Iranica Journal of Energy & Environment 3 (Special Issue on Environmental Technology): 66-73, 2012
ISSN 2079-2115
IJEE an Official Peer Reviewed Journal of Babol Noshirvani University of Technology
DOI: 10.5829/idosi.ijee.2012.03.05.11

BUT

Environmental Impact of Electricity Consumption in Crushing and Grinding Processes of Traditional and Urban Gold Mining by Using Life Cycle Assessment (LCA)

Nur Rafidah Yahaya, Marfaiza Murad, Norhashimah Morad, and Fera Fizani Ahmad Fizri*

Environmental Technology Division, School of Industrial Technology,
Universiti Sains Malaysia, 11800 Minden, Pulau Pinang, Malaysia

Abstract: Mining is not only an essential component of social and economic development since prehistoric time, but it also gives a large impact on our civilization. Gold is a noble metal that is highly valued. The extraction of minerals from earth is known as traditional mining. Gold also can be extracted from electronic waste or e-waste, and this new concept is called urban mining. There are many stages in traditional and urban mining process. However, in this study, the focus was on crushing and grinding processes to produce 1 kg of gold. Crushing and grinding are processes in the milling stage. This research evaluates and compares the environmental impacts of crushing and grinding processes, based on electricity consumption. About 50 to 65% of total electricity in milling was used for crushing and grinding processes. Life Cycle Assessment (LCA) methodology was used as a tool to evaluate the environmental burdens of electricity usage in converting ore and electronic waste to gold bars. The Life Cycle Impact Assessment (LCIA) of this process was interpreted by using Eco-indicator 99 assessment methods in SimaPro software. The impact categories included in this study were carcinogens, respiratory organics, respiratory inorganics, radiation, climate change, ozone layer, ecotoxicity, acidification or eutrophication, land use and minerals. The results showed that crushing and grinding from traditional mining gave the largest impact to the environment with single score of 399 Pt compared to the urban mining with only 1.81 Pt score. The highest impact in both types of mining is to human health.

Key words: Crushing and grinding; Eco-indicator 99; Electricity consumption; E-waste; Gold mining; LCA; SimaPro; Traditional mining; Urban mining.

INTRODUCTION

Mining influences the economic profile of most countries, which are either mineral producers or mineral products consumers, or in many cases both. Mining companies provide minerals to use in industry and then, the industry makes products to satisfy consumers' demand. The demand of minerals remains as old as civilization itself, and is unlikely to change in the future, even though we have seen dramatic changes in the socio-economy or technology. However, the demand of a specific commodity fluctuates greatly with time, as market price does. One good example is reprocessing of mine tailings in Romania to extract gold in response to the high rise in gold prices [1].

The discovery of gold was probably the beginning of Malayan mining. The Malay Peninsula was known as "Golden Chersonese" because of its reputation as a source of gold. Pahang state remains the largest producer of gold from traditional mining in Malaysia from then until now. In 1926, Pahang produced 13042 oz or 369.73 kg of gold from the total amount of 14475 oz or 410.36 kg with the remaining from Perak [2]. In this century, Pahang contributes about 99% of the country's gold production [3]. In 2008, 2400 kg of gold was produced and the production was decreasing from year to year [4]. Gold is mostly derived from hornblende-granite, diorite, and old volcanic rocks which are most abundant in the centre of the Peninsula.

Gold is categorized as metallic ore in a group of precious metals which has high value. It is quite inert which does not tarnish, rust or corrode. It maintains its elemental condition and yellow colour through geological times. Gold is widely used in jewellery due to its singular beauty, brightest color, shiny luster, malleability, and ductility. In this century, most of the electronic appliances use gold due to its high conductivity. About 85% of gold that has ever been mined is still in use and available for recycling [5]. About 2000 ton annually or just over 50% of gold production in the world is used in jewellery [6]. The uniqueness of its physical and chemical properties makes this metal in demand in high-tech industry and

***Corresponding Author:** Norhashimah Morad, Environmental Technology Division, School of Industrial Technology, Universiti Sains Malaysia, 11800 Minden, Pulau Pinang, Malaysia.
Tel: +604-6532236, Fax: +604-6573678, E-mail: nhashima@usm.my

medical applications; hence, making it is highly prized by society [1, 5, 7–9].

