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BEST PRACTICE FOR REDUCING THE CARBON FOOTPRINT OF THE MINING INDUSTRY

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SEVENTH FRAMEWORK PROGRAMME

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Summary

The ImpactMin demo site descriptions and background information are provided in report 3.1. Report 3.1 also contains information on: responsible mining, potential socio-economic impacts of mining, corporate social responsibility (CSR) in the mining industry, environmental and social regulations and standards that are used within the industry, in addition to providing a detailed socio-economic background of each of the demo sites used in this study. Report 3.2 presents the results of the comparative study across the seven ImpactMin demo sites, looking at what people think of mining and how mining has affected their lives. These findings provide information on what the socio-economic impacts of mining have been at each of the sites, including how mining companies develop social responsibility programmes, how they engage with different stakeholders and ultimately what the stakeholder perceptions are from people who have participated in the interviews and surveys.

The purpose of report 3.3 is to increase the understanding of what is being done in the mining industry to reduce its carbon footprint including demand reducing solutions, the potential for integrating renewable energy into mining technology and operations and offsetting.

This report comprises seven chapters: chapter 1 describes the drivers for reducing the carbon footprint in the mining industry, chapter 2 discusses minerals in Europe, chapter 3 mining technologies, chapter 4 carbon offsetting and trading, chapter 5 the case study of setting up a new mine in Roşia Montană and chapter 6 discusses overall conclusions.

Executive summary: Carbon footprint and the Mining Industry

There is now a consensus among the majority of scientists that anthropogenic climate change is a likely to produce significant changes which, ultimately, may severely affect the quality of life for humankind. Global temperature rise would result in global repercussions. The natural process of climate change has been magnified by human activity. This can be attributed to our enormous output of greenhouse gas (GHG) emissions. It is estimated that globally we produce 8 billion tonnes of CO_2 emissions each year (Heinzerling, 2010); nearly 22 million tonnes per day. If we are to maintain quality of life on our planet it will require a change in how we live, how we consume, and, specific to this report, how we produce our raw materials.

The phrase often proclaimed by the mining enthusiast that “if it can’t be grown it, it has to be mined”, is irrefutable. Our world and lifestyles are irrevocably linked to mining and minerals. For example, the computer this report has been written on has necessitated the use of at least 66 minerals (NMA, 2006). These raw materials can be produced in an environmentally and socially responsible manner, thus preparing them for industries that take a responsible approach to manufacturing and consumption.

The mining industry is a major global energy user, making it one of the most significant GHG producers. The EU has set the goal of a 20% reduction in GHG emissions by 2020; if this is to be obtained carbon footprint reduction in the mining industry will play a crucial part.

The term carbon footprint is defined by the UK carbon trust as: “A ‘carbon footprint’ measures the total greenhouse gas emissions caused directly and indirectly by a person, organisation, event or product” (Carbontrust, 2010). A carbon footprint measurement considerers all the six of the Kyoto Protocols classified GHGs, this include:

- Carbon Dioxide (CO_2)
- Methane (CH_4)
- Nitrous Oxide (N_2O)
- Hydroflourocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulphur Hexafluoride (SF_6)

CO_2 emissions were measured to Scope 2 requirements as defined by the GHG Protocol. There are three different scopes of GHG emissions, defined as:

- Scope 1: All direct GHG emissions.
- Scope 2: Indirect GHG emissions from consumption of purchased electricity, heat or steam.
- Scope 3: Other indirect emissions, such as the extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned

or controlled by the reporting entity, electricity-related activities (e.g. T and D losses) not covered in Scope 2, outsourced activities, waste disposal, etc.

Whilst scope 3 emissions do have an impact they were emitted for two reasons. Firstly, they were beyond the scope of the data obtained from mining companies which would have made data collection extremely time consuming and inaccurate. Secondly they are beyond the immediate control of the mining operation. While the mine can, in many cases, choose the supplier of its goods, this is outside of the purpose of this report which will look at the GHG emission directly related to mining and how those can be reduced.

Overall, this report shows the growing need to reduce carbon emissions through energy reduction strategies. The increasing number of regulations and voluntary codes are discussed in chapter 1, such as the ISO 14000 environmental management system and the Kyoto Protocol and Copenhagen Accord. Chapter 2 deals with the European minerals market. Chapter 3 discusses in depth the possible solutions that are currently available to reduce carbon emissions, through evolving mining technologies such as: renewable energy initiatives that can be employed at mine sites, GHG reducing technology, methods of optimising mine site equipment and load and haul fleet technology and best practice. Chapter 4 details options for offsetting or trading carbon emissions using the case study of Roşia Montanӑ, Romania. Chapter 5 also refers to Roşia Montanӑ, using it as a case study of best practical solutions in reducing carbon emissions and energy consumption in establishing a new mine. This unique case takes a practical approach to discussing the best options available in the context of limitations at this specific site. Chapter 6 makes some overall conclusions and recommendations for further research.

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Acknowledgements

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Chapter 1 Introduction

1.1 Aims of the project

ImpactMin Work Package 3 aims to create a better understanding of the socio-economic impacts of mining, investigating how we can develop corporate social responsibility policy that will incorporate and disseminate best practice within the industry. One of the reasons behind the ImpactMin WP3 work is the premise that in the future there will be a need to increase mining within Europe as a way of ensuring security of supply of mineral resources. One of the most urgent priorities of environmentally responsible industry is the reduction of carbon footprint and greenhouse gas emissions. Carbon emissions occur at all stages of the mining life cycle from exploration to closure. The purpose of this report is to explore the carbon footprint of mining projects throughout Europe and internationally. The focus will be on large scale mining operations, who produce the most significant carbon emissions, but also have the greatest means of leading the field in carbon footprint management.

1.2 Regulations

The information gathered within this chapter was based primarily upon the websites of mining companies, trade organisations, regulatory bodies, and governmental legislation. In addition to this a literary review of journal articles and related reports as well as interviews with industry professionals and academics were complied. Relevant guidelines were selected and reviewed based on their appropriateness to the minerals industry, their ability to address CO_2 related issues, as well as their popularity and ease of implementation. Guidelines that were considered narrow or limited to select portions of the industry were excluded in favour of examples that had wide ranging recognition and application. A particular focus was taken on regulations and legislature accepted and practiced with Britain the EU. Problems and areas of improvement within existing frameworks were identified and recommendations made where appropriate.

There is no single standard set to govern “best practice” guidelines regarding carbon footprint and CO_2 emissions in the mining industry. Although carbon footprint “best practices” exist throughout governments and businesses, there have been fewer initiatives in the mining industry. While legislation and metrics for acceptable levels of CO_2 emission do exist, they vary around the globe and lack detailed plans of action, recommendations, or standards specific to the mining industry about how it is expected to control and reduce its carbon footprint. Where best practice guidelines are being employed it is almost certainly due to the initiative of the company as opposed to any independent accrediting or governing body. Possible reasons for this include:

- The most energy intensive stage in producing a metal is often the extractions of the metals, via smelting or via hydrometallurgical prcesses rather than the mining and processing (Norgate and Haque, 2009). Figure 1 provides a graphical representation of the embodied energy of different metals. As can be seen the extraction process generally requires significantly more energy consumption than the mineral processing stages. These metal extraction processes make take place on site at the mine, or many thousand kilometres away at a separate plant. This graph does not account for the energy requirements involved in transport, manufacturing and packaging.

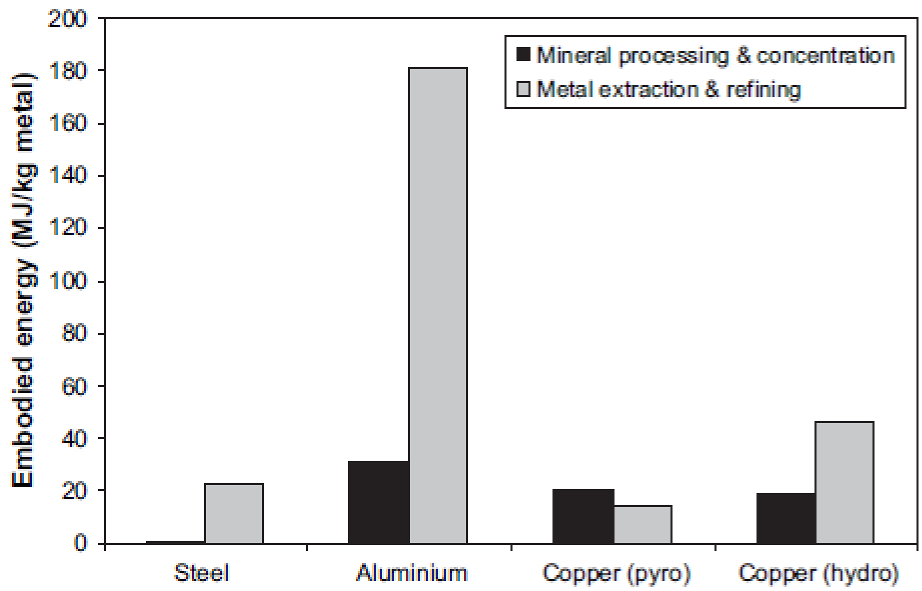


Figure 1 Embodied energy in various metals (Norgate and Haque, 2009).

- Another aspect is that mining often occurs in developing nations that lack the expertise and resources to develop and implement a reliable set of best practice guidelines. These countries are often more attractive to certain companies as their lack of environmental regulation can reduce the costs of operations. The host countries may be loath to lose this incentive to encourage mining companies.
- It is notoriously difficult to accurately and efficiently measure emissions as a result of mining and minerals processing. The fact that many emissions come from numerous sources which vary with terrain, time, and a host of other conditions, only adds to difficulties. For example, it would be both costly and time consuming to accurately measure the emissions of each blast at a mine.

Despite this, in the western world, particularly Canada, Australia, and the EU, there is an abundance of policy regarding carbon footprint, CO_2 emissions, and climate change.

1.2.1 IS0 14000

The International Standards Organisation (ISO) "...is the world's largest developer and publisher of international standards. It consists of a network of the national standards institutes of 163 countries, one member per country, with a Central Secretariat in Geneva, Switzerland, that coordinates the system (ISO, About ISO, 2010)". ISO 14000 is the family of ISO standards that deals specifically with environmental management systems (EMS). According to the website the ISO 14000 system will provide users with a management tool able to:

- “identify and control the environmental impact of its activities, products or services, and to
- improve its environmental performance continually, and to
- implement a systematic approach to setting environmental objectives and targets, to achieving these and to demonstrating that they have been achieved ” (ISO, International Organisation for Standardization: 14000, 2010).

Unlike other standards and best practices mentioned in this report, the ISO 14000 system does not set specific standards and regulations, nor is it specific to mining or carbon footprint management. Rather the ISO 14000 system provides the “...framework for a holistic, strategic approach to the organisation’s environmental policy, plans and actions” (ISO, International Organisation for Standardization: 14000, 2010). This in turn allows the organisation employing the ISO 14000 system to adapt it to their specific needs and industry standards and requirements. It allows an organisation to develop an EMS or set of best practices relevant to their industry.

The ISO 14000 family also lays out guidelines dealing specifically with carbon footprint quantification and greenhouse gas reduction strategies for affiliated organisations. Standards exist for a variety of carbon footprint related topics for example:

- “**ISO 14067** on the carbon footprint of products will provide requirements for the quantification and communication of greenhouse gases (GHGs) associated with products. The purpose of each part will be to: quantify the carbon footprint (Part 1); and harmonize methodologies for communicating the carbon footprint information and also provide guidance for this communication” (Part 2) (ISO14000, 2009).
- “**ISO 14069** will provide guidance for organisations to calculate the carbon footprint of their products, services and supply chain ”(ISO14000, 2009).

The ISO 14000 guidelines provide a comprehensive and adaptable set of environmental management principals and are widely used within the mining industry for developing EMSs. One of their greatest strengths is their ability to be tailored to the specific needs of an organisation. ISO 14000 is able to adapt to external expectations such as regional environmental expectations, and internal objectives, whilst simultaneously ensuring that the organisation is conforming to international standards and is committed to continuous improvement (ISO14000, 2009).

Mining companies all over the world currently employ the ISO 14000 Environmental Management System. ISO 14000 compliant companies include: Barrick Gold, Teck, Rio Tinto, and BHP. As previously mentioned, the EMSs are tailored to the companies’ needs and the regulatory standards of the region. These may or may not include dealing with carbon footprint calculations and reduction, greenhouse gas emissions reduction and other environmental issues. That said, the aforementioned companies are organisations that have taken a proactive approach to GHG reductions and include GHG reduction in their EMS strategy (Rio Tinto, 2006).

1.2.2 European Emissions Trading Scheme (EU ETS)

The European Emissions Trading Scheme (EU ETS) was the first and is currently the largest multinational emissions trading scheme of carbon dioxide (Ellerman et al., 2007). Launched in 2005, the scheme aimed to reduce greenhouse gas (GHG) emissions by 21% from 2005 levels by 2020 (European Commission, 2010). The scheme has run for three periods, the first running from 2005 until 2007, the second from 2008 to 2012 and the third will run from 2013-2020. The EU ETS shares, in many respects, various similarities with the approach taken by the Kyoto Protocol, placing an obligation upon significant GHG contributors to record and inform a regulatory body of its emissions. In the example of the EU ETS, companies that emit significant amounts of carbon dioxide are obliged to monitor, annually report and inform their government of its emissions. Under the ETS, governments of the EU Member States initially agree upon national emission caps which are then subsequently passed down and reallocated to industrial operators. Companies that successfully fall within their allotted emissions limit have the opportunity to keep or sell the remaining emission allowance onto a company for profit. On the other hand, a company which surpasses its emissions allowance will be fined (Phylipsen, 2005).

Despite the similarities of the approach that is taken by the EU ETS and Kyoto, it is clear that the objectives of these two 'schemes' are very different. At the heart of the EU ETS, the "cap and trade" approach has established a sector by sector/ company to company appraisal of carbon trading, a resolution that is in stark contrast to the nation by nation included within the Kyoto Protocol. The obvious shortfall of the EU ETS is its consideration only of carbon dioxide emissions. This is clearly a major drawback given that approximately 17% of EU Member GHG emissions are not carbon dioxide (Phylipsen, 2005). Other greenhouse gases are effectively neglected from auditing however work is currently ongoing into the feasibility of including other greenhouse gases in EU ETS making up the LETS update study. In the first period ETS covers, for example power stations and factories making cement, glass, lime, bricks and ceramics. In 2008, the proposal was made to include aluminium and ammonia producers. In addition, the date for the inclusion of freight transport by road and mining is to be specified by 2013. The proposals were to exclude any of less than 35 MW installations and 25,000 tonnes of CO_2 equivalent of reported emissions in each of the preceding three years. In addition, carbon capture and storage projects are to be financed (OUZKÝ, 2008).

1.2.3 Carbon Pollution Reduction Scheme (CRPS)

In 2008, the Australian Government released its proposal for a Carbon Pollution Reduction Scheme (CPRS) which was intended to serve as a cap-and-trade system for anthropogenic greenhouse gases – a policy which was due to be introduced in 2010. The emissions covered represent around 75% of Australia's emissions (Department of Climate Change and Energy Efficiency, 2010). Under this scheme, businesses and industries covered by the CPRS will need to surrender an emissions unit for each tonne of CO_{2e} that they have emitted during the compliance period. The CPRS will include all greenhouse gases included under the Kyoto Protocol. The objective of this proposal initially targeted at coal mining companies, was to introduce a carbon tax on mining facilities that achieved a threshold of 25,000 tonnes of carbon dioxide per annum inclusive of emissions generated by transport and processing infrastructure. Additionally, coal mines will have to serve as proxies for domestic users of coal which fall below the 25,000 tonnes CO_{2e} per year (Taberner, 2009). This scheme was intended to form part of Australia's long term commitment to reducing greenhouse gas emissions by 60 per cent compared with concentrations from 2000, a clearly ambitious target given that mining alone consumes approximately 10% of Australia's total annual energy consumption. The Australian government has committed to providing assistance to the coal mining sector through the Coal Sector Adjustment Scheme (CSAS) and the Coal Mining Abatement Fund. The CSAS assistance would be 60% of fugitive emissions and available to the coal mines that have fugitive emissions intensity (gassy coal mines) above a threshold of 0.1 tonnes of CO_{2e} per tonne of saleable coal produced. For the latter fund, a quarter of the project cost would be granted for coal sector abatement projects and capital grants with a priority for electricity generation from waste coal mine gas (Department of Climate Change and Energy Efficiency, 2010). Since the measure and mitigation of the coal fugitive emissions technologies are still at the experimental stages. The Australian Coal Association noted that the major coal competing nations of Australia excluded and have yet to commit to applying the coal fugitive emissions pricing (Pegler, 2011).

1.3 Kyoto Protocol

One of the most significant and prolific attempts at controlling climate change and reducing greenhouse gases, on a global scale, is the Kyoto accord (UNFCCC, An Introduction to the Kyoto Protocol Compliance Mechanism, 2010). The stated objectives of the Kyoto accord are:

"The stabilisation of atmospheric concentrations of greenhouse gases at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner" (UN, United Nations Framework Convention on Climate Change, 1997).

The Kyoto protocol set the target of reducing participating countries GHG emissions by an average of 5.2% per annum for five years (2008-2012) using the level of emissions produced in 1990 as a benchmark (UNFCCC, Kyoto Protocol, 2007). Thirty seven first world countries and the EU (referred to as Annex I countries) committed to meeting these targets. The emissions targets set by the Kyoto Protocol, unlike those in the Kyoto accord that merely recommended goals, are legally binding for all Annex I countries. The Kyoto Protocol was officially adopted on the December 11^{th} 1997 and enforced as of February 16^{th} 2005 (UNFCCC, Kyoto Protocol, 2007). Figure 2 is a map representing the countries which have signed the Kyoto Protocol as of June 2009. The countries coloured green have committed to the protocol, the grey countries are undecided, and the red countries do not indend to sign the treaty. (UNFCCC, An Introduction to the Kyoto Protocol Compliance Mechanism, 2010)

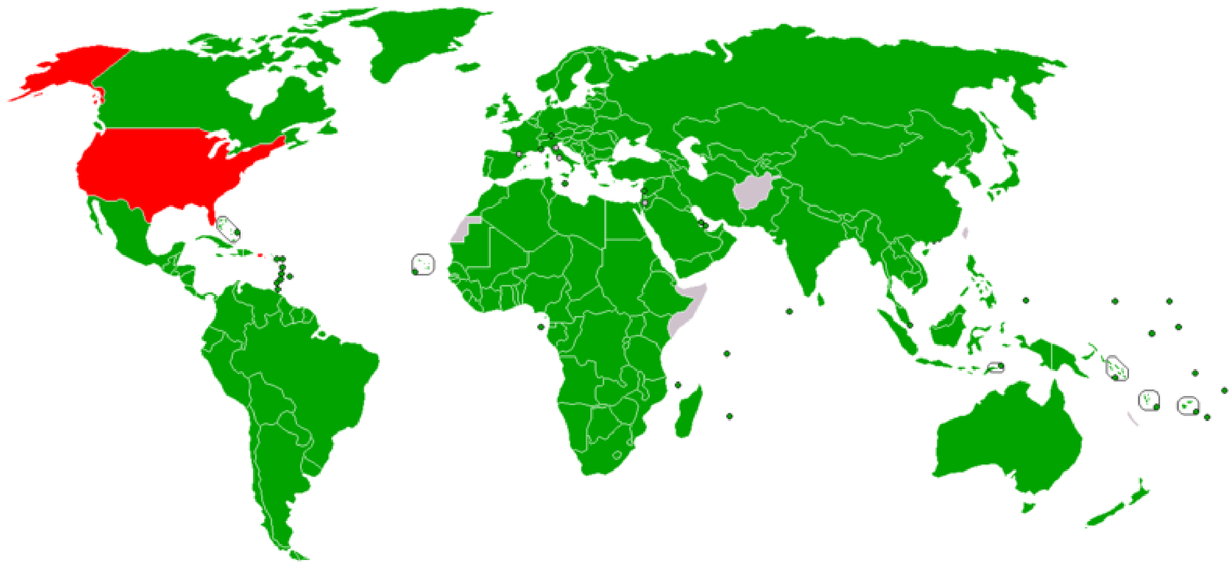


Figure 2 Kyoto protocol participation (UNFCCC, Kyoto Protocol, 2007).

The Kyoto Protocol affects the mining industry in that, like all industries in Annex I countries, it will have to reduce emissions over the five-year period in order to comply with the established targets. Table 1 lists the countries/regions with the top 10 GHG emissions.

Table 1 Ranking of the World's top ten emitters (MNP, 2007).

Rating	Country	Global % of GHG Emissions	Per-Capita Emissions (tonnes of GHG per-capita)
1	China	17%	5.8
2	U.S.A	16%	21.1
3	E.U.	11%	10.6
4	Indonesia	6%	12.9
5	India	5%	2.1
6	Russia	5%	14.9
7	Brazil	4%	10.0
8	Japan	3%	10.6
9	Canada	2%	23.2
10	Mexico	2%	6.4

As can be seen from the above table many of these countries represent nations with major mining industries. The Kyoto Protocol will have an effect on all participating nations. Ensuring industry in those nations will be committed to reducing their carbon footprint. The mining industry is no exception to this.

1.4 Copenhagen Accord

The Copenhagen accord occurred on the 18th of December 2009 at the United Nations framework convention on climate change and is the attempt at a successor for the Kyoto protocol. However, unlike the Kyoto protocol, the Copenhagen accord is not a legally binding document; rather the participating countries agreed to take note of the recommendations laid out in the accord (Wynn, 2009). The convention had been considered widely unsuccessful by media and many countries, in fact the conference was found to have a larger carbon footprint than any climate change conference to date (Graham-Harrison, 2009).

Countries signed the accord with the “intentions” to reduce emissions from anything from 40% to 1.8% of their original 1990 emissions level (UN, Copenhagen Accord, 2009). The intention of the conference had been to start work on developing a successor to the Kyoto protocol which ends in 2012. In this respect the conference is considered to have been a failure. However the more generous reports state that the accord was at least successful in increasing the awareness of climate change issues and in taking illuminating the need for further work in this area (Black, 2010). Although the Kyoto Protocol will certainly affect the Carbon footprint and greenhouse gas emissions “best practices” of the mining industry; it is unlikely that the overall impact of the Copenhagen Accord will be very significant at this time on the mining industry; given the uncommitted nature of the accord.

1.5 Life Cycle Assessment (LCA)

A life cycle assessment (LCA), also known as a “cradle to grave” approach is an ISO 14000 recommended tool used to assess the environmental and social impact of a product throughout its useful life; from its start as a raw material to disposal (ISO, International Organisation for Standardization: 14000, 2010). Mining is the first phase in the lifecycle of a material, and as such it is extremely important; it can often set a material on the path to be used responsibly throughout its lifecycle. In its efforts towards sustainability, the mining industry has used several environmental and economic indicators to assess its performance. In recent years, Life Cycle Assessment (LCA) has proved to be one of the most attractive approaches for this task. As such, it is an excellent tool that can be used to evaluate environmental performance and support decision-making in the mining industry” (Durucan *et al*., 2004).

