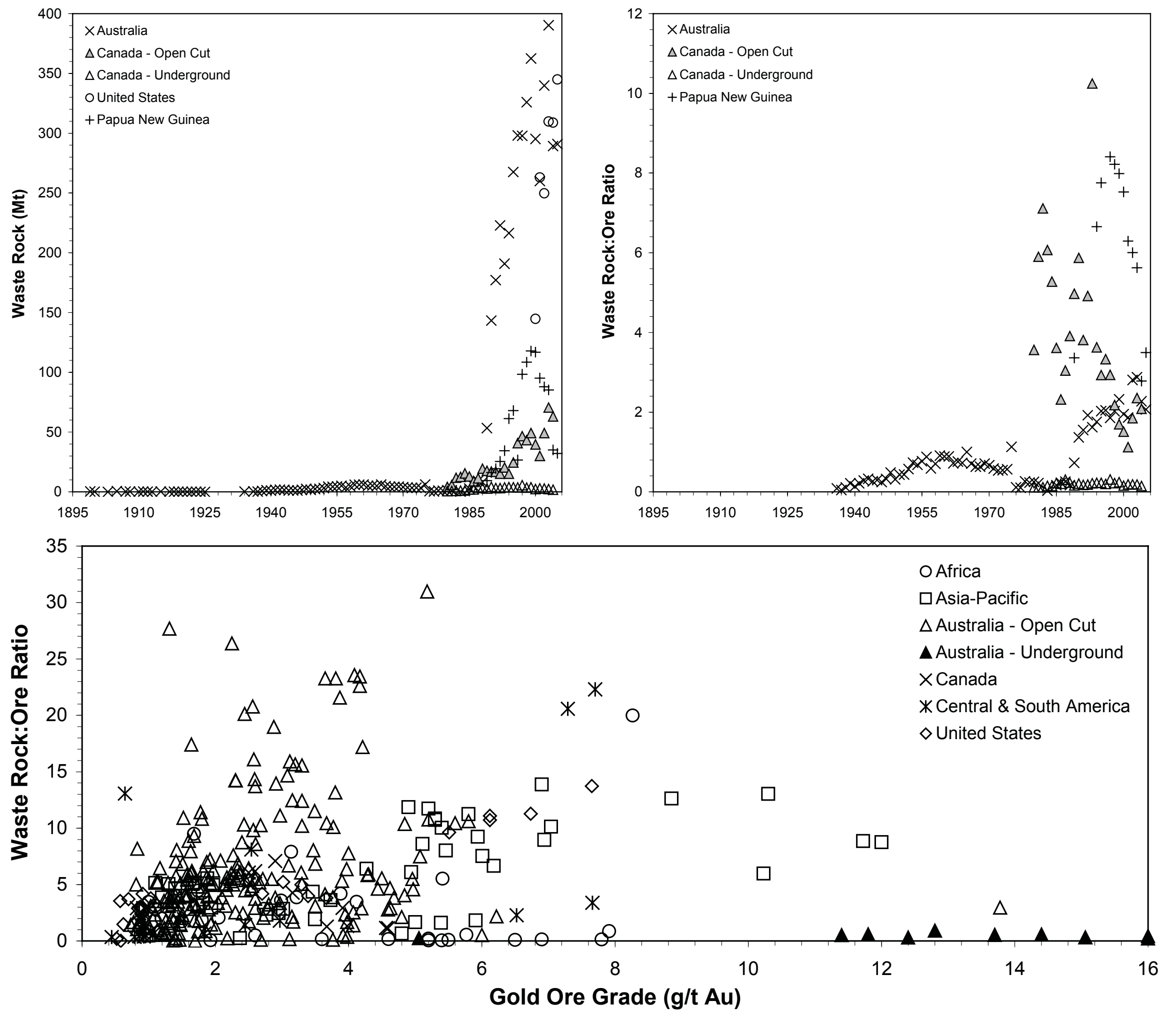

Figure 7. Waste rock from gold mining : total or minimum over time (top left); waste:ore ratios over time (top right); waste:ore ratios versus gold ore grade (above)