Gold mining is always replete with controversy either in politics, economy and impacts to the environment [1–2]. Due to public awareness about environmental issues in this century, gold mining industries come under pressure to ensure all the processing stages in gold ore mining, from the extraction to gold refining, are not harmful to our environment [10]. In gold mining, consumption of cyanide is required to dissolve the gold and has been used by the mining industry for over 100 years in the extraction of noble metals [11]. Cyanide is a poison that has fast acting [12] reaction and the impact of cyanide can be seen through many previous studies where it caused lethal toxicity to birds [13–16]. The cyanide destruction processes were developed as well as cyanide recovery technologies in gold ore mining [10, 17].

Commonly, gold mining is known as the extraction of gold from earth but nowadays, it is called traditional gold mining. The ranges of the gold historic cumulative production were estimated from 157,000 ton to 180,000 ton [5]. About 14% from 2550 ton of annual world gold mine production in 2010 is produced in China. This is followed by Australia and United States with 10% and 9% gold production, respectively [6, 18]. The highest world gold production is 2600 ton in 2001 [19]. In 2010, the demand of gold worldwide was 3970 ton including 1645 ton from recycled sources [6]. The world's gold reserves have not much changed over the last two decades and it was estimated currently to be about 51,000 ton [18, 20–21,]. The highest proportion of gold reserves in the world is Australia (14%), followed by South Africa (12%) and Russia (10%). Currently, the mean ore grade of gold is approximately 3–4 g/ton and this causes the trade of gold ores to decrease globally over the last century [5, 22]. It was estimated by Muller and Frimmel [5], the world mean gold ore grade could decline to about 1g/ton in 2050 based on gold ore grade depression in the last four decades. The sophistication in technology enables precious metals like gold, platinum, palladium and silver to be extracted without involving the exploration of earth. These metals can also be extracted from electronic waste (e-waste) and this is known as urban mining. Urban mining can be defined as recovery and recycling of metals from electronic wastes [23]. Under the First Schedule of Environmental Quality (Schedule Waste) Regulation 2005, e-waste is defined as waste from electrical and electronic assemblies containing components such as accumulators, mercury-switches, glass from cathode-ray tubes (CRT) and other activated glass or PCB capacitors, or contaminated with cadmium, mercury, lead, nickel, chromium, copper, lithium, silver, manganese or PCB [24]. E-waste contains hazardous substances, but many precious metals and other useful materials can be recovered from it. A proper management of e-waste is needed to achieve a number of objectives aimed at a more sustainable approach to resource use and a reduction in the quantity of e-waste going to landfill. The rapid technological advances and consumer demands accelerate the e-wastes generated. Products such as mobile phones which are often treated as fashion items contribute to increasing of e-wastes because they are being replaced before their lifetimes expire [25]. Unlike traditional mining, the sources of urban mining increase from year to year. About 134,036 metric tonnes of e-waste were generated in 2009 and are forecasted to be 1.11 million metric tonnes in 2020 [24]. Based on the projection of the electronic waste inventory in Malaysia by the Department of Environment, the amount of e-waste in Malaysia will be increasing by an average 14% annually [26]. The electronic devices especially mobile phones and computers have a large resource of recoverable metals including gold. On average, about 10.4 g/ton of gold is contained in e-waste as reported by USGS [27]. Estimation of gold content in mobile phones is 300–350 g/ton while for computer circuit boards (PCBs), is about 200–250 g/ton [28, 29].

In Malaysia, the Environmental Quality (Scheduled Wastes) Regulation 2005 was enforced on 15 August 2005 in which e-waste has been listed under this regulation. Through this regulation, it enables Malaysia to control illegal transboundary movement of e-waste in this country. At the national level, all the e-waste generators are required to provide notification of their e-waste generations to the Department of Environment (DOE). License from DOE is required before any e-waste recovery facility is allowed to conduct its recovery operation. At present, there are 138 e-waste recovery facilities licensed by DOE. The disposition of all residues from recovery operation must be done at premises approved by DOE. A prior written approval from the Director General of DOE is needed for the transboundary movement of scheduled waste. The government has provided the Guidelines for the Classification of Used Electrical and Electronic Equipment in Malaysia to facilitate the management of e-waste in this country. The guidelines was published in 2008 and amended in 2010 [24]. Extracting metals from e-waste or urban mining can help in reducing the consumption of non-renewable minerals.