The mining industry first began experimenting with the LCA approach in the mid 1990’s; originally utilising Life Cycle Inventories (LCI’s) in metal production processes to help customers with design and choosing products (Durucan *et al*., 2004). Eventually LCAs began to be used in project and process selection with a strong focus on the processes occurring during concentration and refining. LCAs have been used with less frequency in the extraction phase of an operation (Stewart, 2001). The following is a list of examples where LCA applications are utilised within the mining industry:

- “Copper production from primary and secondary sources, and copper alloy fabrication to semi-finished and final products ;
- Smelting of sulphide ores ;
- Gold, coal, base metals, platinum group metals, ferroalloys and beach sands production ;
- Aluminium ore extraction, smelting, transportation and energy use ;
- Mining, production, packing and shipping of boron products ;
- Various processing routes for nickel and copper production with emphasis on greenhouse and acid rain gas emissions ;
- Base metal refining and producing primary nickel; iron and steel processes ;
- Lead and zinc smelting;
- Uranium ore production;
- Aluminium and steel industry products.” (Durucan, Korre, and Munoz-Melendez, 2004).

Figure 3 shows a graphical representation of the different mining and refining processes that can be managed using LCA to minimise environmental and social impacts.

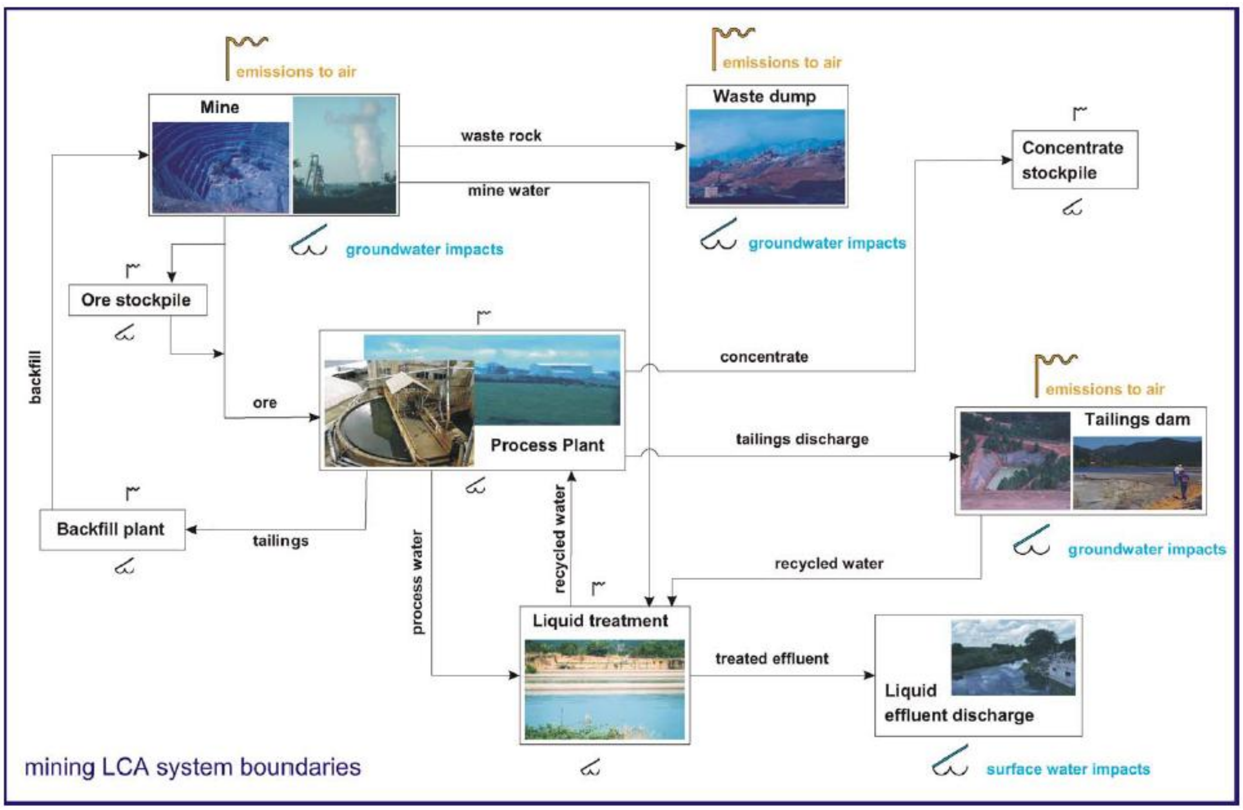


Figure 3 Mining LCA assessment system and model boundaries (Durucan, Korre and Munoz-Melendez, 2004).

Measuring the carbon footprint and CO_2 emissions is an important aspect of this process and is represented on the figure above by the smoke stack icon over the areas they apply. LCA helps a company to divide the "lifecycle" of the material at the mine into a set of processes. These processes can then be broken down and analysed; working to develop the most environmentally and socially friendly method of completing the process. In the case of carbon footprint and greenhouse gas emissions, analysis of the processes can reveal inadequacies and inefficiencies, allowing the relevant processes to be adjusted to maximise efficiency and interact in a way that minimises the project's carbon footprint (Mudd, 2009).

1.6 Best Available Techniques (BATs)

Best available techniques, or BATs, are a concept defined as the "most effective and advanced stage in the development of an activity and its methods of operation, which indicate the practical suitability of particular techniques for providing, in principle, the basis for emission limit values designed to prevent or eliminate or, where that is not practicable, generally to reduce an emission and its impact on the environment as a whole" (EPA, Best Available Techniques Guidance Notes, 2010). This definition has been broken down further in Table 2.

Table 2 BATs breakdown (EPA, 2010).

B	**'best'** in relation to techniques, means the most effective in achieving a high general level of protection of the environment as a whole
A	**'available techniques'** means those techniques developed on a scale which allows implementation in the relevant class of activity under economically the technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced within the State, as long as they are reasonably accessible to the person carrying out the activity
T	**'techniques'** includes both the technology used and the way in which the installation is designed, built , managed, maintained, operated and decommissioned.

The concepts of BATs was created by the European Integrated Pollution Prevention Control Bureau (IPPC) as part of their 'Directive on Industrial Emissions'. The directive has been in place for over ten years, with the most recent version adopted on the 21st of December 2007 and coded as 'Directive 2008/1/EC of the European Parliament (IPPC, 2008). The purpose of this directive is to advise and encourage the exchange of information member states on standards and best practices regarding environmental management. This is accomplished through the use of BAT reference documents (BREFs) which are used to relay detailed information to members states regarding the BATs for “specific industrial/agricultural sector(s) in the EU...” (EIPPCB, 2010). The stated objectives of the BREFs are to:

- “Accomplish a comprehensive exchange of information and views and through the publication of reference documents to help to redress any technological imbalances in the European Community;
- Promote the worldwide dissemination of limit values and techniques used in the Community;
- Assist Member States in the efficient implementation of this Directive. (EPA, Best Available Techniques Guidance Notes, 2010)”.

An example of some of the BREFs relevant to the mining industry include: BREF on Non Ferrous Metals Processes; BREF for Mineral Oil and Gas Refineries; BREF for Surface Treatment of Metals and Plastics, and BREF for Management of Tailings and Waste-Rock in Mining activities (EIPPCB, 2010). Each of these documents contains recommendations and best practice strategies detailing how each process can be undertaken with a minimum environmental impact. This will include strategies on reducing carbon footprint and greenhouse gas output. In this manner the EU has employed BATs as a means of instituting standards and best practice guidelines throughout its member states.

1.7 The International Council on Mining and Metals (ICMM)

‘The international council on mining and metals’ (ICMM) was established in 2001 to act as a catalyst for performance improvement” (ICMM, 2010). It now consists of 19 mining and metal companies along with 30 mining associations working together “to address the core sustainable development challenges faced by the” (mining industry (ICMM, 2010). Encompassed within this is a commitment to reducing the environmental impact of the mining industry; including carbon footprint. The ICMM strives to work with member companies within the mining industry to set standards and to “strengthen our (the mining industry capacity to improve environmental performance” (ICMM, 2010). ICMM aims to align the goals of mining companies with governments and local communities to work together to ensure mining is a mutually beneficial enterprise with limited negative impacts. Essentially ICMM works to create a framework, supported by some of the biggest mining companies, committed to carrying out exploration and mining activities in a sustainable and responsible manner. It also acts as a way of disseminating information within the industry and propagating and improving best practices. From outside of the industry, it acts as a catalyst of increasing awareness about the mining industry.

1.8 Discussion and Conclusions

It is clear that whilst there is no definitive set of “best practice guidelines” or standards relating to carbon footprint in the mining industry; there are an array of options and resources available to organisations to help control and manage their carbon footprint. While some provide emission limits and regulations, such as the Kyoto Protocol; others provide the guidelines and structure to create an internationally recognised environmental management system tailored to the needs of the organisation and demands of the stakeholders; such as ISO 14000 and BATs. As it stands the closest option to an ‘international standard for best practices’ is the ISO 14000. This provides an organisation with a framework to create an internationally certified EMS and a comprehensive set of best practice guidelines for its operations. In addition to this ISO 14000 is recognised and employed throughout numerous and varying industries and organisations; not simply the mining industry. The next step in the process is international legislation and best practices concerning carbon emission, and greenhouse gases with regard to the mining industry. Whilst it is unlikely that governments or the international community, such as the UN, will produce mining specific CO_2 regulations on a global scale, it is possible that trade organisations, such as the International Council on Mining and Metals may help to defin standards. Through organisations like the ICMM standards and best practices can obtain widespread acceptance and permeate throughout the industry. It is also essential for the major international senior mining companies (e.g. Barrick, BHP, Anglo American, Rio Tinto) to uphold these standards both in the countries with strict environmental standards and CO_2 emission regulations (Canada, Australia, the EU) and countries currently lacking the necessary infrastructure (DRC, Eastern Europe, South America). Only in this manner will carbon footprint reduction best practices develop and propagate in the mining industry and gain international acceptance and implementation.

Chapter 2 Promising minerals in Europe

2.1 General Market

The market for minerals across the European Union requires careful assessment in order for the Member States to be best prepared for the future extraction and usage of its mineral resources. Owing to the move towards a more sustainable energy economy, this assessment must be balanced and challenge the traditional approach to resource issues. A 2010 report by the Commission sought to identify the importance and risks of 41 minerals and metals (European Commission, 2011a). Fourteen raw materials were considered critical for the EU, including: antimony, beryllium, cobalt, fluorspar, gallium, germanium, graphite, indium, magnesium, niobium, platinum group metals, rare earths, tantalum, and tungsten.

The trend away from heavy extraction in the industrialised nations towards the Global South has garnered the much attention lately. Key industries in the EU economy, including aerospace, automotive, chemicals, construction, information technology, and telecommunications, are all heavily dependent upon raw materials being readily available and thus maintaining a secure and sustainable supply is essential for economic stability and/or growth.

Current consumption of minerals necessitates EU states to reach outside their borders and import minerals or finished products to fulfil industry and consumer needs. As of February 2011, the EC adopted a new strategy, which acknowledges and emphasizes promoting sustainability, increasing efficiency, and recycling (European Commission, 2011b).

Depending on whether one is focusing upon just the European Union or more broadly, including the European continent, current estimates of mineral availability differ dramatically. For example, Russia holds vast resource wealth and the inclusion of the state along with other countries on the EU's periphery must be considered when calculating the European situation.

Owing to inequalities in geological resources, the competition for specific minerals and ores in particular, requires a clear approach and strategy to maintain the EU's development. Unfortunately, the amount of imports coming into the EU are much greater than the exports in this sector, illustrating the EU's dependency upon global markets, especially for metallic minerals.

The presence of mining companies on the London Stock Exchange is both visible and more significant than any other international exchange, illustrating the strength of European industry in the financial sector. Still, many raw materials which are traded globally are not present on stock exchanges at all, or there are other issues related to transparency of the markets. These issues hinder the ability to accurately forecast where potential shortages may emerge.

With changes in supply and demand, price variation may dramatically affect consumption and availability. Long-term forecasts should consider wide variability between past tendencies and possible precarious futures.

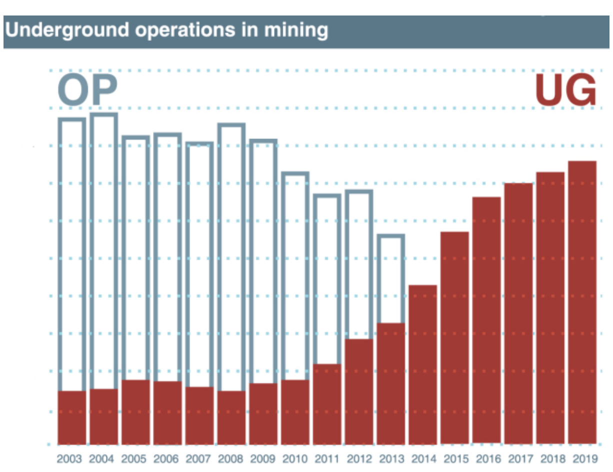
2.2 Availability of Specific Minerals

With respect to construction minerals, EU Member States generally have adequate supplies of aggregate minerals, such as raw materials for concrete, fill, and sand (Hetherington *et* al., 2008). Reports on these minerals are relatively transparent, but as we look at the supplies of other minerals, there are often discrepancies with reporting and this weakness needs to be addressed. As for non-construction industrial minerals, the distribution of supplies is more uneven across the Union. Statistics about these minerals are harder to find and potentially less accurate than for metals. Energy minerals are well-reported and wide scale analysis has been undertaken to forecast their future supply. The scope of energy is far too broad to address in this document, but the obvious push towards renewable energy illustrates the desire for the EU to be less dependent upon importing energy supplies.

The EU is most dependent on imported metals. The EU consumes more than a quarter of the world's metals and this trend looks set to continue despite the dependency and increasing prices (Hetherington *et* al., 2008).

2.3 Environmental Issues

Two major environmental concerns are directly associated with the extractive industries. First, the extraction of minerals, which are non-renewable, impinges on future generations. Their use also can have a negative impact upon the environment itself. Monitoring the full life-cycle of extraction activities is essential to accurately understand the potential long-term damage from mining. Second, the waste from such activities must be dealt with in an appropriate manner. To ensure the most efficient use of resources, as well as to limit the pollution output, the EU Mining Waste Directive legislates on the management of waste products.



Variation across the EU in environmental standards also requires consideration. The difference between some of the New Member States and older ones requires new approaches to reach harmonisation and compliance. Better planning for addressing land use, waste discharge, and environmental standards can move the extractive industry towards more sustainable practice.

Another issue revolves around the usage of certain minerals for environmental protection. The environmental impact of mining may be negative in some cases, but it also provides the tools to improve the current state of the EU's environment.

2.4 Socio-Economic Factors

Trends in society will greatly affect the extractive industries, along with economic and political developments. The growing world population will definitely place pressures upon the world's resources. Inequalities in supplies will be reflected in markets and distribution, possibly greatly altering consumption patterns. But while worldwide population is expected to grow, primarily in developing countries, Europe is aging. This possible population decrease and new age profile, unless countered by migration patterns, will lead to new consumption styles. Additionally, the movement towards and into urban environments may require new minerals or demand different materials.

These developments will alter and must influence the political decisions of EU leaders. Current consumption is not related to production and extraction of minerals from within the EU market. The unsustainable patterns must be reconsidered to match the supply of European resources, or at the bare minimum, come closer to sustainable levels. GDP may decrease in areas short of resource supplies or without much to trade; this possibility is more than a political one, but could have tangible affects upon the quality-of-life for many Europeans.

Introducing new technologies into the European extractive industry is bound to enhance and improve the field, but also greater incorporation of SMEs into activities may be more beneficial in the long run than supporting potential large scale activities. Mining is an important employer, with many communities heavily dependent upon the industry to support them. Enhancing local extraction activities could boost regions, increase high-tech work, and wean the EU off imports.

Chapter 3 Mining technologies

3.1 Renewable Energy

This chapter will review renewable energy technologies as a means of GHG emissions reduction. Renewable energy, energy which is derived from naturally replenished resources, accounts for “one quarter of global power capacity from all sources and delivered 18 percent of global electricity supply in 2009” (REN21, 2010). The mining industry, like many sectors, has begun to embrace a variety of renewable energies on a global scale. Renewables are utilised as a means to reduce energy costs, greenhouse gas emissions, and negative environmental impacts; they are capable of providing significant sources of energy with minimal negative impact. This section will discuss various renewable energies currently available to the mining industry along with some innovative technologies with the potential to reduce the carbon footprint of mining in the future.

Wind Power

Wind power is one of the most successful, popular, and fastest growing forms of renewable energy available today. In 2009, wind power was estimated to produce 157.9 GW of energy per annum worldwide; that figure having grown by 31% from 2008 (GWEC, 2010). There can be no doubt that wind farms are a significant and growing energy source. The mining industry, like many other sectors, governments, organisations and individuals, has begun to embrace the benefits of wind farm technology. The drawback of wind power is that conditions must be appropriate for it to be a viable and reliable source of energy. A high average wind speed alone does not guarantee the feasibility of a wind farm. A wind turbine performs best under consistent wind speeds; normally around 10 to 15 metres per second. At low speeds a windturbine does not produce as much energy to be profitable and under very high speeds the windturbine may have to be turned off owing to dangerous high frequency rotations. It has been found that windturbines often produce a large portion of their energy output in relatively short periods of high wind speed. The New Mexico Wind Resource Assessment case study, completed by the Sandia National Laboratories at their facilities at the Lee Ranch testing centre in 2002 found that 50 % of the energy was produced in ‘bursts of wind’ over 15% of the windmills operating time (SNL, 2002). Because of the inconsistent nature of wind, and thus the inconsistent energy production of windmills they are best used in conjunction with another, more reliable, power source. Research shows windturbines are more effective behaving as a fuel conserver then as a primary power supply (Czisch, 2008). Figure 4 provides a graphical representation between the hours a windmill is used at a given wind speed and its energy output found at the Lee Ranch in New Mexico.

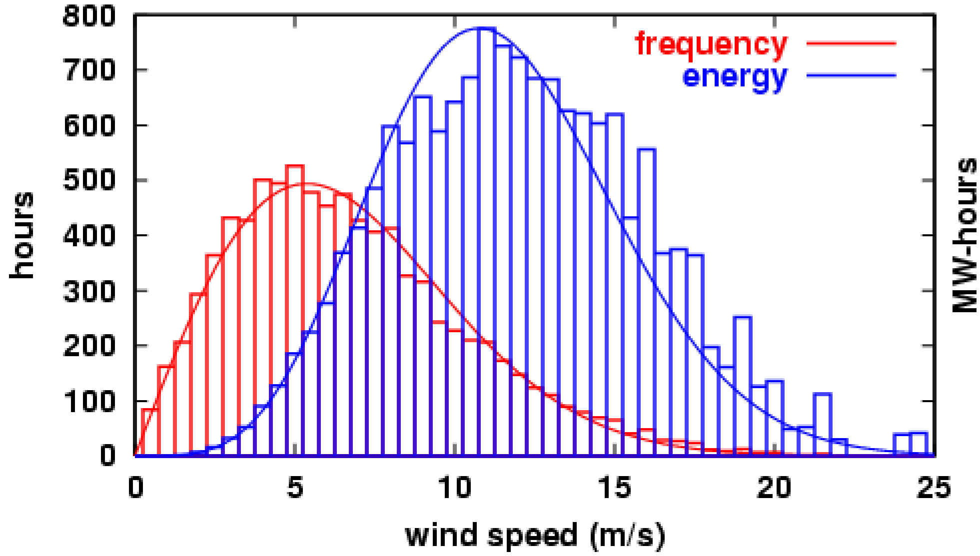


Figure 4 Lee Ranch wind speed / energy correlation (SNL, 2002).

As many mining and processing operations occur in remote locations, where access to grid power supply is unavailable or cost prohibitive, operations are often reliant on diesel electric generators. A popular emerging alternative to diesel only, is to use combination wind/diesel generators; which are optimised at 40% wind generated energy and 60% diesel power (Neilson, 2007). An average mine site diesel generator reduces CO_2 emissions by 1.8 lbs per kWh when used in conjunction with wind power. A one mega watt wind farm responsible for 35% of the power supply will generate an average of 3,066,000 kWh of electricity per annum; thereby reducing $C0_2$ emissions by up to 2,759 tonnes per year (Neilson, 2007). In addition to this wind power typically costs $0.06-$0.08 USD per kWh which is lower than the average diesel power generator which costs between $0.09-$0.19 USD per kWh under typical conditions (Neilson, 2007).

An example of a mining company employing the benefits of Wind Power is Barrick Gold, the world's largest gold company. In 2007, they received approval to build a US$70 million wind farm in the Coquimbo region of Chile (Barrick, Beyond Borders: A Barrick Gold Report on Responsible Mining, 2010). They have constructed ten wind turbines that provide 36 MW of power to the Chilean grid each year. This is currently the largest wind farm in Chile and an excellent example of a mining company not only reducing their own carbon footprint but working to reduce the carbon footprint of the region they operate in. Unfortunately more information is regarding as to how the turbines will interact with the mines energy requirements are unavailable. It does appear though that the turbines will feed directly into the Punta Colorada regional grid (Barrick, Building Pascua-Lama, 2009).

An associate of the mining industry who currently works at an undisclosed metal mine was contacted for telephone interview as part of this study. They explained that their mine currently leases a 30 MW wind turbine which supplies electricty directly to the national grid. It is thought that the mine in question is participiating in a Feed-in tariffs (FIT) policy, whereby fixed rates are paid by national government to the mine and indeed other such producers of electricity for feeding it into the national grid. The Renewable Energy Sources Act (EEG) implemented in Germany is an excellent example where FIT has actively encouraged the production and selling of renewable energies such as wind and solar power to the national grid, offering financial incentives in retun for facilitating government to achieve its set national targets of carbon footprint reductions.

Discussion

Whilst wind power may offer mining companies (in the right locations) an excellent opportunity to capitalise on renewable energy there are some drawbacks. The most obvious being the significant upfront costs of wind turbines. As mentioned previously Barrick Gold spent upwards of US $70 million on a single wind farm. Despite the fact that wind farms are a proven energy source the power they provide is quite small given the significant costs of construction and maintenance. In this case, costing nearly US $2 million per MW produced, it is also important to note that wind farms are unlikely to be running 24 hours a day due to weather variations. This compares with Barrick's natural gas power plant in Nevada which cost $100 million to build and produces 115 MW, or US $869,000 per MW, 24 hours a day 365 days a year. Although there are numerous wind farms worldwide today most are heavily subsidised by governments. In recent years in Spain the government has made a drive towards green energy significantly subsidizing the costs of wind power; as a result electricity costs have risen by up to 60%. It was said that this initiative created 50,000 jobs in the 'green' energy sector but each job was subsidised by the Spanish government at an average of 571,000 Euros (Gorham, 2010).

Despite this, wind farms are a proven form of energy and are known to work very well in conjunction with conventional power sources. As a carbon reducing initiative they are an excellent form of energy and they produce virtually no carbon after they have been constructed. While they may never be an economic solution to a company's power needs they are certainly a viable means of a project's GHG emissions.

Solar Energy

Solar energy is a form of power that utilizes sunlight to generate electricity. In 2008 solar energy accounted for 0.02% of global energy consumption (Solarbuzz, 2009) and just 0.08% in the USA (Hutchinson, 2008). In recent years solar power has come to play a growing role in the mining industry. With mining companies building solar power systems ranging in size from small projects acting in combination with other energy supplies to large facilities powering nearby communities and homes. Solar power is typically produced in one of two ways:

Photovoltaics (PV)

Photovoltaics is a type of solar power which converts solar radiation directly to electricity. This is done by utilising a system of solar panels made up of silicon cells consisting of thin layers of semiconductors carrying opposing charges (+ and -). The electron imbalance caused by sunlight striking the charged panels cause electrical flow, aka electricity (Strathclyde, 2005). Thus is represented in Figure 5.