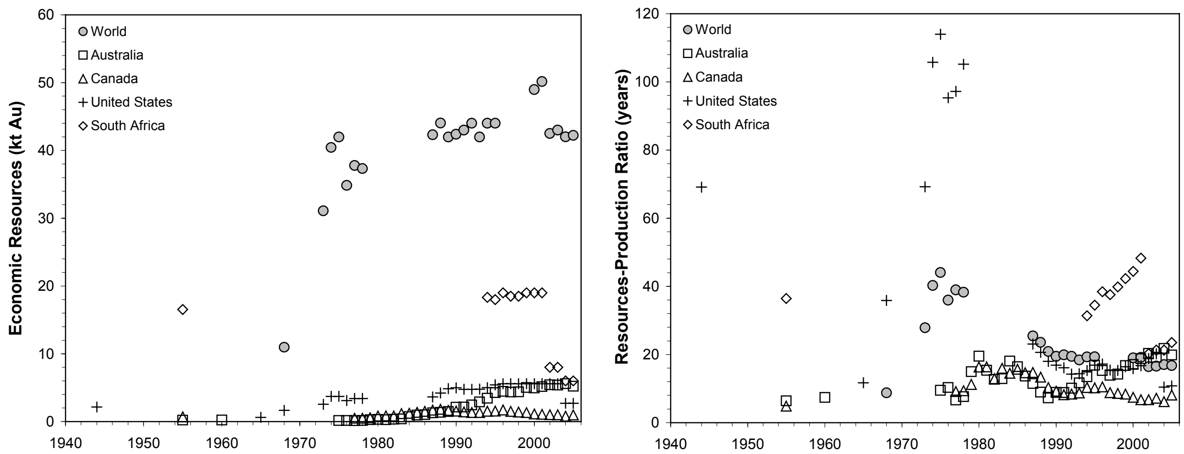

Figure 8. Economic gold resources (left) and resources-production ratio (right)

4. DISCUSSION

A comprehensive data set has been compiled and presented herein on critical aspects of gold mining around the world. A number of issues arise from this data.

The most recent gold mining boom since the late 1970s has been facilitated by the combination of a sustained price rise and the development of carbon-in-pulp ('CIP') milling, and to a lesser extent, the continuing evolution in large scale bulk earth moving vehicles. These factors led to a resurgence in exploration, new mines and the re-development of old fields around the world, often based on open cut mining techniques for more complete extraction and processing of all gold-mineralised ore. This combination led to an extra-ordinary renaissance in some countries such as Australia and the United States. In South Africa, however, this pattern has not prevailed, due to the deep underground nature of their gold mines, and economic and social issues (especially HIV/AIDS). From a global view, based on gold resources data, there is sufficient known economic resources to sustain existing levels of production for less than 20 years. The future pattern of economic resources and production is, of course, difficult to predict but will continue to depend on exploration effort, economics, social and environmental constraints, efficiency and technology.

There is a clear trend of declining ore grade in the countries presented. Although not given in this paper, these ore grades are also reflected by the effective ore grades of these countries economic resources. Further to this, the ore grades of most data sets are expressed as yield or extraction only and do not reflect the true assay of the gold ore as mined. Over the past 150 years the tailings from historic gold milling are easily re-processed to extract residual gold as economics and technology evolve. True ore grades in the 1800s and early 1900s are therefore likely to be considerably higher than that presented. The pace of future decline in average ore grade is difficult to predict, but it is clear, based on existing mines and undeveloped resources, that it is likely to gradually decline.

With regards to water consumption there is a degree of scatter (per kg gold produced and per t ore milled). This is most likely due to the varying complexity of gold mines, such as local climate, water resources, metallurgy of different ores, type and degree of processing (eg. gold bullion, ore concentrate, heap leaching), and the configuration of mines supported. Adding to this complexity is water quality and the degree of water recycling (some companies only report imported water and do not account for recycled water). The demands for water will vary according to these site-specific issues. Despite this, the graphs do suggest that higher grade mines (>6 g/t Au) have a very low water cost per unit of gold produced while lower grade mines (<2 g/t Au) have a higher water cost. Gold mines with a high ore throughput are commonly low grade projects, and the greater water use efficiency per t ore milled is most likely due to economies of scale. The total quantity of water consumed may still be significant locally. There appear to be no noticeable trends with respect to time. Based on the compiled data, gold mining typically requires ~1.42 kL/t ore or ~691 kL/kg Au.

Energy consumption shows a slightly lower degree of scatter compared to water, with the same general trends also apparent. High grade mines use less energy per kg of gold produced while high ore throughputs require less energy per tonne of ore milled. Site-specific variability in energy sources (eg. natural gas, diesel, coal, hydro-power), could help to explain the variability. There appear to be no real trends with respect to time. Based on the compiled data, gold mining typically requires ~0.31 GJ/t ore or ~141 GJ/kg Au.

The extent of cyanide required to produce gold shows a very satisfactory relationship to ore grade. The sensitivity of cyanide consumption per gold produced relative to ore grade is demonstrated – despite a mix of process plant types and other factors. For high grade mines (>6 g/t Au) the cyanide cost is commonly less than 100 kg/kg Au, while for lower grade mines (<2 g/t Au) the cyanide cost increases rapidly as grade declines. Based on the compiled data, heap leach operations appear to be the most cyanide intensive.