Traditional mining can be divided into two methods; i.e. underground mining or surface mining. In Malaysia, gold is extracted by surface mining or more specifically, open-pit mining. This type of mining can be divided into two major parts of operations, which are mine site and milling. Mine site involves drilling, blasting, loading and haulage. Milling operation involves physical and chemical treatments which consist of crushing, grinding, gravity concentration, stripping, and smelting. In the context of technologies, there are many dramatic improvements occurred in less than a century ago to support higher mining rates. For example in the grinding process, the ball mill operation has been changed to the semi autogenously mill operation [4].

Urban mining involves collecting of electronic waste and milling. Usually, recovery companies have their own suppliers of e-wastes or stakeholders. In milling operation, the process starts with the dismantling process, where components like PCB, CFCs, Hg switches are removed manually. Then, the e-waste undergoes a shredding process and easily accessible parts containing valuable materials like cable containing copper, steel, iron and precious metals are segregated. Shredding is a process which fragments, grinds, rips or tears a product into pieces [25]. The saleable or recyclable metals and plastics are separated from e-waste that needs further processing. The e-waste components that contain hidden gold will undergo a crushing process while components that contain apparent gold, go directly to the stripping process. After crushing, acid dissolution process takes over. Several chemicals are used to extract the gold. Then, precipitation principle is used by adding specific chemicals. Gold precipitates out of solution. The gold is filtered and dried before undergoing the smelting process. The gold is then melted and sold as ingots.

Crushing and grinding processes are the largest contributors to electricity consumption with 50–65% from total milling electricity consumption in both types of gold mining. Tenaga Nasional Berhad (TNB) is the largest electricity provider in Malaysia. Based on the annual TNB report in 2010, Malaysia used 53.1% natural gas, 34.1% coal, 12.5% hydro and 0.3% distillate to generate electricity in the last six months of year 2009 and the first six months of year 2010 [30]. This shows that fossil fuels are the main sources of electricity in Malaysia. Recently, the consumption of fossil fuels, especially oil and gas, as electricity sources increased rapidly, and this brings a global energy crisis and environmental impact, especially global warming [31]. Greenhouse gases are responsible to global warming occurrence. There are four important greenhouse gases, namely carbon dioxide, nitrous oxide, methane and fluorinated gases. Carbon dioxide (CO_2) is the largest contributor to greenhouse gases and the emission of CO_2 is primarily caused from fossil fuel combustion. In combustion, for the same energy level use, the amounts of CO_2 released are different depending on the fossil fuels. Oil releases about half more carbon dioxide than natural gas while coal releases double [32]. The subject related to climate change and greenhouse gases such as carbon dioxide, which is derived from industry, has grown into a serious subject to mining worldwide.

It has been proven that it is not enough to evaluate the environmental friendliness of a product without taking its entire life cycle. Life cycle assessment (LCA) is the one method that takes into account the entire life cycle of a product in evaluating their impacts to the environment. LCA method has been established around 1990 and in 1991, the proper name for LCA was agreed in a conference organized by the Society of Environmental Toxicology and Chemistry (SETAC). In 1997, the International Organization for Standardization published its first standard for LCA, ISO 14040 [24]. Malaysia has been adopting the ISO 14040 series on LCA as national standards since the emergence of these standards. From 1998 to 2001, ISO 14040, 14041, 14042 and 14043 were all adopted as Malaysian standards. However, the use of these standards as a tool for environmental management in Malaysia is still small at the present time. LCA is only conducted by several numbers of universities as case studies. It has never been used by any manufacturer, service or agro-industry [33].

To ensure compliance with regulatory requirements prescribed under the Environmental Quality Act 1974, the industrial sectors in Malaysia practices environmental management system on the whole, mainly pollution control or treatment processes. In general, the industrial sectors of Malaysia adopt environmental management systems, predominantly pollution control or treatment processes to comply with regulatory requirements prescribed under the Environmental Quality Act 1974. As a result of strict enforcement and the bad media publicity for culprit companies, a lot of companies have installed facilities to ensure that their air and water emissions to the environment comply with regulations. Environmental Management System (EMS) certification scheme in line with ISO 14001 was launched by SIRIM in 1995. In order to maintain their competitive edge in the international market, multi-nationals and export oriented companies had to make sure that they represented 'green image'. Most of the companies in Malaysia that are certified to EMS are multi-nationals or export-oriented business. The certification to EMS is important to fulfill the demand of their overseas client in addition to mandatory or subtle requirement for international market. ISO 14001 is preferred to be implemented among Malaysia's industries rather than other ISO 14000 series of EMS due to clientele's requirement, mainly from western countries. Since ISO 14001was used, most of Malaysian industries only gave a little attention on the environmental impact of the finished product or the raw materials used. ISO 14001 only needs evidence that the company has an EMS. This could be one of the main reasons why LCA has not been used by the industries in this country [33].