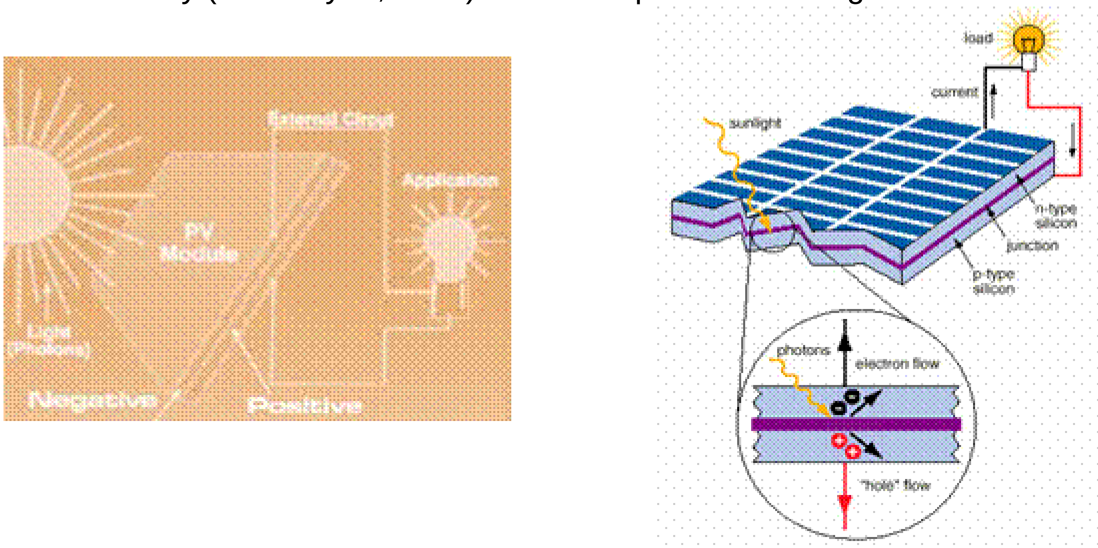


Figure 5 PV solar panel diagram (Strathclyde, 2005).

PV solar panels are typically used for small-scale applications such as satellites, private homes or consumer products (such as calculators or watches). Figure 6 shows a chart of the breakdown of PV use worldwide.

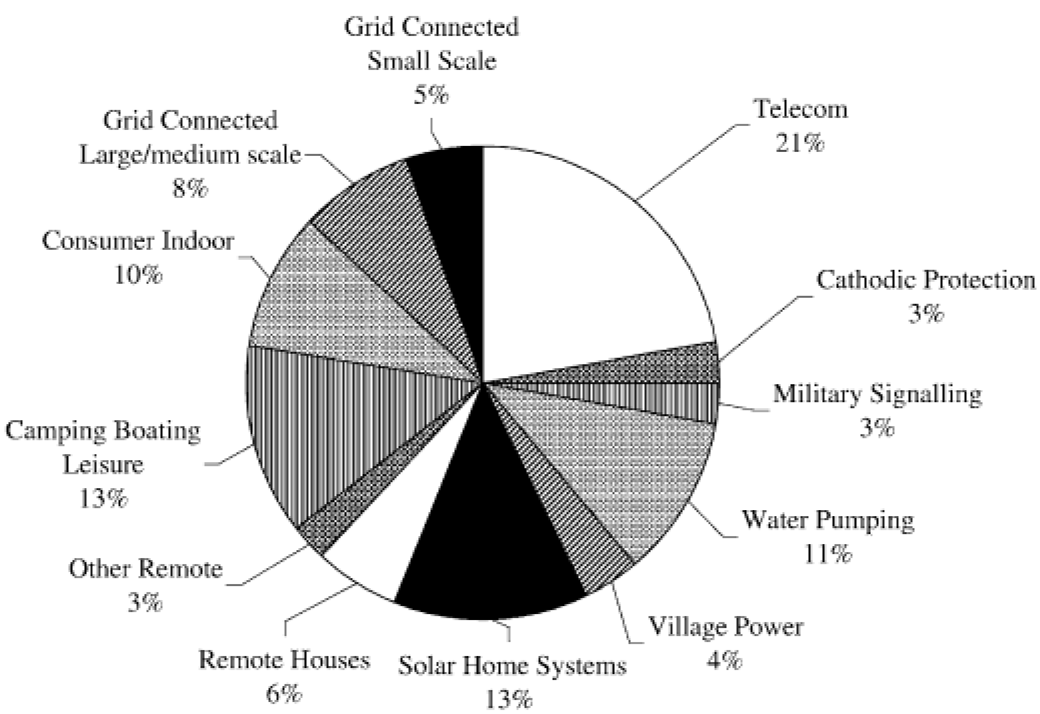


Figure 6 Worldwide PV breakdown (Oliver and Jackson, 1999).

Despite this PV solar panels represent a growing solar industry as they are continually increasing in efficiency and versatility. "World solar photovoltaic (PV) market installations reached a record high of 5.95 gigawatts (GW) in 2008, representing growth of 110% over the previous year (Solarbuzz, 2009)". Although PV panels would be poorly suited for large scale power generation at a mine site or even working in tandem with a alternative energy source (ex. Diesel) there is potential for application in small scale activities. Solar panels of this nature are already widely in use by Barrick Gold, the world's largest gold mining company, on their mine sites as power sources for monitors and other small scale equipment (Josich, 2007); Namdeb, diamond producer in Namibia, uses solar panels to power their security cameras and Cliff Resources iron ore mine at Koolyannobbin, Western Australia use solar panels for geotechnical monitoring equipment (F. Wall, pers comm.). In addition to positive environmental effects it is likely that after initial installation costs the addition of PV panels could have financial benefits as well. They will enable organisation to forgo maintaining expensive power lines to remote locations where only small amounts of electricity are needed. Further research needs to be completed into panels 'payback' period; but it is reasonable to suspect financial benefits as well as carbon emissions reduction.

Concentrating Solar Power (CSP)

The second type of solar energy is 'concentrating solar power', a form of indirect solar energy. This type of solar energy is produced by utilising either mirrors or lenses to concentrate sunlight into a small area and then projecting this energy onto a photovoltaic surface or to heat a working fluid.

When solar energy is used to produce heat for the purpose of generating electricity it is referred to as concentrating solar thermal (CST). This is normally done by using the heat produced from the concentrated sun's rays directly or heating a working fluid such as molten salt or oil (Nenter and Netshilaphala, 2006). The heated fluid or the concentrated sunlight is then used in a conventional power plant (or engine) to produce electricity. This is normally done by heating water to produce steam, which in turn spins a turbine (Hutchinson, 2008). CSP systems can produce heat up to 788 ^{o}C and obtain energy conversion efficiencies up to 31.25%. CSP systems vary in design from long parabolic troughs that all work together to power central turbine (one of which exists in Boulder City Nevada that produces 64 MW; with 13 more on the way) to solar dishes that can be used to power individual motors (40 of which can produce up to 1 MW)(e.g. Figure 7).

Figure 7 Parabolic trough and solar dish CSP (Hutchinson, 2008).

Concentrated photovoltaics (CPV) on the other hand function by utilising the lenses or mirrors to focus the sun's rays on photovoltaic surfaces and producing electrical power directly; without the steam. This works in a similar manner to PV solar power except that the sun's rays have been concentrated on a small PV area. The PV surface is typically constructed from silicon but can also be cadmium telluride; a much more economic alternative (Hutchinson, 2008).

Discussion

Solar power represents numerous opportunities to the mining industry. With its range of options and versatility in application it can be harnessed to provide power solutions to both small and large scale issues. An excellent example of this would be the use of PV panels. Although as previously mentioned they are in use in small scale applications (ex. monitoring, road signs etc.) it is the opinion of this author that it would be worth while investigating the application of PV panels to open pit haul trucks, conveyor belts or mobile crushing units. This would clearly be dependent on climate and weather conditions but it is reasonable to assume that PV panels used in conjunction with diesel generators or other conventional power supplies could significantly reduce fuel consumption, thereby lowering energy costs and harmful greenhouse gas and CO_2 emissions; thus reducing the operations carbon footprint in a small way. It is unlikely at this time, given current technology, that this would reduce costs but with advances techniques it is certainly an opportunity to examine in the future. Perhaps a more economic alternative to this would be utilising solar panels with a trolley assist system (explained in section 3.2) this would reduce the possibility of damaged equipment (as it wouldn't be moving) and increase the area available. Both of these options require significantly more research before true costs can be known.

Concentrated solar power currently represents the greatest opportunity for the mining industry. Its ability to work on large scale and in conjunction with conventional power plants makes it an ideal power supply in the right climates. Although it will act primarily as a fuel conserving measure for diesel and coal plants it could represent significant savings for companies. Several companies have already begun to implement the use of solar power plants. An example of this is Barrick Gold who recently spent US $ 10 million on a 7,404 panel solar power plant in northern Nevada capable of producing 1 Mw of power, or enough to power as much as 300 homes. This solar farm will work in tandem with a $100 million 115 MW natural gas power station already built by Barrick (Seelmeyer, 2008). In 2004 Rio Tinto one of the world's biggest mining companies built a 31 kW PV solar power system in Western Australia; which at the time was the largest system of its kind in the area. This system run as a solar-diesel hybrid consists of 260 solar panels and is estimated to "...contribute 130kWh per day to help meet the nation's power needs" (RioTinto, Social, Safety and Environment Report 2004, 2004). BHP and Rio Tinto are also working together to create the world's largest CST plant, in Australia, at an estimated US $ 1 billion; at an estimated start date of 2011 (Mine giants Rio and BHP bet on solar power, 2008).

While solar power is a proven method of utilising renewable energy, there are some pitfalls. Solar power is an extremely expensive power source both in terms of upfront costs and maintenance. It has been estimated that PV solar panels can take roughly 100 years to pay back installation costs (note: the maximum life of a PV panel is 30 years) (Hickman, 2008). Even concentrated solar power plants require highly skilled experts to build and run, and in general are heavily subsidised, being afforded funding and tax breaks not available to regular power sources. In addition to this the power output of a solar farm is almost negligible to the energy requirements of most mining operations. As previously mentioned, Barrick's 1 MW 7,404 panel power plant in northern Nevada was built next to their 115 MW natural gas power plant, the solar plant being built largely to satisfy state legislation. Given the solar plant cost 10% of the cost of the gas plant and produces 1% of the energy, these numbers bring into question the long term sustainability of solar energy as practical and self sustaining technology. That being said, solar power technology is constantly improving and with the help of subsidies today and legislation encouraging solar energy they may be a cost effective and economic option in the future.

Biofuel

Biofuel is a term which encompasses a wide variety of fuels "derived from biomass or bio waste". These fuels can be used for any purposes, but the main use for which is in the transportation sector (Biofuel, 2010)." Biofuels offer an excellent opportunity to reduce the CO_2 and greenhouse gas emissions of almost all fossil fuel burning mining equipment, from haul trucks, to jumbos, to dozers. Biofuels have been used both underground and on surface to a wide degree of success; and are on their way to becoming a major part in the mining industry (Blades, 2010).

Biodiesel

Biodiesel is a form of diesel fuel created from vegetable oil or animal fat. The general description given of biodiesel by the national biodiesel board in the United States is: "Biodiesel is a domestic, renewable fuel for diesel engines derived from natural oils like soybean oil, and which meets the specifications of ASTM D 6751" (NBB, 2010). Biodiesel can be used in any regular diesel burning engine without modifications; it can be used either on its own or in a mixture with regular petrodiesel, referred to as a biodiesel blend (NBB, 2010). Biodiesel can be made from a variety of products and is typically made from the soya beans and rapeseed in the USA. But biodiesel is also made from mustard, flax, sunflower, palm oil, coconut and hemp throughout the world (NBB, 2010). Table 3 Biodiesel emissions (NBB, 2010). Table 3 summarises the difference in emissions produced by biodiesel and those produced by petrodiesel. Where B100 refers to 100% biodiesel and B20 refers to a mixture of 20% biodiesel and 80% petrodiesel.

Table 3 Biodiesel emissions (NBB, 2010).

AVERAGE BIODIESEL EMISSIONS COMPARED TO CONVENTIONAL DIESEL, ACCORDING TO EPA

Emission Type	B100	B20
Regulated		
Total Unburned Hydrocarbons	-67%	-20%
Carbon Monoxide	-48%	-12%
Particulate Matter	-47%	-12%
Nox	+10%	+2% to -2%
Non-Regulated		
Sulfates	-100%	-20%*
PAH (Polycyclic Aromatic Hydrocarbons)**	-80%	-13%
nPAH (nitrated PAH's)**	-90%	-50%***
Ozone potential of speciated HC	-50%	-10%

*** Estimated from B100 result**
**** Average reduction across all compounds measured**
***** 2-nitroflourine results were within test method variability**

As can be seen from the above figure, biodiesel burns significantly cleaner than its petro alternative, and operations all over the world have taken to incorporating a biodiesel blend in their machinery. Biodiesel is particularly useful in underground workings because it burns much 'cleaner' creating a safer/healthier work environment and taking strain off of the ventilation system. Figure 8 shows data taken from two underground mines examining the level elemental carbon in air. The introduction of biodiesel to the operations shows a clear reduction in elemental carbon levels (Biodiesel, 2009).

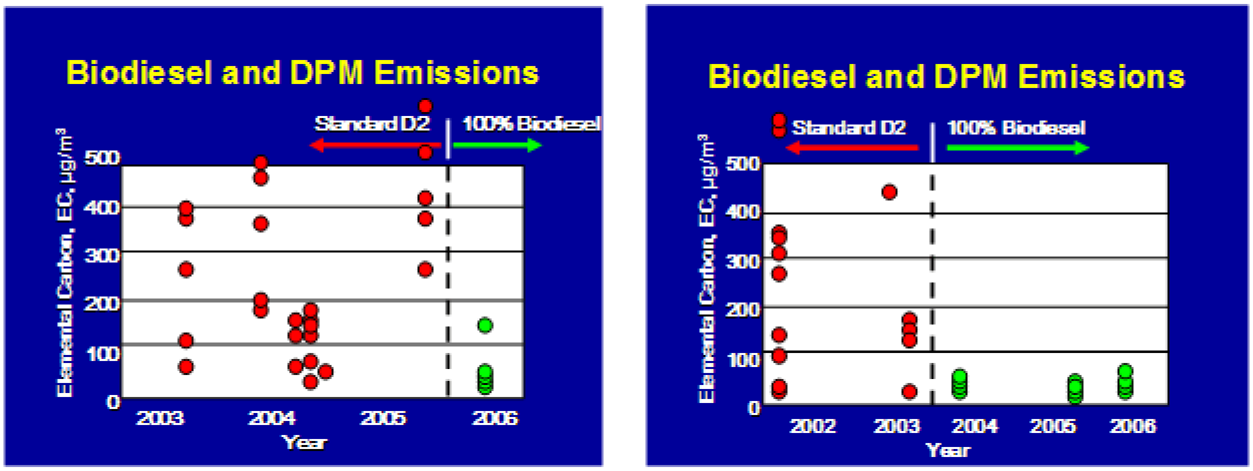


Figure 8 Elemental carbon emissions of biodiesel and diesel particulate matter (Biodiesel, 2008).

Biogasoline

Biogasoline (ethanol or butanol) is a substitute for standard fossil fuel gasoline. Both are alcohols that can be produced from biomass. Ethanol is the most common and the average automobile engine can run with up to 15% ethanol and 85% gasoline, without requiring modification. Butanol is similar to ethanol though chemically closer to gasoline. It can run most engines without any modifications but does not have as high an octane rating as ethanol; thus produces slightly higher CO_2 emissions. Alcohol based fuels do not have the same energy efficiency as gasoline and thus require more volume and a higher flow rate of fuel to do the same amount of work. Biogasoline is much more expensive than conventional fuels. On top of this given the high carbon costs of producing biofuels: heat intensive processing, farming crops, fertilising crops, pesticide production and application, transport of materials and product etc. the actual reduction in carbon footprint is very small (Biofuel, 2010). Despite this some companies are beginning to use biogas and biogas blends in their operations.

Discussion

Many mining companies are whole-heartedly embracing the advantages of biofuels in their operations. Given their low upfront costs (they work in unaltered engines) their versatility (they work a blends or in pure form) and their ease of use and implementation biofuels are one of the most effective and low risk (if they are ineffective companies can stop using them at little or no loss) renewable forms of energy available. The most important biofuel to the mining industry today is biodiesel. Just as the most important petroleum fuel is diesel, this stems from the fact that most mining equipment runs on a diesel engine, including: haul trucks, jumbos, in pit crushers, dozers, and graders to name a few. Although biogas is an important biofuel it plays a smaller role in the mining industry purely do to the limited number of gasoline engines requiring fuel. One prime example of the importance of biodiesel can be seen by again looking at Barrick Gold. Barrick has been using biodiesel in their underground operations in North America, and in their compressor controls and fuel management programmes for the last couple of years (Barrick, Environment: The Opportunities Around Us, 2010). In 2008 alone it is estimated that the use of a biodiesel blend in Barricks underground North American mines offset 4,800 tonnes of GHGs, which would have been produced with conventional petrodiesel (Barrick, Biodiesel use in North America, 2008). In 2009 Barrick burned 6,960 cubic metres of biodiesel (Barrick, Environment: the opportunity around us, 2010). Rio Tinto has also adopted the use of biofuels and in 2009 reported the consumption of 1.3 million tonnes of biodiesel and 16,000 tonnes of renewable waste fuels (Anglo, 2010). In 2009 Vale invested US $305 million to construct a biodiesel plant and purchase 41% of a raw palm oil production company. The plant is expected to produce 160,000 tonnes per year of biodiesel. The Biodiesel will be turned into a B20 blend and used in Vale's locomotives and equipment at the Carajas mines in Brazil (miningmagazine, 2010).

The largest draw back to the use of biodiesel in mining applications is the cost implications involved. Studies have found that cost is prohibitive when prices are over US $3.00 per gallon of biodiesel. When costs fall to US $1.50 per gallon, neat biodiesel was found to economic for light-duty equipment. At costs over US $ 1.50 per gallon filters tend to be a more popular option (Fruin and Tiffany, 1998). Despite these cost implications, filters are effective at filtering out particulate matter (PM) but have little effect on greenhouse gas emissions; leaving biodiesel as the most effective means of CO_2 (and PM) reduction for diesel mining equipment. As mentioned previously, this is particularly effective in underground mining where the decrease in PM and emissions takes some of the strain off of the ventilation system thereby saving electricity consumption.

Despite some benefits, biogasoline is not commonly used or seen frequently on mine sites. So much so that it has been nearly impossible to find specific example of use in the literature. This is likely to be due to the fact that gasoline requirements are significantly less then diesel requirements at most operations, in turn making the reduction of CO_2 emissions from biogas less important. That said, Russell Blades of Barrick gold commented in an interview that "Barrick was beginning to use Biogas at some of their North American operations (Blades, 2010)". This refers generally to support vehicles (ex. pickup trucks) and personnel carriers (Blades, 2010). This may imply that even though it is not publicly stated many companies may indeed be utilising biogas at their mines sites. Despite cost restrictions biofuel remains one of the most accessible and effective renewable energies available to the mining industry. As manufacturing processes become more cost effective and conventional fuel prices rise it is reasonable to expect biofuels to become an ever more popular option available to the mining industry.

Hydropower

Hydropower is electricity generated by the movement of water. It is a form of renewable energy and produces no greenhouse gas emissions (apart from those resulting from the manufacture of the equipment required). This is often accomplished with the help of strongly moving rivers, waterfalls, and tides and waves. When water is not already flowing hydroelectric dams can be used to induce motion to generate electricity. Turbines are the most common means of converting the energy in the water to electricity. Hydropower is responsible for 19% of the World's electricity supply; with China, Canada, Brazil, and the United States representing the largest consumers (EIA, 2009) (Figure 9).

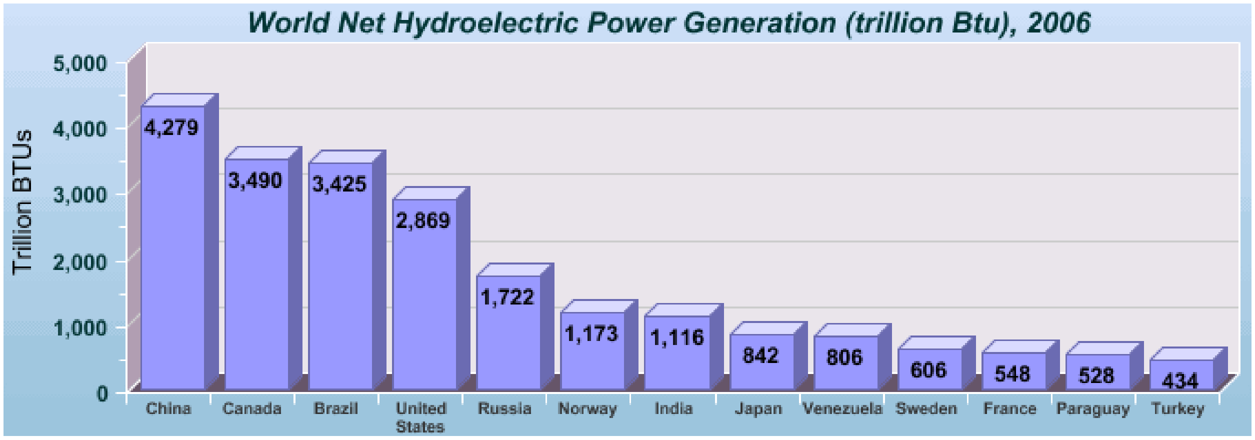


Figure 9 Global hydroelectric power consumption (EIA, 2009).

Hydropower provides unique opportunities for the mining industry. Although it is rare for a mine to be located in a position where hydropower is readily available, it is not uncommon for mining companies to build hydroelectric plants elsewhere in the region and to power their operations and surrounding communities. An excellent example of this is BHP Billiton's 2,500 MW hydropower plant near the Inga Falls on the River Congo in the DRC; which should begin construction in 2014. The plant will provide power to BHP's projects in the area as well as the surrounding area (BHP, 2010). Mining operations can also utilize small scale hydroelectric power to operate mining equipment such as drills. This is common in the deep level South African gold operations where a standing column of water (~2km deep) is used to hydraulically power the drills. This water column negates the use of compressors, known for their significant losses from pipe leakage and compressor inefficiencies (Penswick, 2010). Efficiency from hydro power is estimated to be at 28%, while efficiency from compressed air sits somewhere in the region of 2% (Cloete, 2008).

Barrick Gold has gone a step further and has begun utilising "end-of-pipe" hydroelectric power generation. The Zaldivar mine in northern Chile is capable of producing a 100 kW from a turbine being powered by the flow of tailings through a pipe on their way from the processing plant to the storage facility. This power is then redirected back into the processing plant (Blades, 2010). Unfortunately it was impossible to find more information on this process as Mr. Blades was unable to provide more detail in the interview and was not available for further questioning.