The release of greenhouse gas emissions (as t CO_{2-e}) is a major global challenge. The extensive use of fossil fuels in gold mining, especially diesel, leads to significant emissions. As with cyanide and energy, there is a reasonable correlation between emissions per unit of gold produced and ore grade as well as emissions per t ore milled. The ore grade inflection point, at which unit emissions increase rapidly, is ~5 g/t Au. It is unfortunate that a number of major gold mines and companies do not include emissions in their sustainability reporting. Based on the compiled data, gold mining typically releases ~21.7 kg CO_{2-e}/t ore or ~11.5 t CO_{2-e}/kg Au. Although the high mass ratio of CO_{2-e} to gold is due to the relatively small mass of gold produced, the primary function of gold for jewellery leads to a major ethical and social issue in terms of sustainability accounting for the greenhouse costs.

The data presented and analysed herein raises a number of issues with respect to sustainability reporting protocols, including the statutory Australian 'National Pollutant Inventory' (NPI 2001), the 'Global Reporting Initiative' (GRI 2006), associated Mining Sector Supplement (GRI 2005), and the 'International Cyanide Management Code' (ICMI 2002). Firstly, most protocols are voluntary to adopt (except NPI), allowing some companies to choose not to follow them. Secondly, the protocols do not require consistent and compulsory reporting of key aspects such as waste rock, cyanide, water quality, CO_2 emissions, etc. (gaps are often left unjustified by companies). For example, the GRI states the proportion of recycled water (EN10) as an 'additional' indicator and not 'core'. While the reporting of hazardous and non-hazardous wastes by type and destination (EN22) is core, some mining companies who use the GRI still do not report waste rock under EN22. The GRI Mining Supplement proposes wastes under EN22 as 'site waste, eg. waste oils, spent cell lining, office, canteen and camp waste, scrap steel, tyres and construction waste' (pp 27), and further discusses the need to report 'large volume wastes' – waste rock and tailings – as a function of a site risk assessment (pp 29). Thirdly, many countries now have or are developing systems such as the NPI to facilitate more accurate assessment of pollutant emissions, especially for 'State of the Environment' reporting. The NPI defines waste rock and tailings facilities as 'land transfers' only – leaving this critical data outside the scope of NPI reporting (though any release from such facilities would be reportable). As a minimum the quantity of waste rock and tailings should be a core reporting indicator, with further details noting the nature of the wastes (especially with respect to acid mine drainage issues). The cyanide code does not require public reporting of cyanide consumption even though a mine could be certified for its management regime. The NPI collates and reports on cyanide emissions but it specifically does not report nor allow data to be analysed on an individual site basis (emissions are not the same as reagent consumption). The common lack of key data does not facilitate accurate and transparent sustainability assessment nor allow claims to be tested. Finally, the various codes and protocols are still very new and have not been in use long enough as yet to allow industry to adopt them widely and report more consistently across companies and mines. Given the deficiencies identified above, there remains room for major improvement with respect to gold mining specifically as well as mining generally. With more complete reporting it may be possible to improve the correlations between aspects such as energy, water and cyanide consumption, greenhouse emissions and production variables such as mine type, ore grade, mill type and ore throughput.

5. CONCLUSION

This paper has compiled and presented broad-ranging data on gold mining and production, focusing on the key aspects of mineral resource sustainability and environmental resource costs. Overall, the long-term decline in gold ore grades is demonstrated. The resource intensity shows reasonable relationships between unit resource consumption of water, energy and cyanide and greenhouse emissions and gold mining and production – as ore grades decline, the unit resource intensity commonly increases. In terms of sustainability, given the long-term decline in ore grades, this points to the resource intensity of gold production gradually increasing in the future – an aspect of the sustainability of mining which has to be taken more explicitly into account than recognised at present. Thus it is not simply the amount of economic resources available which will be the greater sustainability challenge for gold mining in the future but its increasing environmental footprint. These findings on the quantification of sustainability of gold mining have major implications for environmental policy and sustainability reporting by the mining industry broadly, but particularly the gold sector.

6. REFERENCES

Dow, J.A.S. and Minns, A.J., (2004), Translating the Challenges of Sustainability and Eco-efficiency into Improved Business Performance at Newmont Operations. In *'Green Processing 2004'*, Fremantle, WA, p21-26.

GRI, (2005), GRI Mining and Metals Sector Supplement (Pilot Version 1.0). Global Reporting Initiative (GRI), Amsterdam, The Netherlands.

GRI, (2006), Sustainability Reporting Guidelines. Global Reporting Initiative (GRI), Amsterdam, The Netherlands.

IIED and WBCSD, (2002), Breaking New Ground : Mining, Minerals and Sustainable Development. EarthScan, London, UK.

Kumah, A., (2006), Sustainability and Gold Mining the Developing World. *Journal of Cleaner Production*, 14(3-4), p315-323.

Mudd, G.M., (2007), Global Trends in Gold Mining : Towards Quantifying Environmental and Resource Sustainability ? *Resources Policy* (In Press; doi: 10.1016/j.resourpol.2007.05.002).

NPI, 2001. NPI Emission Estimation Technique Manual for Mining. National Pollutant Inventory, Canberra, ACT.