In this paper, LCA is used to evaluate the environmental impacts of crushing and grinding processes in both types of gold mining based on electricity consumption. The score for each environmental impact categories between two types of gold mining are evaluated and compared. The functional unit used for the comparison is 1kg production of gold.

METHOD

Life Cycle Assessment (LCA) is defined as a standard and scientific method for assessing the environmental burdens and other impacts of product, service and process chain of systems [34–37]. The entire life cycle of product, process or activity that starts from the extracting and processing raw materials, manufacturing, transportation, distribution, use, reuse, maintenance, recycling and final disposal were included in the assessment ('from cradle to grave')

[34, 36–38]. LCA quantifies the industrial process and products by enumerating flows of energy and material use, and wastes released to environmental burdens associated with energy and material use, and evaluate other alternatives for environmental improvements [38–40]. The methodological framework of LCA is based on ISO standards 14040 to 14043. A complete LCA consists of four phases: goal and scope definition (ISO 14040), inventory analysis (ISO 14041), impact assessment (ISO 14042) and interpretation (ISO 14043) [41]. There are a few models that have been used to

determine LCA's data such as open LCA, Eco-LCA and SimaPro [42]. In this study, SimaPro was used to evaluate the data. SimaPro is LCA software developed by Dutch University and Pre Consultants B.V. Company from the Netherlands [38, 41, 43]. Eco-indicator 99 method is widely used in the production process for measuring the potential environmental impact. In this method, environmental impact is grouped into damage categories including human health, ecosystem quality and resources. There are four steps in the Eco-indicator 99 model: characterization, damage assessment, normalization and single score [41, 43].

RESULTS AND DISCUSSION

LCA Assessment

1. Goal and scope definition

The data for this study were collected from two companies that are well-established in Malaysia. One company data was used for traditional mining and the other one was used for urban mining. The study only involved electricity consumption in crushing and grinding processes. Crushing and grinding processes consume the most energy with approximately 50 to 65% of total electricity consumption in milling operation. Based on 1 kg of gold as a functional unit in this study, the comparison in environmental impacts of energy consumption between traditional and urban gold mining is evaluated.

2. Inventory analysis

Inventory analyses involve collection and analysis of data on the electricity consumption of the crushing and grinding processes. The initial data for electricity consumption were collected from both traditional mining and urban mining companies based on manuals and documents. The average electricity consumption was calculated based on the functional unit of this study. The results of the completed calculation are shown in Table 1.

3. Impact assessment

a) Characterization

In the characterization step, the emission produced from the electricity generation is evaluated into a single number for each environmental impact category. The characterization of environmental impact category is based on scientific methods (e.g., effects of toxic materials in drinking water on human health) [44, 45]. Electricity generation is a complicated process. Many issues need to be considered such as extraction of resources, methods or technologies used, and distribution. There are many different substances produced during electricity generation and different substances can contribute to the same impact category. Electricity generation can cause eleven types of environmental impact and the value of each impact in both types of gold mining is shown in Table 2.

Table 1: Electricity consumption in cushing and grinding processes

Types of Mining	**Electricity Consumption (Crushing and Grinding) (kWh)**
Traditional Mining	7520
Urban Mining	45.4188

Disability adjusted life years (DALY) is used to describe the damage of human health by expressing the number of life years lost and the number of years lived with disability caused by diseases or certain environmental impact categories [44, 45]. The potentially affected fraction (PAF*m2yr) shows the percentage of the species that are exposed to the toxic emission over a certain area, during a certain time. Acidification and eutrophication are measured in Potentially Disappeared Fraction (PDF) is the probability of the plant species to disappear from the area as a result of these both impact categories. Land use is also expressed as PDF which refers to the change in the number of all species on the occupied land and at the natural areas outside the occupied area [44, 45]. The final category is resources, which only assess mineral resources and fossil fuels in units of MJ surplus [44]. This unit is based on the expected increase of energy required for further mining of the resources which are involved in electricity generation. The requirement of an additional energy may be caused by lower resource concentrations or other unfavorable characteristics of the remaining reserves [46].