Discussion

Hydropower provides a plethora of opportunities for mining companies to produce clean electricity, free of GHG emissions. They range from the standard (such as the use of hydroelectric dams), to the innovative use of existing processes. The largest drawback of hydroelectricity is simply availability. Whilst hydro power is a cost effective, reliable, and proven renewable power source it needs a consistent water supply. While in Canada and the United Sates this is a viable option in Australia and much of Africa hydro power would be impossible. Another drawback is often the sheer scale of many hydroelectric projects. Costing up to hundreds of millions of dollars and remaining long after the life of the mine. The advantage to this is that they often provide enough power to provide for the local community and can provide an industry after the mine has closed (BHP, 2010). The next step is to combine small scale hydropower options on mine sites, that when working in unison will create significant energy savings, and CO_2 reductions.

3.2 GHG Reducing Technologies

Section 3.2 discusses existing and emerging technologies that may be used to reduce the GHG emissions of a mining operation. They range in effectiveness, cost and availability but all offer potential solutions to the problem of GHG emissions.

Natural Gas (LNG)

Natural gas is a form of fossil fuel comprised primarily of methane gas. Natural gas is used worldwide as a major source of electricity generation; in the United States alone "...energy from natural gas accounts for 24% of total energy consumed" (NaturalGas.org, 2010). Gas provides one of the lowest carbon footprints of any fossil fuel. It burns much 'cleaner' then either coal or petroleum; producing 45% less CO_2 than coal and 30% less than petroleum (NaturalGas.org, 2010). Table 4 shows a comparison of emission levels of natural gas to other fossil fuels.

Table 4 Fossil fuel emission levels comparison (NaturalGas.org, 2010).

Fossil Fuel Emission Levels
- Pounds per Billion Btu of Energy Input

Pollutant	Natural Gas	Oil	Coal
Carbon Dioxide	117,000	164,000	208,000
Carbon Monoxide	40	33	208
Nitrogen Oxides	92	448	457
Sulfur Dioxide	1	1,122	2,591
Particulates	7	84	2,744
Mercury	0.000	0.007	0.016

Because of natural gases ability to burn 'cleanly' mining companies are starting to take notice and utilise natural gas to power their operations. Barrick gold is currently involved in optimization studies to utilize natural gas at their Donlin Creek project in Alaska, which are expected to be completed in mid 2011. The use of natural gas is expected to reduce overall operating costs of the project (Barrick, Donlin Creek, 2010). Barrick also owns and operates a 115 MW natural gas generating station in western Nevada (BarrickGold, 2007). In 2008 Rio Tinto invested US $400 million in a natural gas power plant to supply energy to its iron-ore operations in Western Australia. It is estimated that the new natural gas plant will generated 25% less CO_2 emissions then the two steam power stations currently meeting the regions power needs, which accounts for an estimated savings of 200,000 tonnes per annum of GHG's (Merwe, 2008).

Natural gas is also being used in the form of liquefied natural gas (LNG). LNG is simply natural gas that has been liquefied to ensure ease of transport and storage. It is then possible to use the LNG to fuel mining equipment, most commonly haul trucks. One of the most popular LNG burning haul trucks is produced by the Canadian company Westport Innovation Inc. with their LNG system for heavy duty trucks (WestportInnovations, 2010). Westport estimate that their LNG systems reduce GHGs by 20-25% from conventional diesel engine emissions (Siuru, 2007). Serious testing of the use of LNG as a means of fuelling haul trucks for mining applications began in the early 2000's by Westport at a Newmont mine in Nevada (CMJ, 2002). Barrick Gold has started utilising LNG at many of their operations as an alternative to diesel in their haul trucks. They are currently operating fleets of haul trucks of up to 2,500 horse power (Blades, 2010). A new US $138 million LNG plant was recently built in Western Australia specifically to provide LNG to heavy duty vehicles, providing up to 157 tonnes a day of LNG (GasToday, 2007). Drawbacks of LNG is the fact that the process of converting natural gas from gaseous to liquid form is energy intensive and produces significant CO_2 emissions. It is estimated that burning LNG produces 20-40% more CO_2 then domestic natural gas (LNGpollutes, 2010).

Despite these gains in GHG emissions, Natural Gas and LNG represent a valuable opportunity for mining companies to reduce emissions. Even with added carbon costs, LNG is still much 'cleaner' then its diesel alternative. The use of LNG in haul trucks is still relatively new technology and efficiency improvements and technological gains are being made all the time. Mining companies all over the world are utilising this technology, providing significant savings in GHG emissions (Blades, 2010).

Organic Rankine Cycle (ORC)

The organic rankine cycle (ORC) is a thermodynamic process which is used to recover and recycle waste heat generated by low temperature sources such as conventional power plants or diesel engines (Quoilin and Lemort, 2010). To understand the 'organic' rankine cycle we must first understand the rankine cycle. The rankine cycle is the process by which external heat is applied to a closed loop where water (usually) is heated until a phase change occurs and steam is produced the "...superheated steam is generated in a boiler and then expanded in a steam turbines" (Cogeneration, 2010) which in turn drive a generator. The generator then produces electricity. The organic rankine process utilizes a high molecular chemical (such as Freon, butane, propane, and ammonia) in the place of water. The chemical is capable of recovering heat from 'low heat sources' such as a diesel engine and then converting this heat into useful energy, such as electricity. Figure 10 shows a typical schematic diagram of the ORC.

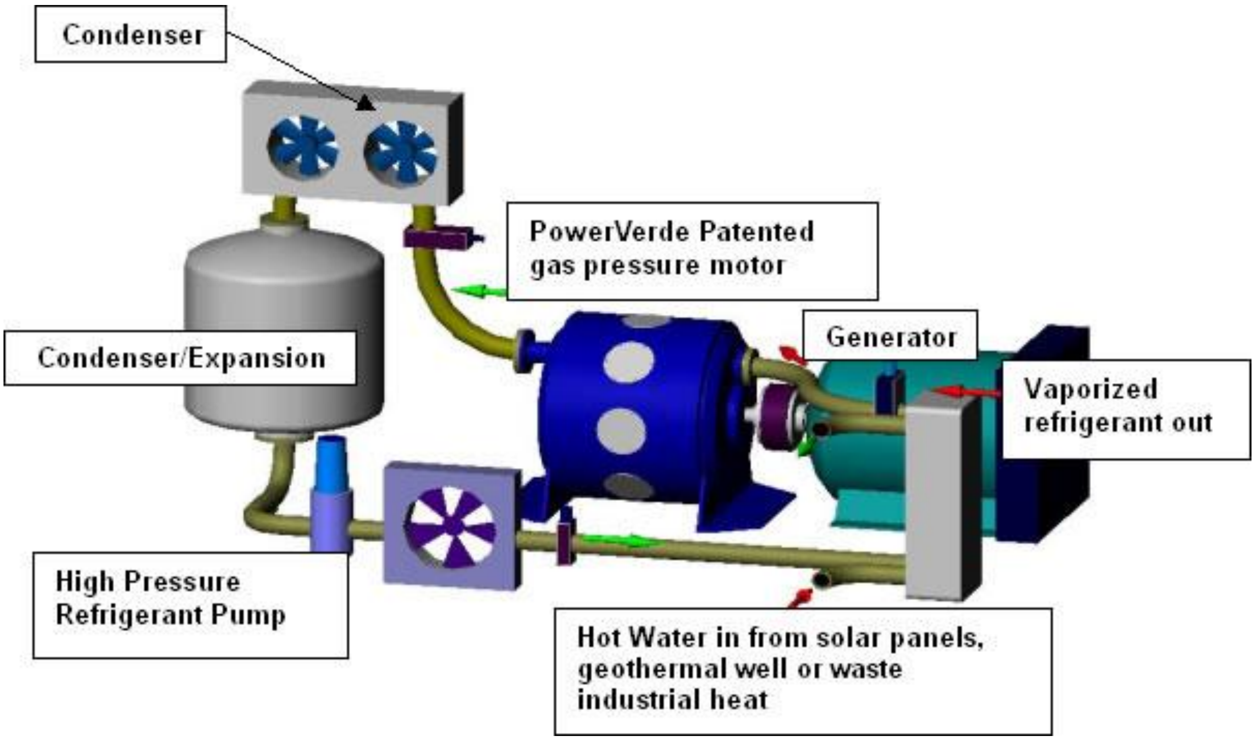


Figure 10 Organic Rankine Cycle Technology (Powerverde, 2010).

Because of the ORCs ability to be used in conjunction with various heat sources and its ability to generate local and small scale power the ORC provides an excellent opportunity for the mining industry to conserve energy and reduce GHG emissions on many fronts; thereby lowering an operations carbon footprint as well as saving money in energy costs (Quoilin and Lemort, 2010).

The ORCs ability to convert excess low temperature heat to energy means it is an ideal process for capturing and utilising the heat produced by internal combustion engines. In the mining industry this means: haul trucks, loaders, drills, dozers, and a host of other equipment. For example in “a typical 1.4 litre Spark Ignition ICE, with a thermal efficiency ranging from 15 to 32%, 1.7 to 45 kW are released through the radiator (at a temperature close to 80 - 100°C) and 4.6 to 120 kW through the exhaust gas (400 - 900°C) ” (El Chammas and Clodic, 2005). This accounts for up to 165kW of wasted energy and unnecessary GHG emissions. In the 1970’s prototypes involving a 288 horse power haul truck incorporating ORC technology were found to create a 12.5% increase in fuel efficiency (Quoilin and Lemort, 2010). Current prototypes have been able to increase engine thermal efficiency by up to 28.9-32.7% (Endo, 2007). This represents huge gains in fuel efficiency and GHG reduction. If implemented on a fleet of 250 tonne haul trucks it could also represent enormous financial savings each year. Although this technology is still in the experimental/prototype stage, mining companies are investigating the potential of incorporating ORC technology with diesel haul trucks says Russell Blades sustainability manager at Barrick Gold’s Toronto based head office (Blades, 2010). In 2009, BMW found that the use of an ORC system can increase power output by 10% on a four cylinder engine. Honda, for example, has found that by incorporating ORC technology into their hybrid cars they are able to improve thermal efficiency of their engines by 3.8%. On top of this, researchers at Loughborough University and the University of Sussex have found increases of 6.3% to 31.7% in fuel efficiency when using ORC systems in light-duty vehicles (GCC, 2009). This technology contains enormous potential for mining companies, with the thousands of litres of fuel being consumed each year by mine support vehicles (pickup trucks, personnel carriers etc.). Add to this the fact that the typical 200+ tonne diesel mining haul truck gives off significantly more heat than a standard vehicle, the economic benefits, as well as the potential reduction in GHG emissions, could be substantial. Further research is required to fully understand how this technology can be adapted to operate in the demanding conditions of a mining environment, however, the potential for both energy conservation and carbon footprint reduction is prolific using this type of technology. With companies like Barrick leading these changes it is very possible we will see the technology adapted to the rigors of the mining industry in the near future.

In addition to its ability to optimise the performance of combustion engines the Organic Rankine Cycle technology has potential for large scale applications. As ORC can be utilised with almost any heat generating process this opens up a wide range of potential opportunities at any given mining operation. ORC has been used successfully in conjunction with conventional power plants such as coal and gas, as well as renewable power sources such as solar farms. ORC also represents a significant opportunity to increase the energy efficiency and reduce the carbon footprint of mineral processing plants, given the energy intensive process of mineral liberation.

In recent decades the ORC has gained increasing popularity as a means of energy conservation within conventional power plants. ORC has been employed on plants ranging in size from 300 kW to 130 MW. One such example is the 6.5 MW Gold Creek power plant in Alberta Canada. The plant was built in 1999 and utilises ORC technology. As a result $C0_2$ emissions are reduced by 25,000 tons per year. Clearly it is not a stretch of the imagination to conclude that this technology could be successfully applied to many of the diesel, natural gas or coal power plants currently being used to power mining projects around the globe. Another example of successful large scale application of ORC technology being the 1.5 MW Heidelberger Zement AG Plant in Lengurt, Germany. The ORC technology in this cement plant reduces CO_2 emissions by 7,000 tons a year (Bronicki, 2009). ORC technology has been employed to recover heat lost throughout the plant both by means of power production and other stages in the cement making process. This makes an excellent comparison to the mineral liberation processes. With the access heat produced via crushing, grinding, and heap leaching, etc there is ample opportunity to employ ORC technology within mineral processing plants.

In addition to its popularity in conventional power plants, ORC technology has become a popular component in renewable energies such as geothermal energy, and biogas generation plants (Schuster *et al*., 2007). As both of these forms of power are becoming more and more important to the mining industry, by reducing their energy needs the carbon footprint of the mining industry is in turn being reduced. The Neustadt-Glewe geothermal plant in Germany uses the ORC process to convert geothermal heated waters of 98^0 C to 210 kW of electricity (Schuster *et al*., 2007). It is estimated that there are "approximately 600 MW of geothermal power plants using this (ORC technology have been installed in 18 countries". ORC modules ranging in power from 1 to 30 MW have been installed in over 40 geothermal power plants, such as a 125 MW geothermal power plant in the Philippines (Bronicki, 2009). ORC also has significant potential of being utilised within biogas plants. Due to the substantial amount of waste heat generated in the biodiesel production processes ORC technology offers an opportunity to help improve the feasibility of biogas as a potential alternative fuel source. The incorporation of the ORC could save significant amounts of energy and help ensure that heavily subsidised biogas plants as economically sustainable. Thus benefiting the mining industry, and reducing carbon footprint (Schuster *et al*., 2007).

3.3 Optimization

In any mining project, the company has a range of choices to make from mining method, open pit or underground, shaft or ramp, and a variety of other choices. Each choice will impact on recovery, costs, timeline, and the environment.

3.3.1 Haul Ramp vs. Shaft (underground)

The pros and cons of haul ramps vs. shafts in underground mining is a heavily debated subject within the mining industry. Both have benefits and draw backs in terms of costs, efficiency, safety and environmental impact. Whilst shafts appear to be more prevalent in North America, haul ramps dominant underground mining in Australia. Whilst numerous studies have been completed which take into account depth, grade, deposit type, gradient, and fuel costs versus electricity costs the main focus tends to be economic benefits of the design. Whilst safety issues play a part, there seems to be little consideration of the environmental effect of the decision, in particular the carbon footprint. This could be because it is yet to be considered an important issue in the decision or alternatively because it seems quite obvious. The shaft appear the ideal choice (in terms of CO_2 output) as an electric hoist would emit considerably less CO_2 than a fleet of diesel engine haul trucks; it would also place significantly less pressure on the ventilation system. That said if the mine is in a country like South Africa, or Romania, that is heavily reliant on coal fuelled power plants to produce electricity the overall reduction in carbon footprint could less then imagined. In addition to this it may be found that the haul trucks are able to deliver the material far more efficiently and in less time and few loads meaning the mine will spend shorter time in production; drastically lowering carbon footprint. While generalities do exist (ex. Shafts produce less carbon emissions) it is necessary to explore the merits of both systems on a case-by-case basis. Currently no literature exists on the issue and in-the-field research into this problem is beyond the scope of this study. It is the author's recommendation that further research need be accomplished in this area before conclusive statements regarding the carbon footprint optimization of the ramp vs. shaft comparison can be made.

3.3.2 Truck vs. Conveyor

The comparison of the carbon emissions of haul trucks to mine conveyor systems is similar to that of ramps to shafts. A conveyor system is clearly a significantly 'cleaner' transport method in terms or emissions. This again comes down to the fact that conveyors are typically powered by electricity as opposed to the diesel of haul trucks. In addition to this, conveyors will significantly decrease the distance the ore has to travel, owing to the fact that conveyors take the ore in a relatively straight line as opposed the switchback roads the trucks are forced to follow. In South Africa's Palabora mine the implementation of an in pit crusher with a conveyor was able to reduce hauling distance by 4km (one way) (Penswick, 2010). Needless to say, this represents an enormous reduction of diesel consumption, replaced instead with electrical power. It must be noted again, however, that this occurred in South Africa in the 1990's where electricity is generated via burning coal, thus producing significant amounts of GHG emissions.

Figure 11 demonstrates the power consumption of a 5.2 km conveyor located in Germany, designed by Conveyor Dynamics Inc, based on throughput in tonnes per hour.

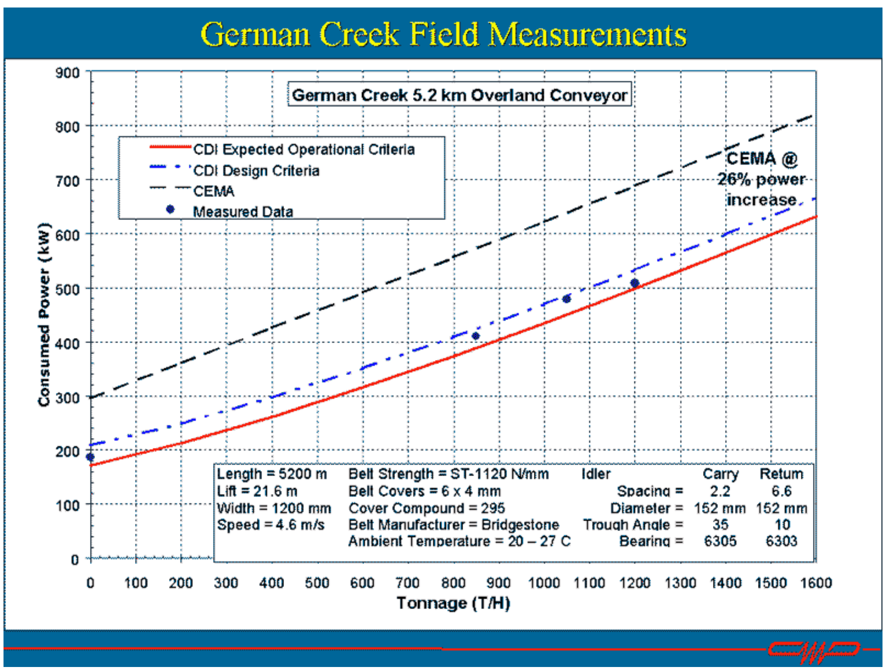


Figure 11 Conveyor power consumption (Nordell, 2010).

In order to deliver 1200 tonnes per hour of ore this would take nearly 6 haul trucks travelling the 5.2 km at 14 km/h to do the same work as the conveyor has. In reality, it would take longer than this as these simple calculations do not take into account such aspects as: slower travel on grade, longer distances of travel (due to switch backs), trucks not always carrying full loads, inexperienced drivers, bad weather conditions, refuelling and maintenance delays, delays due to shift changes and loading/dumping times. Assuming the truck is burning 100 gallons per hour when fully loaded on grade (Hutnyak, 2004) (and this accounts for 70% of the travel time) and 50 gallons per hour on the return journey than nearly 446 gallons of diesel will be consumed per hour of operation. This would result in a total of 5.47 tonnes of CO_2 emitted per hour. The conveyor belt on the other hand will consume just over 500 kW to deliver 1200 tonnes per hour. This would result in just 425 kg of CO_2 emission for a coal power plant, 295 kg for an oil power plant, and 185 kg for a natural gas plant. Assuming: "Existing coal-fired power stations emit around 850kg of CO2/MWh; oil-fired stations emit 590kg/MWh and gas stations give out 370kg/MWh" (Jha and Macalister, 2008).

As can be seen from the example above, the use of a conveyor system represents a significant savings in energy consumption and CO_2 emissions. Not only are hauling distances shorter with the use of a conveyor system, the speed with which a conveyor can deliver the ore (tested at up to 1200 tonnes per hour) would require a significant fleet of haul trucks working around the clock. The millions of gallons of diesel saved per year represent a significant reduction in CO_2 emissions. However, there are many other factors to be considered when deciding to use a conveyor system of haul trucks. Conveyors represent at significant upfront investment for any operations and are usually only justifiable in large scale projects. There are a host of maintenance and technological costs associated with a conveyor. And unlike haul trucks if the conveyor malfunctions it can shut down the entire operation for a significant period of time. Conveyors are also only really favourable in warm dry climates. Excessive cold or precipitation makes it difficult or impossible to employ a conveyor system (ex. Canada, Romania, Scandinavia, etc.). Whilst a conveyor system can offer an operation a significant reduction in carbon footprint, this is only one of many factors that must be considered and unfortunately usually one of the less urgent.

3.4 In-Pit Crushing and Conveying

3.4.1 Introduction

This section is the study on applying the in-pit crushing and conveying system (IPCC) into a mine as the reduction strategy for reducing CO2 emissions. The background of the system will be introduced together with the advantages and disadvantages.

Material transportation significantly affects the capital and operating costs. A conventional truck haulage system is the most common in open-pit mining due to its reliability and flexibility. The haulage cost can be up to 50% of total mining costs (International Mining, 2011). The cost depends on fuel, tyre, labour and maintenance expenditures. With the rising fuel prices and environmental responsibilities being highlighted, in-pit crushing and conveying are considered to have great advantages in terms of fuel savings and CO2 (CO_2) emissions (Parker, 2008).

How it works

An in-pit crushing and conveying system consists of the crusher near the mine face in the pit, accompanied by belt conveyors that transport the crushed materials to their destination out of the pit. The crushing unit can be jaw gyratory, gyratory, hammer, impact, roll, and jaw crushers. The systems are classified by their mobility capabilities that range from fully mobile crushers to fixed crushers. The fixed crushers have low mobility while the fully mobile crushers are mounted on a frame base, allowing the unit to be moved by a transporter, such as a crawler system or a walking mechanism. The units rest on the bearings and mechanics so maintenance cost is the highest of the other in-pit crushers and the lowest in availability (Parker, 2008). Lastly, semi-mobile crushers stand on the ground closer to the mine face. The relocation takes a few days, in which the operation is completely stopped. This makes them a popular choice in terms of the cost-benefit ratio (Parker, 2008).

The in-pit crushers are fed by typical excavator-truck fleet with the short haulage distance that gradually increases from the mining face. The moveable crushers, with their ability to move the crusher along the mining face, can be fed directly by the excavator. A crawler-mounted lifting device is used, to move the components to a new position in the pit. (Table 5)

Table 5 Comparison of in-pit crusher systems (Tutton and Streck, 2009)

Feature	Fixed	Semi-fixed	Relocatable	Moveable
Capacity	High	High	Medium	Medium-low
Typical crusher	Gyratory / Jaw	Gyratory / Jaw	Twin roll crushers or sizes	Twin roll crushers or sizes
Relocating	Rarely relocated	Every 3-5 year	Every 6-18 months	Often relocate to follow the shovel
Common feature	Associated with transport tunnel	Associated with transport tunnel or wide truck ramp	Multiple crushing stations with conveyor ramps and conveyor distribution point	Feed onto bench conveyor or conveyor bridge

During the design phase, a number of factors are to be considered to install the in-pit crushing system, including the rigidity of the conveyors, the layout of the infrastructure and electricity, energy required, the width of the haul road and traffic management and the mine layout. Relocation of the system also needs some considerations, such as the relocation of the ramp, bridge, ground compaction and power lines that need moving.

Advantages – disadvantages

The advantages of truck haulage system are that they are flexible and manoeuvrable (Hartman and Mutmansky, 2002). They have moderate gradeability and can handle coarse or blocky rock. On the other hand, trucks require good haul roads, high operating cost and they are slowed by bad weather. The advantages of belt conveyor systems are that they can deliver high and continuous output with very good gradeability and low operating cost. This study also noted that the belt conveyor systems help reducing the labour requirement have better operational system safety and more environmentally friendly than trucks. However, they require a high investment cost. Furthermore the conveyors are inflexible and limited only to carrying small or crushed rock. Crushing is required to limit the maximum lump size for conveyor transportation of hard rock even if it is not needed later, (for example, waste material) and this could increase crushing costs and CO_2 emissions.