b) Damage Assessment

In damage assessment step, the environmental impact scores calculated from characterization were added to obtain a single score for each of the three damage categories; human health (DALY), ecosystem quality (PAF/PDF*m2yr) and resources (MJ surplus) [35]. The total ecosystem quality damage was calculated by adding PAF and PDF values after converting PAF*m2yr into PDF*m2yr unit [44, 45]. These two impacts were combined since it was possible to determine whether the damage was caused by changes in the nutrient level or by acidity. This step can also be interpreted as grouping. Table 3 shows the results of three damage assessment categories for traditional mining and urban mining.

Table 2: Score for each environmental impact category

Types of Mining	Environmental Impact Category										
	Carcinogens	Resp. Organics	Resp. inorganics	Climate change	Radiation	Ozone layer	Ecotoxicity	Acidification/ eutrophication	Land use	Minerals	Fossil fuels
Traditional Mining	0.00158 DALY	1.21E-6 DALY	0.00943 DALY	0.00179 DALY	3.76E-6 DALY	5.19E-8 DALY	605 PAF*m2yr	222 PDF*m2yr	89.4 PDF*m2yr	14.4 MJ surplus	1.51E3 MJ surplus
Urban Mining	7.43E-6 DALY	5.47E-9 DALY	4.24E-5 DALY	8.08E-6 DALY	1.69E-8 DALY	2.34E-10 DALY	3.23 PAF*m2yr	0.997 PDF*m2yr	0.402 PDF*m2yr	0.126 MJ surplus	6.81 MJ surplus

Table 3: Results of three damage assessment for traditional mining and urban mining

Types of Mining	Damage Category	Crushing and Grinding
Traditional Mining Urban Mining	Human Health	0.0128 DALY 5.79 E-05 DALY
Traditional Mining Urban Mining	Ecosystem Quality	372 PDF*m2yr 1.72 PDF*m2yr
Traditional Mining Urban Mining	Resources	1.53 E3 MJ surplus 6.94 J surplus

c) Normalization, weighting, single score

The results from characterization cannot be compared since they are usually presented in different units. Through normalization and weighting step, the three damage assessment of traditional mining and urban mining are calculated to form a single score as shown in Table 4.

Table 4: Results of the three damages assessment with single score for traditional mining and urban mining

Types of Mining	Damage Category	Crushing and Grinding
Traditional Mining Urban Mining	Human Health	334 Pt 1.51 Pt
Traditional Mining Urban Mining	Ecosystem Quality	29 Pt 0.134 Pt
Traditional Mining Urban Mining	Resources	36 Pt 0.165 Pt
Traditional Mining Urban Mining	Single score	399 Pt 1.81 Pt

From Table 4, the electricity consumption gives major impact to human health while less impact to the ecosystem quality. There are seven impact categories that contribute to human health impact during the electricity generation including carcinogens, respiratory organics, respiratory inorganics, climate change, radiation and ozone layer. The processes like extraction of fossil fuels, transportation and burning of fossil fuels for generating electricity are the major contributors of hazardous substances such as CO_2, SO_2, NO_x, CO, O_3, particulate matter, HF and VOC. All these substances cause several of human health impacts like damage to the lungs, irritation of eyes, nose and throat, birth defects and damage to respiratory systems. In addition, ozone depletion also brings damage to human health including skin cancers, cataracts, and suppression of the immune system. Extreme weather causes increase in malnutrition and other diseases [47]. This situation can be seen in Iran during 1998 until 2001 which is central Asian drought causing about 80% livestock loss and 50% reduction in wheat and barley crops. About 60 million people were affected by the drought when agriculture, animal husbandry and water resources had been limited throughout the region. Even small changes in temperature can give large impact to the production of many crops species, hence decreasing the supply of food [48]. Factors like under nutrition, inadequate and unsafe water, and poor quality nutrients are influenced by climate and weather changes, which is the main cause to health risks in the poorest countries [49]. It was estimated that climate change had caused 154,000 (0.3%) deaths per year, 5.5 million (0.4%) disability-adjusted life years (DALYs), with sub-Saharan Africa and South Asia being the regions with the greatest proportional burden [50].

Fossil fuels give a larger impact to resources damage than minerals do. The consumption of fossil fuels as the main sources of electricity generation leads to the resources depletion. Fossil fuels are produced continually by the decay of plant and animal matter. However, these resources are assumed as non-renewable resources because they need thousands of years to form naturally and cannot be replaced as fast as they are being consumed [51].

Electricity gives the lowest damage to ecosystem quality than other categories. There are three factors that affect this category: acidification or eutrophication, ecotoxicity and land use. The main precursor of acidification is SO_2 and the other precursors are NO_x, ammonia (NH_3), hydrogen chloride (HCl) and hydrogen fluoride (HF). According to Pusat Tenaga Malaysia (PTM), the emission of SO_2 per kWh is very low, that is only about 1 to 2% of the emission of CO_2 per kWh. NO_x is the major contributor to eutrophication damage. However, 1 kWh only releases less than 1% of NO_x [52]. The atmospheric N is needed by cyano-bacteria when nitrates are limited in aquatic media [44]. Acidification and eutrophication are closely connected because the pollutants and sources are the same especially NO_x [46]. Ecotoxicity is caused by vanadium, chromium, nickel, cadmium, and mercury, most of which are produced from oil and coal power plants [53, 54]. The complete electricity production cycle affects the pattern of land use by transforming the existing landscape into a mining area and a site for the construction of power plants, power transmission, fuel refineries and other infrastructure such as roads and pipelines.

The percentages of damage caused by electricity to human health, ecosystem quality and resources in both types of mining are 83.7%, 7.3% and 9%, respectively.

CONCLUSION

Electricity consumption gives the largest damage to human health with respiratory inorganics giving the highest score in environmental impact category that contributes to this damage. The crushing and grinding processes in traditional mining give multiplied environmental impact compared to the urban mining due to the much higher amount of energy required in traditional mining. The major reason is that gold ore is harder than e-waste and difficult to be broken. To produce 1 kg of gold, the single scores for traditional mining and urban mining are 399 Pt and 1.81 Pt, respectively.

ACKNOWLEDGEMENT

The authors would like to thank the members of our research team for their guidance and support, especially Mdm. Ang Chai Tew. We would also like to express our gratitude to the management of companies involved in this study and special thanks to Mr. Dinesh Rajamanickam for the data provided.

REFERENCES

1. Spitz, K. and J. Trudinger, 2008. Mining and the environment from ore to metal. CRC Press/Balkema. The Netherlands.
2. Scrivenor, J.B., 1928. A sketch of Malayan mining. Mining Publications, Limited. London.
3. Nawi, S., 2011. Mining Industry of Malaysia 2007 [online]. Available online at: http://www.jmg.gov.my/en/mining-industry-of-malaysia-2007.html. Retrieved on 3 January 2012.
4. Tse, P.K., 2008. The Mineral Industry of Malaysia. USGS 2008 Mineral Yearbook Malaysia [online]. Available online at: http://minerals.usgs.gov/minerals/pubs/country/2008/myb3-2008-my.pdf. Retrieved on 25 November 2011.
5. Müller, J. and H.E. Frimmel, 2010. Numerical analysis of historic gold production cycles and implications for future sub-cycles. The Open Geology Journal, 4: 29-34.
6. World Gold Council, 2011. Gold Demand Trends, May 2011. Available online at www.gold.org.
7. Spitzer, M. and R. Bertazzoli, 2004. Selective electrochemical recovery of gold and silver from cyanide aqueous effluents using titanium and vitreous carbon cathodes. Hydrometallurgy, 74(3-4): 233-242.
8. Ramesh, A., H. Hasegawa, W. Sugimoto, T. Maki, and K. Ueda, 2008. Adsorption of gold (III), platinum (IV) and palladium (II) onto glycine modified crosslinked chitosan resin. Bioresource Technology, 99(9): 3801-3809.
9. George, M.W., 2011. Gold: US Geological Survey 2009 Minerals Yearbook [online]. Available at http://minerals.usgs.gov/minerals/pubs/commodity/gold/myb1-2009-gold.pdf. Retrieved on 30 November 2011.
10. Harcus, M., May 2011. Golden age. Mining Magazine, 57-67.
11. Reyes-Cruz, V., C. Ponce de Leon, I. González, and M.T. Oropeza, 2002. Electrochemical deposition of silver and gold from cyanide leaching solutions. Hydrometallurgy, 65(2-3): 187-203.
12. Environment Australia, 1998. Cyanide management: a booklet in the series on best practice environmental management in mining environment Australia, Canberra.
13. Barcroft, J., 1931. The toxicity of atmosphere containing hydrocyanic acid gas. J Hyg., 31(1): 1-34.
14. Davis, R.H., 1981. Cyanide detoxication in the domestic fowl. B.E. Vennesland (Ed.), Cyanide in biology, Academic Press, New York.
15. Eisler, R., 1991b. Cyanide hazards to fish, wildlife, and invertebrates: A synoptic review. Contaminant Hazard Reviews Report 23, US Fish and Wildlife Service Biology Report: 85(1.23): pp. 1-55.
16. Reece, R., 1997. Cyanide toxicity to birds, ACMRR. Short course notes on management of cyanide mining, ACMRR, Perth.
17. Dai, X., A. Simons, P. Breuer, 2012. A review of copper cyanide recovery technologies for the cyanidation of copper containing gold ores. Minerals Engineering: 25, 1-13.
18. USGS 2011 (United States Geological Survey), January 2011. Mineral Commodity Summaries.
19. Denham, D., October 2009. Has Australia's gold production peaked forever? The AusIMM Bulletin, 10-14.
20. Mudd, G., 2007a. Global trends in gold mining: towards quantifying environmental and resource sustainability? Resources Policy: 32, 42-56.
21. Mudd, G., 2007b. Gold mining in Australia: linking historical trends and environmental and resource sustainability. Environmental Science and Policy: 10, 629-644.
22. Mudd, G., 2007c. From production to sustainability reporting - towards quantifying sustainable gold mining. In: Proceedings of World Gold Conference, Cairns, Queensland: pp. 117-127.