The “rule of thumb” by McIntosh Engineering states that the belt operation is more economical than truck haulage if the conveying distance is further than 1 km. While beyond 1 km distance, CEMA handbook states that the weight-distance cost of transportation by belt conveyor may be as low as one tenth of cost by haul truck. Trucks also tend to be empty on the return journey (Yardley and Stace, 2008). Furthermore only 40% of the energy consumed is expended hauling material. The remainder is employed hauling the truck itself while the conveyors consume some 80% of the energy delivering the payload. In addition, energy consumption for truck is 3 times greater than for conveyors on the level and up to 8 times greater lifting the payload out of the pit.

Table 6 Comparison of truck haulage and in-pit crushing units

	Truck haulage	In-pit crushing and conveyor
Flexibility	Flexible	Inflexible
Size	Possible for coarse rock	Limited size to crushed rock
Gradeability	Moderate gradeability	Ability to operate over a range of grades
Operating and maintenance cost	Higher	Lower
Initial investment cost	Lower in most cases	High
Power	Mostly fuel	Mostly electricity

Environmental benefits also include reducing of pollution because the conveyor can be housed in enclosures retaining dust and noise. Since fewer trucks are required, the belt conveyors use less fuel and most importantly, produce lower CO2 emissions (Table 6).

However, a study that evaluated belt conveyor and truck haulage systems in an open pit mine using life cycle assessment showed an unexpected result in terms of environmental impact. The study was conducted using a hypothetical hard rock gold mine in Canada with the transport distance of waste and ore of 4 and 15 km respectively. The results show that, for 4,000 tph, the conveyor has 2,820 kg CO_{2e} per functional unit, compared to 648 kg for the truck option. It is to be noted that the study included the production and transportation of oil and electricity (coal-fired power plant) in addition to the operation of the mine site (Awuah-Offei *et al*., 2009).

3.4.2 Recent projects

IPCC are widely used in the continuous loading such as bucket wheel excavator as well as in the lateral and unconsolidated deposits with wide benches such as coal and oil sand and most of projects that can be found are in the coal mines. Schröder (2003) suggests that it is not profitable to dig homogenous material with discontinuously working excavators, and that type of material is best dug by continuously working excavators.

This study focuses on the IPCC in the gold mine case studies. The section will represent the projects related to IPCC in open-pit mines that develop vertically. This is known as the case of large open pit mines which can be found, for instance, in iron ore, copper and gold mines. The main challenges for consideration are hard rock, deep pit, phase or push back development, narrow bench width, impact of blasting and flexibility where waste and ore deposit in the same bench and the materials go the a number of destinations. Furthermore, it is also necessary to consider the fully mobile unit or the semi mobile unit. In hard rock and stone mining, there is little possibility of hauling by conveyor without preliminary sizing. Therefore the UK hard rock quarries employ blasting and out-of-pit primary stage crushing, off-highway trucks with a degree of flexibility far in excess of fixed position belt conveyors, truck still predominate(Yardley and Stace, 2008). However there is a successful example in a hard rock mine at Midland Quarry Products Cliffe Hill granite quarries in Leicestershire, UK. The quarries conveyed its rock 1.44 km from the semi-mobile primary crusher at the old site through a 713 m long tunnel to the new plant at up to 2500 tonne per hour (Yardley and Stace, 2008). This example points out that material has to be crushed before transported by belt conveyor which means waste rocks also needs to be crushed using this system. In the gold mines, for example, where the stripping ratio is relatively high, this factor needs to be considered.

In a recent project, CITIC Pacific Mining, a large iron project has installed four in-pit crushers from ThyssenKrupp, each with the capacity of 4,250 tonnes of magnetite iron ore per hour. The systems are powered electrically and moved by crawler units (CITIC Pacific Mining, 2010). There is also information that in China, conveyor belt systems in opencast iron ore mines are becoming popular especially in large open pits of more than 100 m deep (SBM, 2011).

Figure 12 Example of IPCC in large open-pit mines. a and b (Tutton and Streck, 2009), are from Chuquicamata mine in Chile with a steep conveyor. C is Escondida mine, Chile (Schröder, 2003) and d is Highland Valley Copper in Canada.

Some open pit copper mines use IPCC (Figure 12). However, these crushers were in fixed locations with relocation on a project basis. This can be regarded as the vertical in-pit conveyor and also Chuquicamata mine is the example for the waste crusher in hard rock open pit mines (Tutton and Streck, 2009).

A case study of a semi-mobile crusher in copper mine from ThyssenKrupp shows that the system has 8,000 tph capacity (40 million tpa) and a short truck haul. With an average distance of 0.75 km and a depth up to 600 m, CO2 reduction compared with a truck system would be 150,000 tpa (Tutton and Streck, 2009).

For a fully mobile system, Tutton and Willibald (Tutton and Streck, 2009), stated that the relocatable systems are not common in deep hard rock mines as well as to date (2009), no fully mobile systems in large scale, hard rock mines yet. The comments from Dave Tutton can also be found in the International Mining magazine, May 2011 (International Mining, 2011), that the IPCC for large open pit copper and gold mines will require more flexible systems and the ability to accommodate them within the mine plan without significantly impacting the metal and waste schedules. The systems are currently still being examined.

The study of replacing trucks by fully mobile crusher and conveyors in Carajas, the largest open pit iron ore mine in Brazil claimed to be the first metalliferous, deep open pit operation in the world to consider a fully mobile system. The system was designed to have two fully mobile crushing plants with a capacity of 3,900 tons/hour each for waste. The result was feasible and the system would replace 15 haul trucks. For the ore, three units of fully mobile crushers at 2,000 tons per hour each would be applied. The system would replace four trucks. CO2 reduction accounts for up to 133,000 tons per year (Lúcio *et al*., 2009).

There are some general statements for the IPCC system listed by Sandvik for basic overview of the system feasibility before the detail study (International Mining, 2009):

- Mine life: at least 4 years to pay back capital and more than 10 years is ideal
- Tonnage: at least 10 Mtpa per stage and 25 Mtpa is preferred
- Energy cost: electricity costs per kWh less than 25% of diesel price per litre
- Space for operation: at least 100 m is needed
- Rock strengths: up to 150 MPa
- Gravity: conveyors can generate power on downhill runs
- Truck cycle times: IPCC may not work well below 25 minutes cycle times

3.5 Load and haul fleets efficiency

Mining heavy equipment, especially haulage fleets, consume large volume of fuel as presented in chapter 3. Only slightly saving results in significant volume of fuel used. Energy efficiency plays a vital role in fuel saving and CO_2 emissions.

In Australia, mining operations have to conduct the energy mass balance (EMB) to meet the requirements of the Energy Efficiency Opportunities (EEO) program, as detailed in the EEO legislation. The aim of the EMB is to improve understanding of the overall energy system and to provide insights into potential energy efficiency opportunities. The key requirements include the data collection process, the energy analysis process and a comparison of performance to theoretical and actual energy use. For electricity and gas consumption, the scope for error margins should be within ± 5% from billing data and larger for some energy and mass flows that cannot be accurately measured (The Energy Efficiency Opportunities, 2010).

In this study, energy efficiency of haulage fleet is conducted to identify potential opportunities on saving fuel resulting in CO_2 emissions. Comparisons of performance of theoretical and actual fuel use are estimated in some cases.

Cycle time analysis

Cycle time consists of the time to complete one cycle of operation including loading, hauling, dumping and returning to the operation area. The cycle time changes depends on the changing of working face, distance, material, haul road conditions and excavating conditions. The optimum matching fleet can be estimated from the points that truck capacity should be approximately four times of excavator bucket capacity at minimum and it should not exceed 6-8 times at maximum (Ekka, 1989).

Loading and hauling account for a large proportion of total fuel consumption in open pit mine as presented in chapter 3. Idling trucks lower production and waste fuel so match time of equipment is important. A way to reduce emissions from fuel usage is to improve the mining fleet efficiency. This can be done using cycle time analysis. In this section, actual cycle time from field observed was used. Potential production can be calculated from truck and excavator time.

Haul road condition

An important measure of haul road surface conditions is the rolling resistance. Rolling resistance is the force needed to maintain the forward movement of a truck or the energy lost from tyre penetration. Rolling resistance affects wear and tear on the truck, reduces fleet productivity, and increases fuel consumption (Tannant and Regensburg, 2001) (Figure 13).

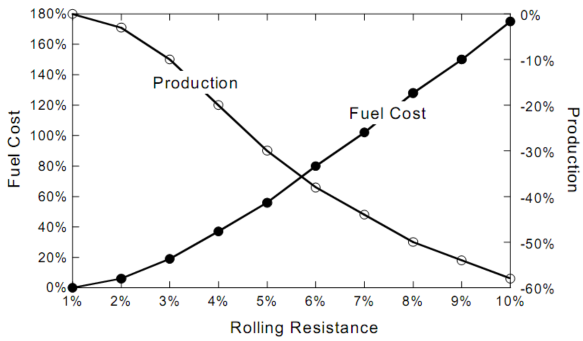


Figure 13 Rolling Resistance versus performance (Tannant and Regensburg, 2001).

A study on CAT 777 operating on a 7.3 km 7% incline, decreased rolling resistance from 8% to 4% would reduce capital cost by 29% and operating cost by 23% for 5 million tons per annum rate (Thompson and Visser, 2003). Another analysis on rolling resistance highlights that for CAT793, if rolling resistance increased from 6% to 15%, the truck has to change from 5^{th} gear at 35 km/hr to 4^{th} gear at 20km/hr or lower. This means the truck will consume more fuel to travel the same distance (Tannant and Regensburg, 2001). In this section, the study on effect of Rolling Resistance on CO_2 emissions was conducted. This section used the data from Truck handbook cycle time comparison section (Case A, CAT777) and different Total Resistances were applied. This analysis was conducted on 3.6 million tonnes at 46.2 l/h fuel burn rate. Given 2,883 m one-way haul distance on surface ground, assuming grade resistance equal to zero (flat surface), and 7.4 minutes of loading, dumping and waiting time. Rolling Resistance from 4% (good road) to 10% (poor road) was applied. Total truck travel time ranges from 8.3 to 19.2 minutes (Table 7).

Table 7 Effect of total Resistance on fuel consumption and CO_2 emissions.

Total Resistance	4%	6%	8%	10%	
Truck cycle time	15.6	18.7	22.4	26.6	mins
Potential production	345	288	241	203	tph
Potential hour	10,518	12,602	15,057	17,882	hour
Fuel used	485,921	582,235	695,637	826,127	litre
CO_2 produced	1,237	1,483	1,772	2,104	t CO_2
CO_2 produced	0%	20%	43%	70%	

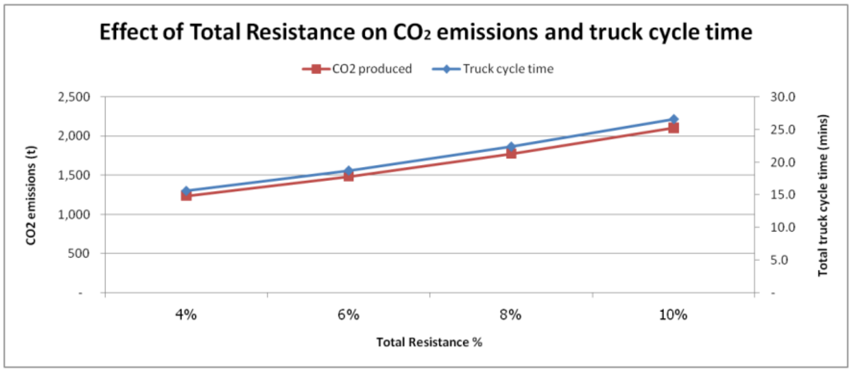


Figure 14 Effect of Total Resistance on CO_2 emissions and truck cycle time

Increased Total Resistance results in increased cycle time and has a negative effect on fuel consumption and CO_2 emissions (Figure 14). If Rolling Resistance increased from 4% to 10%, CO_2 emissions, at the same rate as truck cycle time, increases by 70%.

Engine load

Another factor that control fuel consumption is engine load factor which determines the portion of full power required to operate the machine. Low engine load also means low fuel burn rate. To simplify, loaded journey uses more power than empty journey and travelling uphill needs more power than downhill. Estimation of engine load factor and fuel consumption can be found in the performance handbook. Load factor guide from Caterpillar are as listed (Table 8).

Table 8 Load factor guide (Caterpillar, 2007)

Engine load factor	Operation at gross weight	Haul roads	Overloading	Load factor
Low (20%-30%)	An average gross weight less than recommended.	Excellent	No overloading	Low
Medium (30%-40%)	An average gross weight approaching recommended.	Good	Minimal overloading	Moderate
High (40%-50%)	At or above maximum recommended gross weight	Poor	Overloading	High

According to Runge (1998), fuel consumption can be determined from the following equation (Kecojevic and Komljenovic, 2011):

Fuel consumption (L/hr) = Engine power (kW) x 0.3 x Load Factor

Payload management

Gross weight of truck has large influence on fuel consumption. For example machine weight and payload are needed to determine maximum speed attainable, gear range and available rimpull using the Rimpull-Speed-Gradeability curve. The Australian

Energy Efficiency Opportunities guidance presented the effect of payload to fuel consumption for CAT789C truck as seen alább (Figure 15).

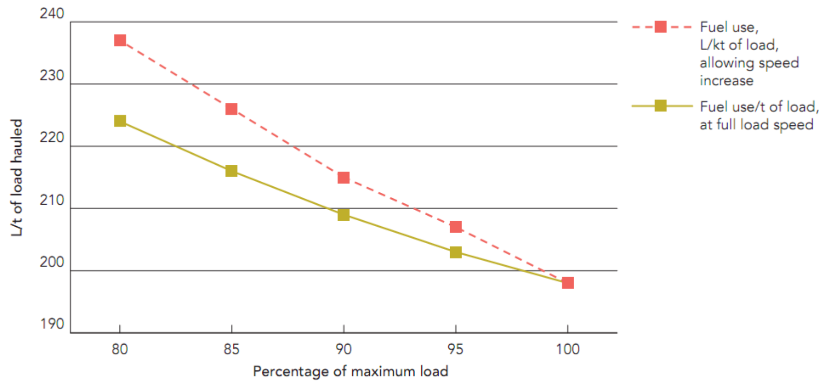


Figure 15 Sensitivity analysis: Effect of velocity constraints on fuel intensity (The Energy Efficiency Opportunities, 2010)

Fuel consumption per tonne is at its lowest when the truck is fully loaded and increases as payload decreases. Reducing load to 80% of maximum can increase fuel consumption rate by 20%.

Caterpillar also mentioned that for its 793F electric truck which is heavier than its mechanical one consumes more fuel and has higher emissions (Jamasmie, 2010). At Blair Athol, Rio Tinto; dragline's electric motors were upgraded, and bucket and rigging weights were decreased. This improvement saved 4,300 tonnes $CO_{2\text{-}e}$ emissions per year (Queensland Resources Council, 2010). Moreover, Thiess has identified potential of CO_2 reduction from improvement of payload management in several coal mines in Queensland. It argued that this has the potential to reduce up to 8,200 tonnes $CO_{2\text{-}e}$ emissions per year (Queensland Resources Council, 2010).

Operational practice

Equipment operating practices can sometimes provide greater fuel efficiency benefits than improved engine technologies. For example, equipment operator training could yield energy savings of about 10% (The Energy Efficiency Opportunities, 2010). Some examples of fuel efficiency from operating behavior are listed as follows.

Driving behaviour

A recent study recorded fuel consumption and engine speed during the dumping cycle of seventy two 240-ton haul trucks and found thatt fluctuation in fuel consumption was explained by the observation that the operator pushed the accelerator pedal while dumping (Modular Mining Systems, 2010). This raised the engine speed from 1500 rpm to the excess of 1900 rpm. However the dumping time was not affected by the engine speed and this behaviour consumed 80% more fuel. Theoretical fuel savings estimation associated with solving excessive engine speed was conducted across a range of 30 to 100% of total loads. Fuel savings were 83,000 – 275,000 litres per year or up to 736 t CO_2 (Modular Mining Systems, 2010).

Excavator operating

Proper excavator operating position provides efficient digging. Suggested positions from the machine handbook should be considered. Ideal operating positions for Caterpillar series 300 are provided for a clear idea, as listed (Caterpillar, 2007).

1. Bench height and truck distance should equal to stick length for consolidated materials and less for unconsolidated material. And the truck body rail is below the boom stick hinge pin.
2. Figure **16 Recommended excavator and truck operating position**
3. , a)
4. Optimum work zone and swing angle should be limited to 15° either side of machine center or about equal to undercarriage width. Trucks should be positioned as close as possible to machine centreline. (
5. Figure **16 Recommended excavator and truck operating position**
6. , b)
7. Distance from the edge, for the best breakout force and time saving, should be that the stick is vertical when the bucket reaches full load. And the operator should begin boom-up when the bucket is 75% of the way through the curl cycle, as the stick nears the vertical position. (
8. Figure **16 Recommended excavator and truck operating position**
9. , c)
10.

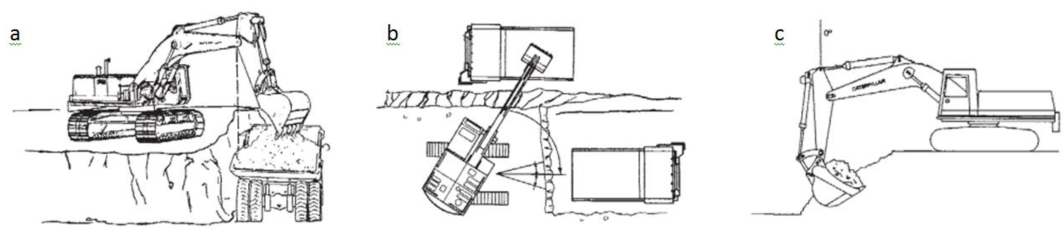


Figure 16 Recommended excavator and truck operating position

Sammut, Komatsu Germany, argues that the correct position with the excavator on the higher level with the bucket raking up the face and a low swing angle (20º to 30º) can result in cycle time as low as 20-23 seconds. While if the truck is on higher level the efficient drops as the shovel operator has to load the bucket and swing and lift to load the truck. Moreover, double-side loading proved to be a more productive because the excavator does not have to wait for trucks (Fiscor, 2010) (Figure 17).

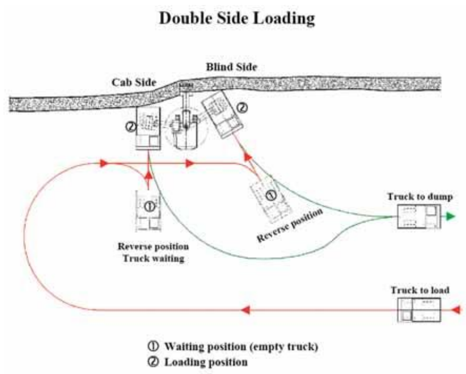


Figure 17 Double side loading of excavator and trucks

Operators' training is important to operational efficiency of the equipment. Ahrenkiel, manager of technical applications, Terex Mining, mentioned that a gain in cycle time is possible but if the operators are not trained properly then all the effort is wasted(Fiscor, 2010). Downer EDI Mining has implemented improved use of haul trucks, operator training and improved fuel-use efficiency. It presented that this reduced fuel use 3.9% per annum. It also argued that, the use of mining-equipment operator-training simulators to teach techniques for maximising fuel efficiency will reduce 940 tonnes of GHG per year across sites the company operates in 2009 (Queensland Resources Council, 2010). In 2010 operator training in equipment simulators saved 5,728 GJ (Queensland Resources Council, 2011) or about 400 tonnes $CO_{2\text{-}e}$ emissions. Using fuel consumption data gathered from operator training using Caterpillar's Electronic Technician software, it was shown that this training can reduce fuel consumption by 5%-9% and thus save 15 – 26 t CO_2 per year (Antunovic, 2009).

Trolley Assist

Trolley assist is a technology used in conjunction with diesel electric haul trucks providing an alternative power source for diesel-fueled haul trucks. Trolley assisted hauling or a trolley truck is a method of incorporating a diesel electric mine haul truck with an electric overhead wire system to assist in the truck's power supply. It was developed during the energy crisis in 1980s to minimise diesel fuel consumption (Koellner, 2008). The system consists of electricaloverhead lines connected to the haul trucks in order to power them along the designated route, usuallyy anuphill ramp. The diesel engine will be temporarily idled. The power available for the traction motors is greatly increased and so is the speed (Koellner *et al*., 2004). The speed of the trucks, on grade, is limited by the quantity of electricity which the truck's diesel engine can generate. Trucks with trolley assist collect electricity from overhead conductors, so the speed of the truck on grade is limited by the electrical drive system and size of the motors and not by the size of the truck's engine (Hutnyak, 2004). In other words, this electric power gives an additional boost to the haul truck allowing it to increase speeds and carry more tonnage, in turn increasing the overall efficiency of the truck (Penswick, 2010). One clear example of the increase in efficiency is the significant reduction in cycle time. If the cycle time is reduced by 20%, 32 trucks on trolley produce the same as 40 trucks on diesel" (Siemens, 2010). This system can provide a more efficient operation with a reduced carbon footprint. Siemens (2010) report that their trolley-assist technology can reduce fuel burn during haulage by as much as 80%. In addition to this, trolley assisted hauling can be economically beneficial expensive diesel fuel is being substituted for cheaper electricity (Hutnyak, 2004). Siemens and Komastsu are the only manufacturers of mining trolley-assist trucks however Liebherr, Caterpillar and Hitatchi are undertaking research into trolley-assist technologies with plans to manufacture trolley-assist trucks in 2012.

There are numerous factors to consider before a trolley assist system can be integrated into a mining environment. The mine is most likely to be open pit and is usually a very large-scale operation. Trolley assist can either be used as a high voltage direct trolley, where the truck is almost entirely powdered by the electric lines, or it can be used as a low voltage diesel boost operation where the electric power works with the diesel engine (Siemens, 2010). Trolley assist is most useful on steep uphill grades where it is estimated that 70-80% of total fuel consumption (Siemens, 2010) and the greatest speed reduction occurs. An increase in electric power (and therefore speed) will improve the overall efficiency of the operation. Because of the significant upfront costs of the trolley system, the project must be of sufficient tonnage and have substantial hauling costs (fuel, maintenance, etc) to warrant the technology. Under favourable circumstances trolley assisted hauling is expected to increase energy savings, extend component life, decrease maintenance requirements, reduce fuel costs and increase operational productivity (Hutnyak, 2004).

An excellent case study for the use of the trolley assist system is Barrick Gold's Goldstrike property in Northern Nevada, which at the time was North America's largest gold mining operation; with gold production exceeding two million ounces per year (1996) at an estimated rate of 410,000 tonnes of ore per day. Gold Strike implemented a trolley assist system, with great success between the years 1994 to 2001. At its height, the Barrick trolley system consisted of seventy five 190 tonne haul trucks and 4.5 miles of trolley lines. The lines were implemented primarily in steeply graded areas where they could provide the greatest benefit. In areas of 8% gradient the trolley assisted trucks were running 80% faster than they were with conventional diesel electric engines. This allowed Barrick to design the mine with steeper and fewer ramps, as well as fewer trucks than would have been required without the trolley system. In addition to this, when the trucks were using the trolley system fuel consumption was cut from 100 gallons per hour down to 7.5 gallons per hour, this represented a 50% reduction in mines fuel consumption, saving Barrick millions of tons of diesel fuel each year. In addition to the enormous economic benefits of the system the reduction in carbon footprint of the Goldstrike project was immense (Hutnyak, 2004).

In addition to the Goldstrike project trolley assist systems have been successfully installed all around the globe. One of the most well known uses of the trolley system is at the Palabora mine in South Africa (upon which the Goldstrike design was based). The Palabora trolley system ran successfully between 1980-2001 and accommodated up to 26 vehicles incorporating haul trucks (170 tonnes), water trucks, and fuel trucks. Similar savings were found at Palabora as Goldstrike (Hutnyak, 2004). It is important to note that in order to employ trolley assisted hauling economically, certain conditions must be present The electricity consumption of the Trolley Assist will also account for carbon output. In the case of Palabora, all South African electricity is generated via burning coal (Penswick, 2010), the carbon output of a coal furnace will be significantly higher (~45%) than Barrick's natural gas and solar power plants currently supplying its operations in Northern Nevada (Barrick, Environment: The Opportunities Around Us, 2010).

Electric drive trucks

The electric drive transmission includes a diesel engine connected to an electrical generator which creates electricity to power electric traction motors. The system eliminates the complex mechanical transmission system hence reduces the wear rate and maintenance brakes. However the electrically driven wheels still power by diesel. Electric drive trucks are claimed to have advantages over the mechanical drive trucks on higher speed and gradeability, higher availability and better safety (Koellner *et al*., 2004). However, Caterpillar states that with it's the 793F electric unit is heavier than the mechanical unit. Although its speed is 5 km/h faster than the mechanical one, Caterpillar believes that this does not compensate for the extra weight. The mechanical drive offers the best efficiency and less power is required at the same speed. Thus fuel consumption and emissions are lower (Jamasmie, 2010). The most important advantage is that the electric drive truck can be used in trolley assist application (Koellner *et al*., 2004). Both AC and DC drive trucks can be utilised with trolley assist. However, the advantage of AC drive truck over DC one is that the ac inverters decouple the traction motor voltage and speed from the dc line voltage. The AC drive truck can take the trolley line and move on the line at any speed while the DC drive truck at the low speed cannot take the line the fixed voltage - speed relationship.

The AC drives have 6-7% higher efficiency over DC drives of comparable size (Hitachi Construction Machinery 2008). The AC drives also provide more rimpull and better retarding capability. The system allows faster speed and also reduces diesel consumption. Komatsu indicate that AC has an 18% downhill speed advantage to an equivalent DC drive truck (Coastal News, 2007). In addition, according to the technical specification, Terex MT 3300 AC has a speed 40 mph over the DC one at 33 mph as well as the AC one provide higher power**.**

Advantages and disadvantages

The main advantages of trolley assist haulage are cost saving through reduced fuel consumption (Mudd, 1992). Normally, 70 to 80% of mine haulage fuel is consumed on grade (Koellner, 2008); idling the diesel engine on the uphill journey, fuel consumption can be reduced up to 50% (Alvarado, 2009). Adding to that, overhaul intervals and components life can be extended, as a result maintenance and operating costs can be reduced. Additionally, with this system, grade can be up to 12% which impact greatly on mine design and strip ratio.

The speed of driving haul truck uphill is limited by the engine horsepower. The power drive from Trolley Assist can provide more horse power than the diesel engine whilst the truck speed increases. According to Ford, the power line can supply 90% more horse power than diesel engine (Ford, 2006, Hitachi, 2010). Euclid-Hitachi truck, EH4500, operating in Grootegeluk Coal Mine; the truck speed increased from 14.1 km per hour in diesel to 26.1 km per hour in trolley(Alvarado, 2009). The cycle time is shorter with a corresponding increase in productivity by 10 to 20% (Koellner, 2008). Concerning environmental impact, noise will be reduced because the engines idle. Emissions can be reduced significantly from a great reduction of fuel consumption. The Trolley Assist system is flexible as the speed is independent of the line voltage means that the driver can run at any speed. Connection to the trolley line is possible at all speeds with quick and smooth system transition to any trolley line.

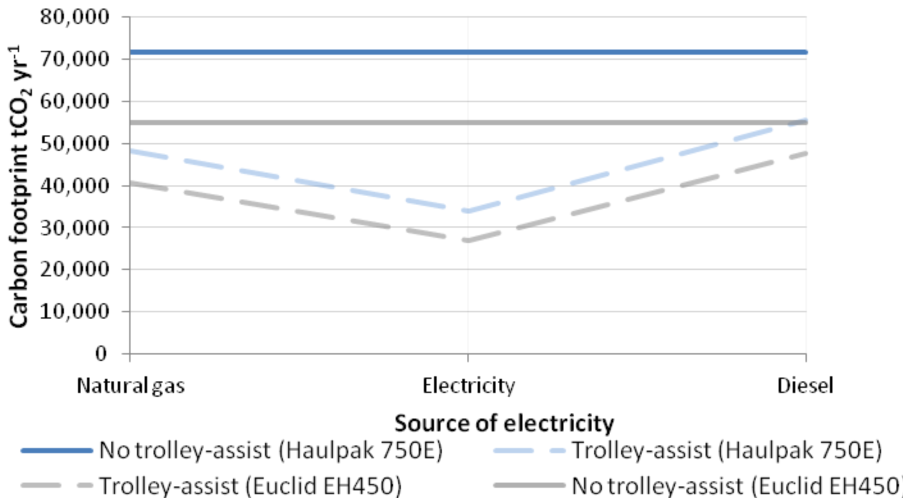
Trolley Assist is practical in deep open pit mines where the main haul roads do not move so frequently because of the installed power lines. In addition to this, the smallest capacity is 136 t such as Terex Unit Rig MT 3300 AC and GE 150 AC. The system should be considered at the design stage. Ramp grade, width, lanes and area for the trolleys are to be taken into account as well as the engine needed to be modified. Although it is then less flexible than normal truck operations, considering reduction in fuel consumption and CO_2 emissions, the system is reasonable to consider especially in the deep mines. Additionally, the capital cost and payback period is claimed by Siemens of 1 to 3 years (Koellner, 2008).

Existing projects

Some mines in South Africa and North America operate with the Trolley Assist system, examples are, Barrick Goldstrike Mines, Palabora Mining, Sishen Iron Ore, Grootegeluk Coal Mine and Rossing Uranium; the latter three have still been operating in 2006 (Ford, 2006). Recently, the Lumwana copper mine in Zambia has implemented a trolley system in 2008 (International Mining, 2007). Rössing Uranium in Namibia report that the truck speed increases by 5kph on a ten% gradient. Fuel consumption with a payload of 182 tonnes reduces from 350 to 25 litres an hour (Rio Tinto, 2011). Thorum (2011) studied the feasibility of trolley assist in 184,000 tons per day open pit gold mine. The AC trucks used are 17 of 186 t Komatsu Haulpak 730E and 12 of 280 t Hitachi Euclid EH4500 over the 2 km ramp. The results for grid based electrical generation shows that, with trolley, 186 t Komatsu reduced 37,715 tons CO_2 and 280 t Euclid reduced 27,877 tons CO_2. These are equal to around 50% less CO_2 emissions. For the on-site diesel electrical generation CO_2 emissions reduction for 730E and EH4500 are 23% and 13%. Lastly, the on-site natural gas electrical generation made 33% and 26% CO_2 reductions respectively (Thorum, 2011).

Another case study on the advantage of trolley assist was conducted for the open pit black coal mine, Grivice, in Bosnia-Herzegovina. Overall material movement was 385 million Bm^3. Using 254 t Hitachi Euclid EH4500 AC drive trucks, fuel consumption reduced as high as 80% for the haul ramp and 50% for the entire haulage system. The authors point out that a trolley system should be seriously considered where the depth is deeper than 150 m (Nurić *et al*., 2009). Using a Bosnia-Herzegovina specific emissions factor of 0.77 t CO_2/ MWh (U.S. EIA, 2010), CO_2 reductions for this analysis are 20%-23%.

Figure 5:5. Graph comparing carbon footprints from haulage with and without trolley-assist, Livengood Mine



3.6 Conclusions

There are numerous means available to the mining industry to reduce greenhouse gas emissions. These range from the simple and relatively inexpensive method of planting trees to offset CO_2 emissions, to proper planning and optimization and, to solar power plants and wind farms costing tens of millions of dollars. All of these play a role in reducing energy consumption and carbon emissions, helping the mining industry of the 21st century in the fight against climate change. The goal now is to achieve a sustainable form of GHG reduction, one that balances the needs of all stakeholders, including: the environment, communities, and companies involved. There is no one answer to fighting climate change or reducing greenhouse gases. In order to be truly effective and maintainable GHG reduction must be achieved slowly through numerous, ever improving, innovative and economically sustainable solutions. It is simply not enough to throw money at the problem of global warming, heavy subsidization and economic benefits are not a maintainable strategy, whist they are important to help low carbon and renewable technologies develop they are not a long term solution. In order for green technology to be sustainable it must also be economic. Whilst solar power plants, hydro electricity, and wind turbines are proven forms of energy with little to no GHG emissions the multi-million dollar investment makes them outside the range of all but the largest companies. In addition to this the building of large renewable energy power plants seems to occur more as a means of appeasing ‘environmentally friendly’ legislation, like Barricks solar power plant in Nevada (Barrick, Beyond Borders: A Barrick Gold Report on Responsible Mining, 2010). Alternatively, they could be used as a bargaining chip to receive funding from organisation like the World Bank or improve their corporate image. Examples of this include the World Bank’s investment of US $500 million in South Africa for renewable energy (Focus, 2009), or Indonesians US

$400 World Bank funding for geothermal development (Lxrichter, 2010); both are countries with a rich mining industry.

In order for GHG reducing technology to really take hold in the mining industry it must pay its own way. While subsidies and grants are essential in developing and improving technology they will not last forever and if these technologies are going to remain a part of industry they must be affordable. It is essential to begin with small scale applications and technologies with limited risk. Good examples of this include the organic rankine cycle and biofuels both significantly curtail diesel consumption and CO_2 emissions. They are both effective technologies and are affordable to midsized operations. In addition to this if either of these technologies proves to be unsustainable or too costly they can be discontinued with minimal effects to the operation or budget. Innovative small-scale technologies such as Barrick's end-of-pipe hydroelectric power generation at their Zaldivar mine in northern Chile represents the benefits of small-scale innovations throughout the operation which have the potential to add up to large CO_2 emissions savings.

While large-scale projects have their role in setting an example, funding technological improvements, and providing low emission energy, it is not the belief of this author that they are the key solution to carbon reduction in the mining industry. The only way to truly reduce emissions is to reduce the energy consumed, and provide energy in a clean and economically viable manner. A culmination of small scale savings, more efficient processes, proper planning and optimization and innovative techniques could be a more suitable alternative. Although there is still much to learn, improvements are being made; the mining industry continues to lead research, improve techniques, and reduce its carbon footprint, albeit incrementally, yet this is a step towards carbon reduction, meeting progressive targets and still producing significant benefits to companies, regions, communities and markets.

Company Comparison

During the course of this research, many methods for reducing carbon footprint were investigated. To provide a better understanding of the degree to which renewable energy and GHG reducing technologies have infiltrated the mining industry ten of the most proactive in reducing their carbon footprint have been compiled. All are ICMM member companies, and leaders within the mining industry, in terms of financial success as well as GHG emissions reduction. Table 9 lists these ten companies along with some of the most popular carbon footprint reducing technologies and techniques they use.

Table 9 GHG reduction methods in the mining industry (Keech, 2010).

Company	Wind	Solar	Hydro	Biofuel	Geothermal	Natural gas	Trolley Assist	Reforestation
Barrick	X	X	X	X	X	X	X	X
Anglo	X	X	X	X		X		X
BHP		X	X	X		X		X
RioTinto	X	X	X	X		X	X	X
Goldcorp		X	X	X	X	X		
Teck			X			X		X
Newmont		X	X	X		X	X	X
Xstrata		X	X	X		X		X
Gold Fields	X	X		X				X
Vale			X	X		X		X

As can been seen from the above table, all of the ICMM member companies compared employ wide range of reduction methods and are taking a proactive approach to carbon footprint management. Whilst some technologies are more widely used then others and in varying stages of development all play an important role in emissions reduction. The economic feasibility of each technology can be estimated by is popularity. Biofuels and reforestation are used by nearly every company. This is likely in large to be due to the fact that they are relatively inexpensive methods of CO_2 emissions management. On the other hand, wind power is less popular likely due to the fact that it requires a large upfront investment as well as a suitable location. Technologies such as Trolley assist and geothermal energy, which also require specific conditions to be viable, are also less popular. This table further supports the conclusion that the most effective way to reduce the carbon footprint of the mining industry is through the slow accumulation of small to medium scale economically viable techniques and practices. While large scale projects (ex. Wind farms) may work for specific projects of mayor companies to make a significant difference in the carbon footprint of the mining industry as a whole it is important to develop, encourage, and implement technologies within the price range and technical expertise of small to medium sized mining companies as well. In this manner the greatest and most sustainable reduction in carbon footprint can be achieved.

Mitigation measures

Impacts on CO_2 emissions reduction from each mitigation option and potential to implement have been ranked based on the authors evaluation and experience. Some impacts of mitigation options are not in a common measurement unit because of the limited availability of data. A summary of the mitigation options and mitigation assessment matrix are presented in Table 10 and Table 11.

Table 10 Comparison of all mitigation options (please note: the scores are based on the author's opinion.)

Case	Mitigation strategies	Performance, potential effect		Potential implementation possibility	
		score		score	
	CO_2				

	reduction				
B20	Alternative fuel: Biodiesel	3	% reduction = % biodiesel blend (score is based on B20)	3	+ More mines are considering - Engine efficiency and modification
B100		5	B100 biodiesel	1	+ 0% emissions - high fuel price, low availability - Engine efficiency and modification
Forestation	Reforestation	5	Teak: 60 t CO_2 per year	3	+ may require by permits, EIA - takes long time and/or large areas (to uptake high emissions)
IPCC	In-Pit Crushing and Conveying	3	IPCC < truck (30% CO_2) (score is based on open pit gold mine)	1	+ low fuel and operating cost - high investment, less flexible
Trolley	Trolley Assist	3	20% - 50% CO_2	1	+ low op cost - high investment - limited to large capacity, deep pit
	Load and haul efficiency				
Cycle time	Cycle time analysis – actual time	3	20%-29%	4	Depends on operators' experience, machine condition, fleet matching, work condition, road
Cycle time (manual)	Influence of cycle time to fuel consumption and CO2 emissions	3	Excavator: 11% less time = 48% less CO_2 Truck: 22% less time = 31% less CO_2	3	
	Haul road condition	5	6% higher RR= 70% higher CO_2	5	usually concerned

	Engine load factor	4	20% increase = 50% higher CO_2	3	Related to haul road condition and payload management
	Payload management	3	80% load of max - increase 20% CO_2	4	Usually maximise
	Operational practice	2	Various	3	+ usually concerned - easily neglect
Colour codes; red, yellow and green mean high, medium and low priority to consider, respectively. Options are divided into reduction strategies as the whole system and fuel efficiency.					

Table 11 Mitigation option assessment matrix

Remark: Bold and underline represents whole system reduction strategies while *italic* represents fuel efficiency option.

		Potential effect of CO2 emissions reduction / Performance				
		Insignificant (0-14%)	**Low (15-29%)**	**Medium (30- 49%)**	**High (50-69%)**	**Significant (>70%)**
Implementation probability		**1**	**2**	**3**	**4**	**5**
Already common practice	**5**					***Haul road condition***
Commonly practiced	**4**			***Cycle time, payload***		
Moderately commonly practiced	**3**		***Operational practice***	**B20**, ***Cycle time (handbook)***	***Engine load***	**Forestation**
Sometimes practiced	**2**					
Rarely practiced	**1**			**IPCC, Trolley**		**B100**

Considering both potential carbon footprint reduction and the possibility to implement the various measures, haul road condition should be prioritized, followed by efficiency in engine load. This is because fuel efficiency improvement affects greatly the CO_2 emissions and is easy to apply in almost all operations. For the whole process reduction strategy, forestation should be considered. Cycle time, payload management and biodiesel B20 and B100 are to be considered as medium priority. Operational practice is can also produce useful savings. The first two can be considered at most operations right away, while B20 should be considered if the supply and technology is available. B100 considerably reduces carbon footprint but is rarely used owing to its price and availability. IPCC and Trolley Assist are used less because they are suitable for fewer mines sites, however, if the mine is suitable (steep slopes, large trucks), these options can be give a significant reduction in carbon footprint.

In theory, forestation and B100 can mitigate all CO_2 emissions from a mine so that the mine can be a ‘zero carbon’ metal producer. In practice both methods can be difficult to implement, owing to restricted supply of B100 and available land for forestation. Howoever, offsetting by forestation can be carried out away from the mine site

Chapter 4 Carbon offsetting and carbon trading. Case study: Roşia Montană (Romania)

4.1. Introduction

Kyoto Protocol is an international agreement which attempts to implement the objectives and principles agreed within the United Nations Framework Convention on Climate Change (UNFCCC) treaty from 1992. According to the 2nd Article of Kyoto Protocol, the main objective is the "stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (Grubb *et* al., 1999; Kyoto Protocol: Status of Ratification, 2009). The Protocol was initially adopted on the 11th December 1997 in Kyoto (Japan) and entered into force on 16 February 2005. It was signed and ratified by 191 states by July 2010 (Kyoto Protocol: Status of Ratification 2009, Oberthur and Ott, 1999).

Under the Protocol, 37 countries (see Annex I countries) have committed to reduce the emissions of four greenhouse gases (GHG) (carbon dioxide, methane, nitrous oxide, sulfur hexafluoride) and two other groups of gases (hydrofluorocarbons and perfluorocarbons). The main target of this commitment was a mean reduction of 5.2% of GHG emissions (from 1990 levels) by the year 2012 (Kyoto Protocol to the United Nations Framework Convention on Climate Change**,** 1998). According to Kyoto Protocol in 2012, the Annex I countries must have fulfilled their obligations of reducing the greenhouse gases emissions, established for the first commitment period (2008–2012) (see Annex B of the Protocol) (Kyoto Protocol to the United Nations Framework Convention on Climate Change**,** 1998). The Protocol expires at the end of 2012 (Kyoto Protocol to the United Nations Framework Convention on Climate Change**,** 1998).

In Annex B of the Protocol, the 'caps' or 'quotas' for the greenhouse gases emissions are listed and assigned to each developed Annex 1 country. These quotas are known as assigned amounts units (AAUs) and represent the allowance to emit one metric tonne of carbon dioxide equivalent (CO_{2e}) (Grubb *et* al., 1999; Kyoto Protocol: Status of Ratification, 2009). In turn, these countries set quotas on the emissions of installations run by the local business and by other organizations, generically named "operators". The operators, that have not used up their quotas, can sell their unused allowances as carbon credits, while the operators, that are about to exceed their quotas, can buy the extra allowances as credits either privately or on the open market.

4.2. The "flexible mechanisms" of Kyoto Protocol

Kyoto Protocol provides three mechanisms that enable countries or operators in the developed countries to achieve their emission targets. These mechanisms support 'parties' in achieving their emission reductions or removing carbon from the atmosphere by a cost-effective way

The three 'flexible mechanisms' of the Kyoto Protocol refer to:

- *Joint Implementation (JI)*. According to the 6th Article of the Protocol, any Annex I country can invest in emission reduction projects (referred to as "Joint Implementation Projects") in any other Annex I country as an alternative for the reducing of domestically emissions. In this way countries can lower the costs of complying with their Kyoto targets by investing in greenhouse gas reductions in an Annex I country where reductions are cheaper, and then by applying the credit for those reductions towards their commitment goal (Grubb *et* al., 1999; Kyoto Protocol: Status of Ratification, 2009; Harris, 2007).
- *Clean Development Mechanism (CDM).* CMD is defined by the 12th Article of the protocol, and it is intended to meet two objectives: (1) to assist countries not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the UNFCCC, which is to prevent dangerous climate change; and (2) to assist countries included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments (greenhouse gas emission caps). CDM states that a developed country can “sponsor” a greenhouse gas reduction project in a developing country where the cost of greenhouse gas reduction project activities is usually much lower, but the atmospheric effect is globally equivalent. The developed country would be given credits for meeting its emission reduction targets, while the developing country would receive the capital investment and clean technology or beneficial change in land use (Grubb *et* al., 1999; Kyoto Protocol: Status of Ratification, 2009).
- *International Emissions Trading (IET) (*also known as *cap and trade)*. According to the 17th Article of Kyoto Protocol, countries can “trade” their emissions (assigned amount units (AAUs), or allowed emissions units) in the international carbon credit market. A central authority (usually a governmental body) sets a limit or a *cap* regarding the amount of a pollutant that can be emitted. This cap is allocated or sold to firms in the form of emissions permits or *carbon credits,* which represent the right to emit, or to discharge one ton of carbon or carbon dioxide equivalent (CO_{2e}) (Stavins, 2001; Cozijnsen, 2011). Firms that need to increase their emission permits must buy carbon credits from those who require fewer permits (Stavins, 2001). The transfer of carbon credits represents a trade through which the buyer is paying a charge for polluting, while the seller is rewarded for having reduced the emissions.

4.3 Romania’s commitments according to Kyoto Protocol

Romania signed the UNFCCC in 1992 at the Rio Earth Summit and ratified the UNFCCC by the Law no. 24/1994. Romania was the first country, included in the Annex I of the UNFCCC, which ratified Kyoto Protocol, by the Law no. 3/2001. In accordance with the Kyoto Protocol, Romania has committed to reduce the GHG emissions by 8%, between 2008 and 2012, compared to 1989 (Romania’s Initial Report under the Kyoto Protocol, 2007). Romania is using 1989 as a base year, instead of 1990, taking into consideration the flexibility provided by the Article 4.6 of the UNFCCC, Decision 9/CP.2, and based on the Article 3.5 of the Kyoto Protocol.

Romania has also committed to establish, no later than 2007, a national system for the estimation of greenhouse gas emissions and also to set up a National Registry of greenhouse gas emissions before the start of the first commitment period and to draft and implement policies with a view to promote sustainable development (Romania's Initial Report under the Kyoto Protocol, 2007).

4.4 The implementation stage of Romanian commitments

By approving the National Strategy on Climate Change (NSCC) (G.D. no. 645/2005) and the National Action Plan on Climate Change (NAPCC) (G.D. no. 1877/2005), the Romanian Government has taken important steps to meet the UNFCCC and Kyoto Protocol commitments. As shown in Figure 18, the total GHG emissions decreased significantly between 1990 and 1999, because of the transition process to a market economy. The decrease in energy-related emissions was a consequence of the decline of economic activities and energy consumption. The GHG emissions increased between 1999 and 2004, stabilising out between 2005 and 2009.