23. Yoshikawa, M., 2008. Gold mine of metals. Startwo, 17 June. pp: T7.
24. Fenny Wong N.Y. & S.B. Goh, 2012 [online]. E-waste Management in Malaysia. Department of Environmental Malaysia. Available online at: ch.bcrc.cn/download.jsp?pathfile=/atm/7/20120507121740105.pdf. Retrieved on 5 June 2012.
25. Hester, R.E. and R.M. Harrison, 2009. Electronic Waste Management. Design, Analysis and Application. The Royal Society of Chemistry, UK.
26. Perunding Good Earth Sdn Bhd, 2009 [online]. The e-waste inventory project in Malaysia. Available online at: http://www.env.go.jp/en/recycle/asian_net/Project_N_Research/E-wasteProject/06.pdf. Retrieved on 8 December 2011.
27. USGS (United States Geological Survey), July 2001. Fact Sheet FS-060-01.
28. Hageluken, C. and C. Meskers, 2010. Complex life cycles of precious and special metals. In: Graedel, T., van der Voet, E. (Eds.), Linkages of Sustainability/Ernst Strungmann Forum. MIT Press, pp. 163-197.
29. UNEP (United Nations Environment Programme), July 2009 [online]. Recycling e from Ewaste to Resources. Available online at www.unep.org.
30. Tenaga Nasional Berhad, TNB. Annual Report 2010 [online]. Powering a Sustainable Future, 2010. Available online at: http://www.tnb.com.my/tnb/application/uploads/annualreports/9701b2624e4d83df2799ce3da16134e2.pdf. Retrieved on 9 August 2011.
31. Rahimnejad, M., A.A. Ghoreyshi, G. Najafpour, and T. Jafary, 2011. Power generation from organic substrate in batch and continuous flow microbial fuel cell operations. Applied Energy, 88(11): 3999-4004.
32. Environment. World Development Indicators, 2010 [online]. Available online at: http://data.worldbank.org/sites/default/files/section3.pdf. Retrieved on 4 May 2011.
33. Chen, S.S., 2002 [online]. General Activity of Life Cycle Assessment in Malaysia. Environmental and Technology Centre, SIRIM Berhad. Available online at: https://www.aist-riss.jp/old/lca/asianetwork/symposium/report/2002/71.pdf. Retrieved on 13 February 2011.
34. Zbicinski, I., J. Stavenuiter, B. Kozlowska, and H. van de Coevering, 2006. Product design and life cycle assessment. The Baltic University Press. Uppsala.
35. Ross, S. and D. Evans, 2002. Use of Life Cycle Assessment in Environmental Management. Environmental Management, 29: 132-142.
36. Baty, J. 2012 [online].The Role of Tilt-up in Getting Green. DC&D Technologies, Inc. 2012. Available online at: http://dcd.com/bpr/bpr_nd_5_2004.html. Retrieved on 30 April 2012.
37. Apisitpuvakul, W., P. Piumsoomboon, D.J. Watts, and W. Koetsinchai, 2008. LCA of Spent Fluorescent Lamps in Thailand at Various Rates of Recycling. Journal of cleaner Production, 16: 1046-1061.
38. Ciesielski, K. and I. Zbicinski, 2010. Evaluation of Environmental Impact of the Spray-Drying Process. Drying Technology, 28 (9): 1091-1096.
39. Khan, F.I., V. Raveender, and T. Husain, 2002. Effective Environmental Management through Life Cycle Assessment. Journal of Loss Prevention in the Process Industries, 15: 455-466.