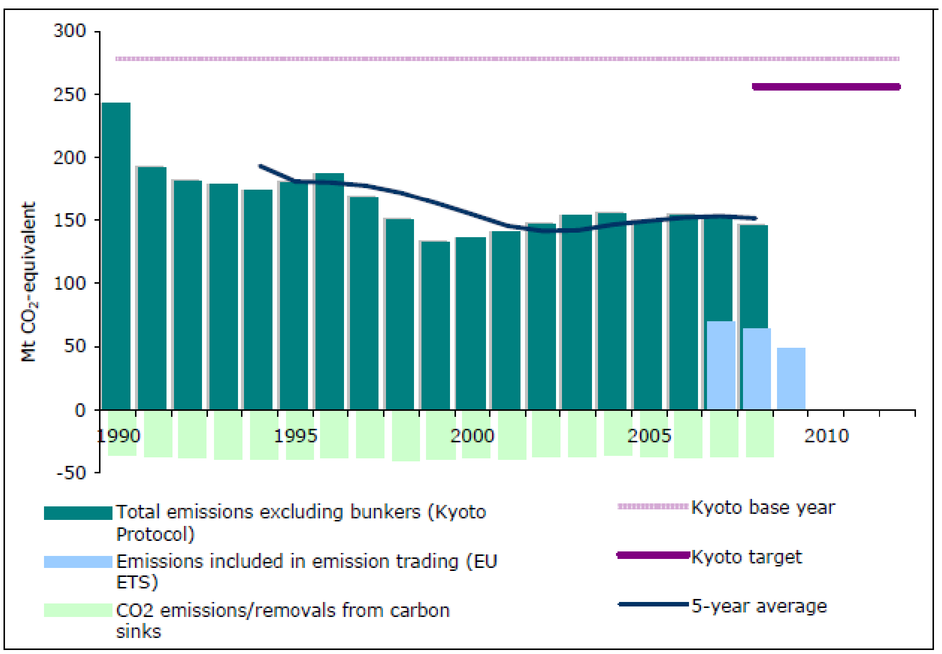


Figure 18 Trends in the total emissions and removals of greenhouse gases in Romania (EEA, 2010).

In order to achieve the greenhouse gases limitation target, Romania is using two of the three flexible mechanisms provided by the Kyoto Protocol, namely: the Joint Implementation (JI) and the International Emissions Trading (IET).

4.4.1. Romania versus the International Emissions Trading (IET) mechanism

As was mentioned before, Romania committed to reduce its GHG emissions by 8% between 2008 and 2012 from the levels of emissions recorded in 1989. This means that Romania has the right to emit 1 279 billion tonnes of CO_{2e}, between 2008 and 2012 (Romania's Initial Report under the Kyoto Protocol, 2007; Yuan, 2010). In 2009, Romanian industries emitted 40% less CO_2 than its AAUs of CO_2 emission. This surplus of carbon allowances can then be traded for money (Yuan, 2010).

In the case of Romania, the national carbon emissions cap for 2008 - 2012 period, represents a combined total of 379,721,760 certificates *or* 75 944 352 certificates annually (http://carboncreditromania.wordpress.com). As shown in Figure 19 the energy sector received most of these certificates. According to the trading scheme from the G.D. no. 60.2008 (see Annex 1), more than half of the national certificates of GHG emissions will be allocated to eight companies, which represents the biggest sources of pollutants in Romania (Table 12).

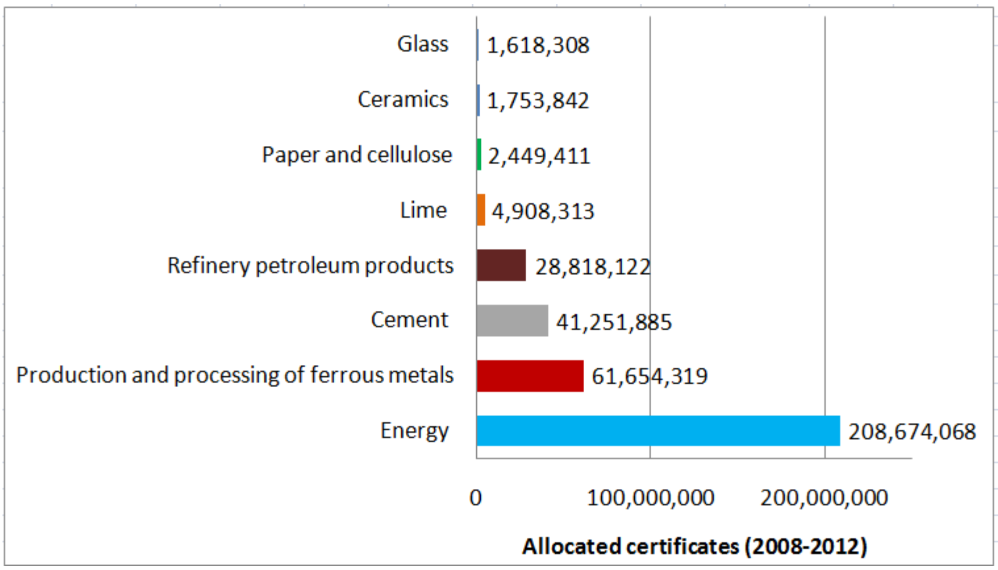


Figure 19 The national carbon emissions cap allocated for different sectors (http://carboncreditromania.wordpress.com).

Table 12 The top of the allocated greenhouse gases emissions national certificates during 2008 and 2012 (GD No 60/2008).

Name of the company	Number of the national certificates allocated
Mittal Steel Galati	71 millions
SC Energetic Complex Turceni	34 millions
SC Energetic Complex Rovinari	28 millions
SC Deva Electrical Plant	20 millions
Energetic Complex Craiova – Isalnita	17 millions
RAAN Romag Termo	14 millions
Lafarge Cement (Romania) Medgidia	12.3 millions
Petrom SA Arpechim Pitesti	9.6 millions

According to the Kyoto Protocol, the certificates record is held by a standardised system of national registries in each EU member country. For Romania, this task belongs to the National Register for Emissions. Companies who are large polluters have internal departments for trading carbon credits, and those who do not have such a department work with the banks. There are also profile companies or foreign brokers who are members at one of the mentioned stock exchanges, who are intermediaries in the trading of certificates allocated to the Romanian companies.

Since 2009, Romania has been part of the EU's scheme for carbon trading, where the 12 000 industrial and energy polluters can trade CO_2 emissions. Since the beginning of 2009, Romanian companies have traded around 40 millions of carbon credits. The business, potentially worth billions of Euro in transaction volumes, represents a big interest for big name brokers (http://unfccc.int/resource/docs/natc/romnc3.pdf). The money gained from carbon credits must be used for: the development of the green energy sector which is necessary for the reduction of carbon emissions; the rehabilitation of the coal based power plants; or for the implementation of the wind energy projects. If Romania doesn't sell its carbon credit surplus, these allowances will automatically expire by 2012 (Yuan, 2010).

4.4.2. Romania versus the Joint Implementation (JI) mechanism

Romania has signed several JI programmes with different countries like: Netherlands, Norway, Denmark, Austria, Sweden and the World Bank's Prototype Carbon Fund. Due to the investments made by some of these countries, a total of 11 JI projects have started or they have already been finished in Romania (http://unfccc.int/resource/docs/natc/romnc3.pdf). The approved JI projects include:

➢ ***5 projects designated for the energy efficiency*, with respect to:**

- The district heating: "Swiss Thermal Energy Project in Buzău and Pașcani" (Switzerland); "Development of the Municipal Utilities-Heating System in Făgăraș" (Norway); "Municipal Cogeneration Târgoviște" (Netherlands); "Rehabilitation of Bucharest District Heating System" (Switzerland)
- The industrial technology improvement (cement plants): "Refurbishing of the Cement Factories Aleșd and Câmpulung" (Netherlands)

➢ ***4 projects designated for renewable energy projects*, like:**

- Hydropower: "Modernization of 3 Hydro Units at Porțile de Fier I Hydropower Plant" (Netherlands); "Modernization of 4 Hydro Units at Porțile de Fier II Hydropower Plant" (Netherlands)
- Biomass (sawdust): „Sawdust 2000" Project (Denmark)
- Geothermal: "Geothermal Energy Use in Oradea-Area II and Beiuș District Heating Systems" (Denmark)

➢ ***1 projects designated for landfill gas recovery*:** "Landfill Gas Recovery in 4 Major Cities: Baia Mare, Satu Mare, Oradea, and Sf. Gheorghe" (Netherlands)

- ***1 project designated for the afforestation phenomenon*****:** "Afforestation of 7000 ha Degraded Agricultural Land Host Country Agreement" (host country agreement)

It was estimated that these JI projects would generate over 7.5 mil. tonnes of CO_{2e} in the first commitment period (2008-2012), corresponding to a value of approximately 40 million Euros (http://unfccc.int/resource/docs/natc/romnc3.pdf).

4.5 CO_2 reduction strategies in the case of Roşia Montană mining project

The goal stated by Roşia Montană Gold Corporation is for the project to be "Carbon Neutral" by the end of the mine life. RMGC has explored three strategies in order to achieve this goal: (1) purchase green credits from emissions market (Carbon Trading); (2) invest in cleaner technology and "green energy" (wind, solar, hydro, etc.); and (3) develop a "carbon sink" reforestation programme in the project area. Possible sites include the Apuseni Mountains. Of the three options, the third one appears to be the most feasible given the context of the site location and logistics of the three options.

4.5.1 Carbon Trading

Romania has been a part of the EU's scheme for carbon trading since 2009. Romanian companies have been traded around 40 million carbon credits, although the business is potentially worth billions of Euros in transaction volume. At present there is still a weak carbon trading market within Romania. As a consequence this option is not feasible at this time for the Roşia Montană project.

4.5.2 Invest in cleaner technology and 'green energy'

There is little potential at the present to invest in 'green energy' (wind, solar, hydro, etc.) in Roşia Montană area. In order to reduce the CO_2 emissions, RMGC propose they will invest in cleaner technology by using the best available techniques (BAT). Some of the possible options in this case could be (RMGC, 2008):

-***The use of GHG reducing technologies:***
- *T*he use of electrical equipments/vehicles instead of diesel equipments/vehicles
- The electricity generation from other raw materials than coal
- The use of liquefied petroleum gas as fuel for high efficiency boilers used for heat production, in order to reduce fuel consumption
- The purchase of vehicles/mobile equipment with low fuel consumption engines
- The mention of certain specifications, like fuel efficiency or low sulphur content, at the purchase of new equipment/vehicles
- The use of wet scrubbers to reduce emissions from the electrolysis cells, from the furnaces used to reactivate the active carbon, from the melting furnace, etc. - The construction of chimney-dispersion at the processing plant, in order to improve the pollutants dispersion

-**For *technology optimisation:***

- The use of electricity generating systems equipped with non-selective catalytic reduction of emissions
- The use of vehicles/mobile equipment equipped with engines with pollutant emissions below the legal limit

- ***For the optimisation of the existent infrastructure:***

- Planning procedures for regular maintenance of vehicles/equipments
- Strategic planning of delivery routes, in order to avoid the heavy traffic
- Enforcement of speed limits

4.5.3 Reforestation

The Apuseni Mountains area is heavily affected by the forestry industry, where approximately 600 ha of forest are lost a year. As a consequence, reforestation represents the best option for CO_2 emission reduction. For the reforestation "carbon sink" scenarios, the estimated CO_2 absorption rate was the same for both young and mature forest, although it is known that the maturity and health level of the forest influences the CO_2 absorption rates. In order to create several scenarios regarding the "carbon sink" for Roşia Montană mine project, it was assumed that each cubic metres of indigenous forest can absorb an average value of 0.5 t CO_2 a year. Based on local forestry data, it was estimated that one hectare of indigenous forest contains 140 m^3 of wood and after year 5, the forest is growing at a rate of 7.6 m^3 per ha a year (Bobar, 2009). Based on this assumption it is possible to predict the area of forest which must be planted in order to absorb sufficient carbon for the project to become carbon neutral by the end of the mine life (currently proposed as being in year 17). Taking into account the Romanian energy blend, which produces CO_2 emissions at a rate of 0.737 kg per kWh (Bobar, 2009), a total of 8 000 ha of "carbon sink" indigenous forest must be planted for the project to become carbon neutral by year 17. The estimated cost for this operation is of 5 million USD. The estimated cost includes only the cost of the forestation programme and it assumes that the costs for the recovery of the degraded land or damaged protected forest will be provided by local or central forestry authorities. Figure 20 shows the "carbon sink" scenario in the case of reforestation with 8 000 ha of indigenous forest. The red bars represent CO_2 emissions caused by the mine activity, while the blue bars represent the CO_2 absorption of the trees. The yellow line represents the balance between the CO_2 production and absorption and marks the point at which the project becomes carbon neutral (year 15). The red dotted line represents the end of Roşia Montană mine project (year 17).

On the other hand, if the Romanian energy sector is able to align with the EU energy standards, in order to generate 0.375 kg CO_2 emission per kWh the project will require only 5 000 ha of new indigenous forest at a total cost of 3 million USD. Figure 21 shows the 'carbon sink' scenario in the case of reforestation with 5 000 ha of indigenous forest.

Unfortunately at this time the reforestation of 8 000 ha is not feasible. RMGC has been committed to reforestation of 1 000 ha of land. The reforestation surface (1 000 ha) respects the Romanian legislation (Low No.46/2008 or the Forest Code from 19/03/2008 last modified on 04/06/2009, Art.37/alin.3) namely: that cut forest land must be reforested with a surface which has five times the value of permanently removed forest and cannot be less than three times the removed forest area.Considering the Romanian power blend (0.737 kg CO_2/kWh), this will result in a period of 50 years until carbon neutrality is achieved (Figure 22). If Romania aligns to EU emissions requirements (0.375 kg CO_2/kWh), the time range will be shorter - 39 years.

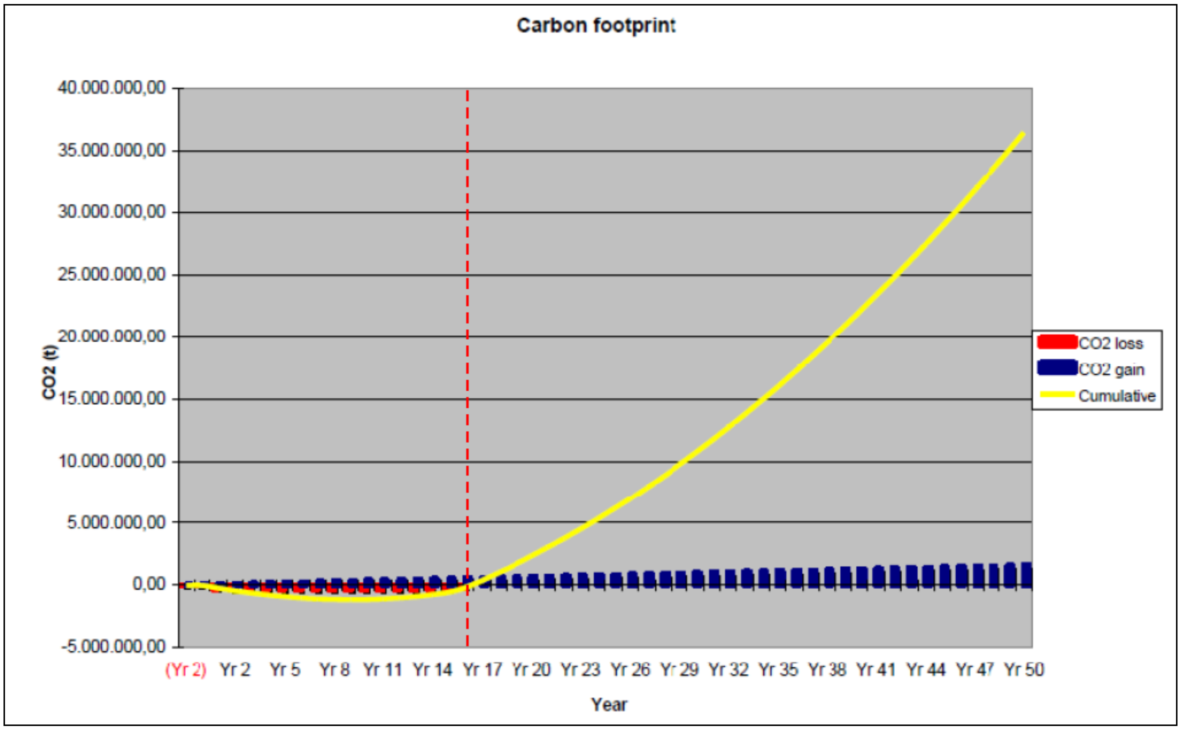


Figure 20 Cumulative carbon footprint assuming 8000 ha reforestation, Romanian energy blend (Bobar, 2009).

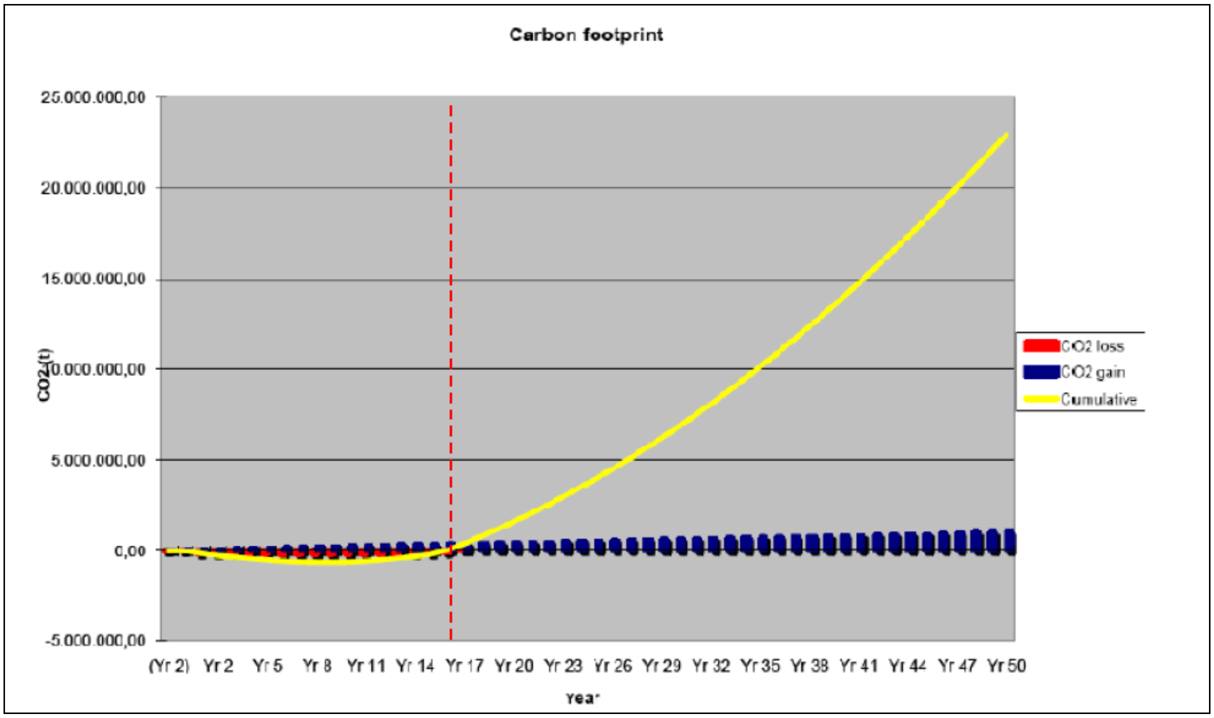


Figure 21 Cumulative carbon footprint assuming 5000 ha reforestation, EU energy blend (Bobar, 2009).

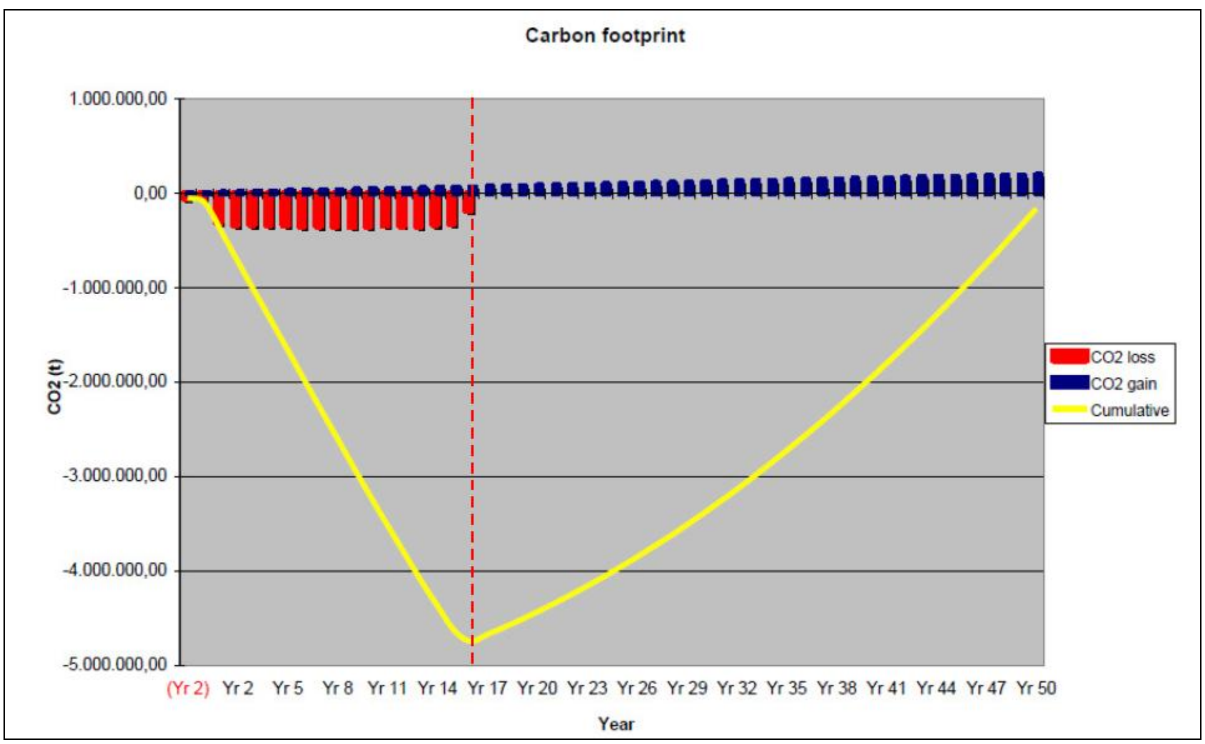


Figure 22 Cumulative carbon footprint assuming 1000 ha reforestation, Romanian energy blend (Bobar, 2009).

4.6 Conclusions

Romania was the first country included in the Annex I of the UNFCCC, which ratified the Kyoto Protocol Law no. 3/2001. In accordance with the Kyoto Protocol, Romania has committed to reduce the GHG emissions by 8%, between 2008 and 2012, compared to levels emitted in 1989. In order to achieve the greenhouse gases limitation target, Romania is using two of the three flexible mechanisms provided by the Kyoto Protocol, namely: the Joint Implementation (JI) and the International Emissions Trading (IET).

At present, there is a weak carbon trading market within Romania. As a consequence, this option is not feasible at this time for Roşia Montană project. At the moment, there is little potential to invest in “green energy” (wind, solar, hydro, etc.) in the Roşia Montană area. In order to reduce the CO_2 emissions, RMGC will invest in cleaner technology by using the best available techniques (BAT). At present with the Roşia Montană mining project, reforestation represents the most feasible option for the reduction of CO_2 emissions.