40. Krozer, J. and J.C. Vis, 1998. How to get LCA in the right direction? Jounal of Cleaner Production, 6: 53-61.
41. Li, Y. and J. Guan, 2009. Life Cycle Assessment of Recycling Copper Process from Copper-slag. International Conference on Energy and Environment Technology, 1: 198-201.
42. Bowman, R. and A. Halog, 2012 [online]. Environmental Assessment of Wood Derived Hemicellulosic Ethanol Using Alternative LCA Models. Available online at: http://www.lcacenter.org/LCA9/presentations/233.pdf. Retrieved on 30 April 2012.
43. Pré Consultants, 2001 [online]. The Eco-indicator 99. A damage oriented method for Life Cycle Impact Assessment. Available online at: http://www.pre-sustainability.com/content/reports. Retrieved on 20 January 2012.
44. Olivetti, E., J. Gregory, and R. Kirchain, 2010 [online]. Life Cycle Impacts of Alkaline Batteries with a Focus on End-of-Life. A study Conducted for the National Electrical Manufacturers Association. Massachusetts Institute of Technology: Materials Systems Lab: Available online at: http://www.calpsc.org/assets/products/2011/batteries_MIT%20Battery%20LCA%20by%20NEMA%20Final.pdf. Retrieved on 23 February 2012.
45. Jolliet, O., M. Margni, R. Charles, S. Humbert, J. Payet, G. Rebitzer, and R. Rosenbaum, 2003. Impact 2002+: A New Life Cycle Assessment Methodology. International Journal of Life Cycle Assessment, 10 (6): 324-330.
46. Goedkoop, M., S. Effting, and M. Collignon, 2000 [online]. The Eco-indicator 99: A Damage Oriented Method for Life Cycle Assessment, Methodology Report, second edition 2000. Available online at: http://users.rowan.edu/~everett/courses/soclii/LCA/EI99_manual_v3.pdf. Retrieved on 13 February 2011.
47. Botkin, D.B. and E.A. Keller, 2010. Environmental Science. Earth as a living planet. Seventh edition. John Wiley & Sons, Inc. Asia.
48. Liu, L.Y., 2007 [online]. Back Ground Paper on Drought – An Assessment of Asian and Pacific Progress. Available online at: http://www.un.org/esa/sustdev/csd/csd16/rim/escap_drought.pdf. Retrieved on 25 February 2012.
49. WHO 2007. The World Health Report 2007. A Safer Future: Global Public Health Security in the

21st Century. Geneva: World Health Organization.

50. WHO 2002. Reducing Risks: Promoting Healthy Life. Geneva: World Health Organization.
51. Ghosh, T.K. and M.A. Prelas, 2009. Energy Resources and Systems. Volume 1: Fundamentals and Non-Renewable Resources. Springer Science + Business Media B.V. USA.
52. PTM 2003. National Energy Balance Malaysia 2003. Ministry of Energy, Communications and Multimedia, Malaysia.
53. Santoyo - Castelazo, E., H. Gujba, and A. Azapagic, 2011. Life cycle assessment of electricity generation in Mexico. Energy, 36 (3): 1488-1499.
54. The International Energy Agency, 2002 [online]. Implementing Agreement for Hydropower Technologies and Programmes. Environmental and Health Impacts of Electricity Generation: A Comparison of the Environmental Impacts of Hydropower with those of Other Generation Technologies. Available online at: http://www.ieahydro.org/reports/ST3-020613b.pdf. Retrieved on 2 May 2011.