The main goal of RMGC is for the project to become carbon neutral by the end of the mine life (year 17). In order to become carbon neutral by the end of the mine life, the required surface for carbon sink forestation programme is 5 000 ha of indigenous trees based on EU guidance, or 8 000 hectares if the Romanian energy sector is not be aligned to EU standards. The estimated cost for this operation is over 5 million USD. Unfortunately at this time the reforestation of 8 000 ha is not feasible. RMGC has been committed to reforestation of 1 000 ha. Considering the Romanian power blend (0.737 kg CO_2/kWh) this will result in a period of 50 years until carbon neutrality is achieved. If Romania aligns to EU emissions requirements (0.375 kg CO_2/kWh) the time range will be shorter ~ 39 years.

Chapter 5 Case Study of setting up a new mine: Roşia Montană-Romania

5.1 Introduction

Chapter 5 is the case study of Roşia Montană Gabriel Resources (RMGR) project in Transylvania, Romania. The Roşia Montană project is owned by Roşia Montană Gold Company (RMGC), which is owned by Gabriel Resources - a Toronto based Canadian company (80 %), by the Romanian government (19.31 %), and by other investors (0.69 %) (http://www.gabrielresources.com/i/pdf/EIA/01/C1.pdf). The project is located in a historic mining region in Romania. The Roşia Montană project is set to become one of the largest gold operations in Europe. It will consist of three open pits, a tailings facility, several waste rock dumps and a processing plant. Roşia Montană Resources comprise 350 Mt, with an average grade of 1.3 g Au/t and 6 g Ag/t (Table 13) (RMGC, 2006). The total content of gold is of 14.6 Moz while the silver total content is of 64.9 Moz. In addition the inferred resources are of 30 Mt at a grade of 1.2 g Au/tonne and 3 g Ag/tonne. Mean annual production rates will be13.4 Mt, producing 626 000 oz of gold per year during its first 5 years of operation and 500 000 oz per year from the mines entire duration. The estimated cost is of 272 USD per ounce (for the first 5 years), and 335 USD per ounce (during the anticipated 16 years of mine life) (Sahy and Schütte, 2006). Table 13 summarises the estimated grade and tonnage of the deposit.

Table 13 Roşia Montană Gold Project categorized grade tonnage.

	Gold cutoff grade	Mt	Au (g/t)	Ag (g/t)	Contained gold (Moz)	Contained silver (Moz)
Measured	0.4	171.51	1.3	8	7.3	43.2
	0.6	139.83	1.5	8	6.7	38.1
	0.8	113.11	1.7	9	6.1	32.8
	1.0	90.70	1.0	10	5.5	27.8
Indicated	0.4	341.22	0.9	3	9.9	38.0
	0.6	210.52	1.2	4	7.8	26.8
	0.8	137.65	1.4	4	6.2	19.5
	1.0	94.40	1.0	5	5.0	14.6
Measured and indicated	0.4	512.73	1.0	5	17.1	81.1
	0.6	350.35	1.3	6	14.6	64.9
	0.8	250.76	1.5	6	12.3	52.3
	1.0	185.10	1.8	7	10.5	42.4
Inferred	0.4	44.81	1.0	3	1.4	4.1
	0.6	30.29	1.2	3	1.2	3.0
	0.8	22.20	1.4	3	1.0	2.1
	1.0	17.53	1.5	3	0.9	1.6

5.2 History of mining activity in Roşia Montană

Roşia Montană has a long history of mining activity since the Roman occupation of Dacia. Exploitation peaked for the first time during Roman times (106-237 AD), when the settlement was known as *Alburnus Maior*. This is certified by the wax tablets found in the area dating back to the 6th of February 131 AD (Tóth *et* al., 2006). These tablets written in Latin or Greek consist of details of mining contracts, real estate transactions, and other commercial activity during the early Roman Empire. Mining has attracted immigrants to the region from Germany, Italy, Hungary, and Austria, who formed a significant fraction of the population. Historical mining activity peaked during the Austro-Hungarian period in the 1800s (Figure 23), when the area was known as Verespatak, meaning "Red River." High production levels were attained during the time of the Austro-Hungarian Empire (the end of the 19th century and the beginning of the 20th century) and before World War II, with exploitation carried out by means of underground mining techniques. This mining activity focused predominantly on high grades zones and veins (Tóth *et* al., 2006).

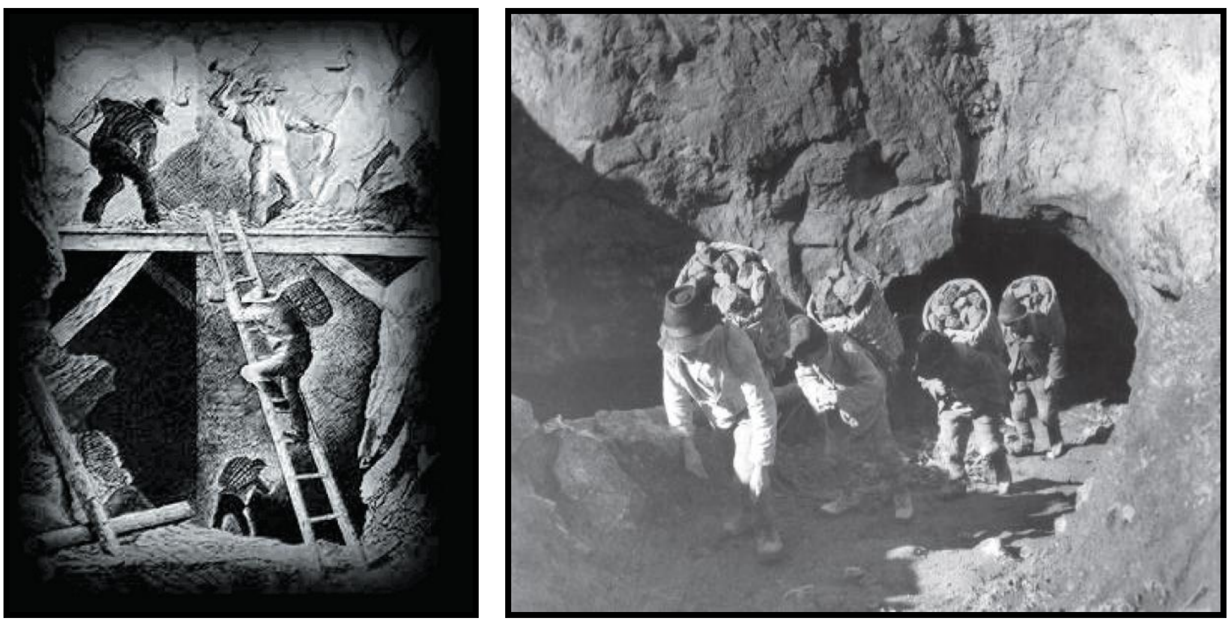


Figure 23(a, b) Gold underground exploitation method used in the 18th century. Engraving placed inside the Museum of SM Certej. Ancient photography of miners from Roşia Montană (Toth *et* al., 2006).

After 1948 (the Communist period), when all the private holdings were nationalized, the extraction of precious metals continued in the State-owned mine. The late 1970's marked the introduction of open-pit mining, a method that continued until April 2006. In 1970 an open pit operation was initiated on Cetate deposit. In 1975 the underground development of Cetate deposit was closed and the bulk mining of the disseminated low grade gold commenced (Tóth *et* al., 2006). During the Communist regime and after 1989, the State mine from Roşia Montană incurred many losses, with overall expenses estimated at being almost three times higher than the benefits. The old technology, the lack of investments and lack of a clear development plan resulted in the closing of the mine in 2006 (Tóth *et* al., 2006). Roşia Montană Gold Corporation (RMGC) acquired the mining license for the area in 1995, and has been conducting several feasibility studies in the area in order to set up a state-of-the art open-pit mining operation in the near future in joint venture with the Romanian State and other Romanian share-holders (Manske *et* al. 2006).

5.3 Location of Roşia Montană mine and geological settings of the area

Roşia Montană is a commune of Alba County, located in the Apuseni Mountains - western Transylvania, Romania. It has 3 872 inhabitants. Roşia Montană is located in a historical gold mining region known as the "Golden Quadrilateral" (Tóth *et* al., 2006). The Golden Quadrilateral covers an area of approximately 500 km^2 within the Metaliferi Mountains (South Apuseni Mountains) (Tóth *et* al., 2006). The Golden Quadrilateral includes gold and silver deposits which, without doubt, constitute the most productive gold area of the Eastern Europe (Figure 24) (Tóth *et* al., 2006).

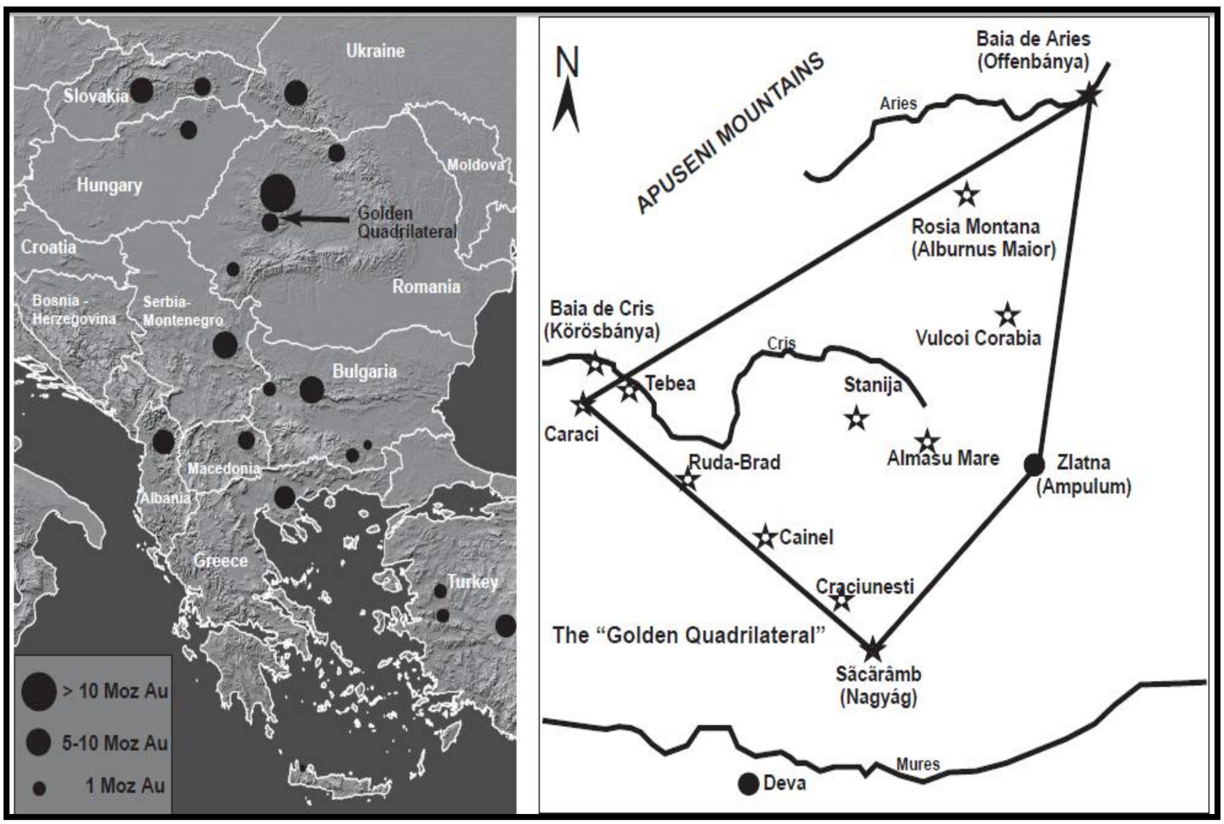


Figure 24 The "Golden Quadrilateral" (Metaliferi Mountains): a) the location of the "Golden Quadrilateral" within the Eastern European cold "anomaly map" (Márton *et* al., 2006); b) major historical mining districts (Manske *et* al., 2006).

Roşia Montană property lies on a 23.8 km^2 concession (http://www.datametallogenica.com/pages/minidisc/html/rosiamontana-mapsect/page.html). Roşia Montană Project will consist of three open pits, a tailings facility, several waste rock dumps and a processing plant (Figure 25).

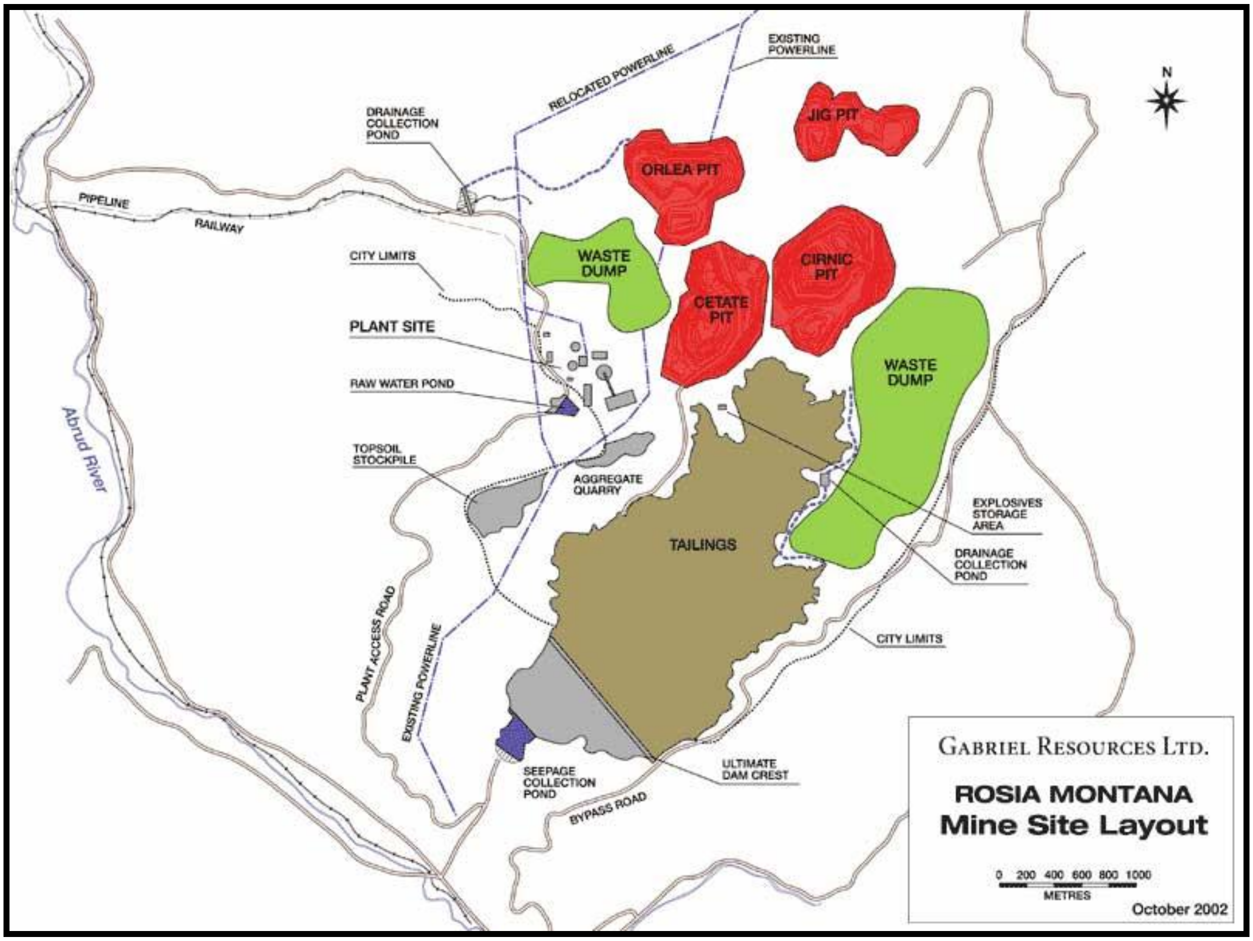


Figure 25 Roşia Montană mine site layout (http://data,etallogenica.com/pages/minidisc/html/rosiamontana-mapsect/page.html).

Deposits at Roşia Montană are located within a maar-diatreme complex emplaced within a pile of Cretaceous sedimentary rocks assigned to the flysch facies overlaying the Paleozoic basement (Sahy and Schütte, 2006). Formed by multiple phreato-magmatic eruptions due to the interaction of hot, dacitic magma and the groundwater, the major Roşia Montană diatreme lithology is locally referred to as 'vent breccia'. The vent breccia hosts the Carnic and Cetate massifs, believed to be either two separate dacitic bodies that intruded vertically through the complex, or a single dacitic intrusion that was later split by a NE trending strike-slip fault (Sahy and Schütte, 2006). Another sub-vertical breccia body termed Black ('Glamm') Breccia crops out adjacent to the dacitic bodies and consists mainly of clasts of Cretaceous black shales, and altered dacite (Sahy and Schütte, 2006). Small, well-mineralized, intrusive, polymictic breccia bodies were mapped between Tarina and Jig; they are interpreted as been formed due to deep-seated phreato-magmatic eruptions (Manske *et* al., 2006). To the northeast, the diatreme complex is concealed below thin to moderately thick andesitic extrusive rocks with pyroclastic block and ash flows forming the lower part of the sequence, overlain by andesitic lava flows (Leary *et* al., 2004). Figure 26 provides an overview of the geology of Roşia Montană deposit; a cross-section through Carnic and Cetate intrusive bodies is presented in Figure 27.

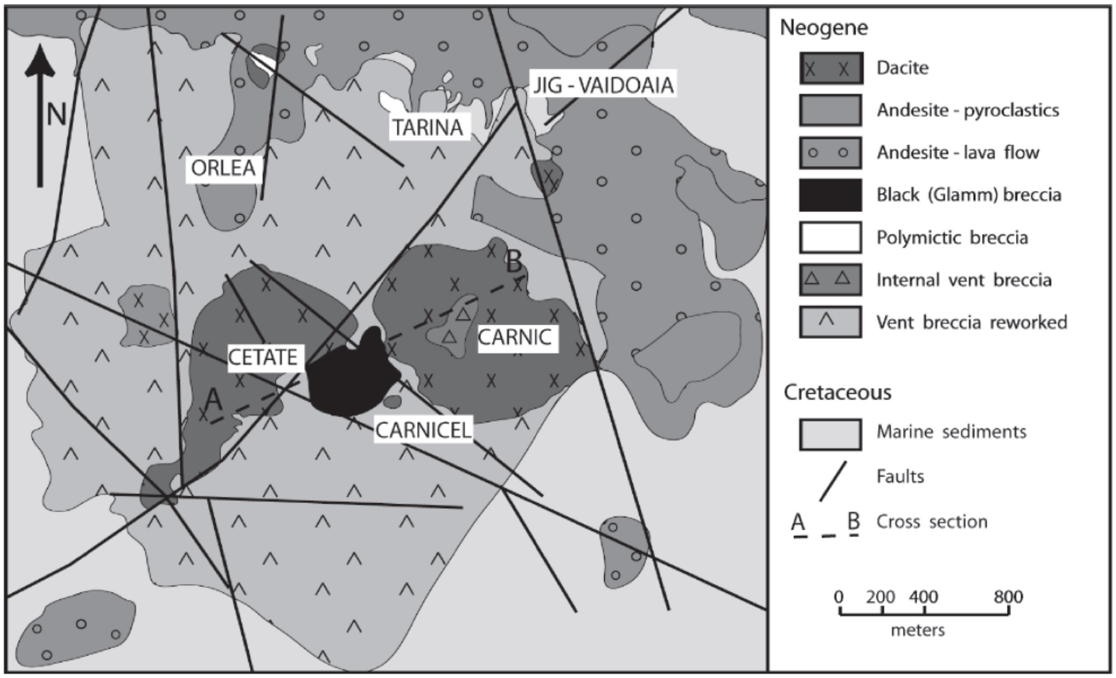


Figure 26 Geological overview of Roşia Montană Au-Ag deposit, Apuseni Mountains, Romania (Leary *et* al., 2004; Sahy and Scütte, 2006).

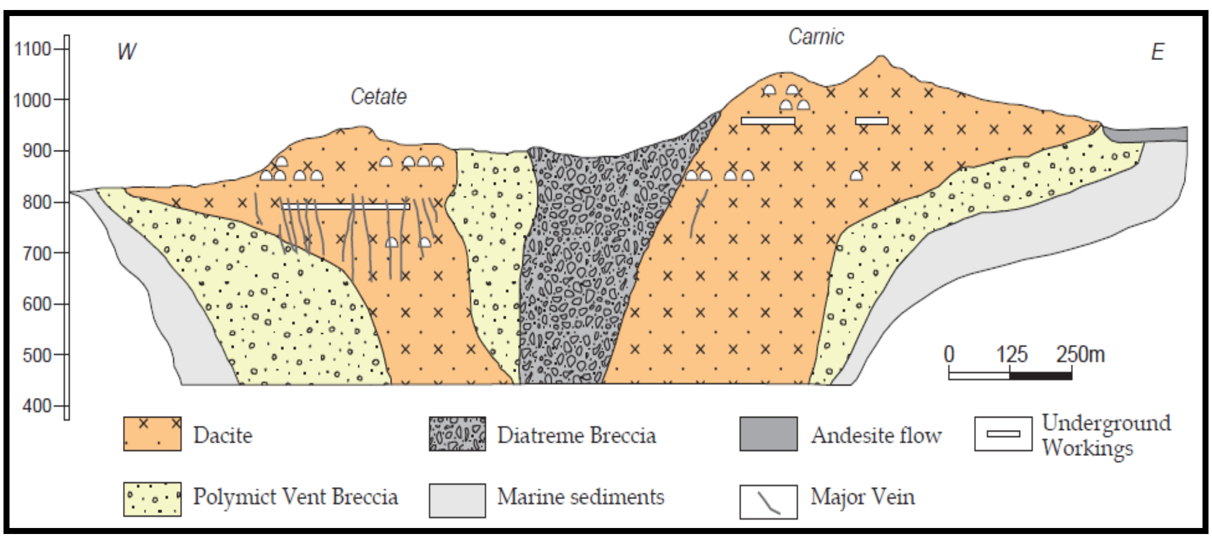


Figure 27 Geological cross-section through Carnic and Cetate Dacitic intrusions of Roşia Montană Au-Ag deposit, Spuseni Mountains, Romania (O'Connor *et* al., 2003; Sahy and Schütte, 2006).

5.4 Carbon footprint

5.4.1 Introduction

Romania has harmonised its mining legislation according to the European Union requirements for environmental protection. The Mining Law no. 85/18.03.2003, adopted by the Romanian Parliament, obliges mining companies working in Romania to meet a high standard of environmental best practices. Regarding the greenhouse gas emissions, the Order of the Ministry of Environment and Water Administration no. 1175/2006 for the approval of the "Guidelines regarding the monitoring and reporting of greenhouse gas emissions", stipulates that operators have an obligation to monitor and report the greenhouse gas emissions generated by the sources belonging to their operations. One of the activities stipulated by Annex no.1 of GD no. 780/2006 is performed and the greenhouse gas emissions in relation with the respective activities, with the exception of the emissions generated by the internal burning engines in the transport sector (Deva Gold, 2011). The methodology regarding the calculation of burning emissions and process emissions for the specific activities is stipulated in the annexes of this order (Deva Gold, 2011).

In 2006, mining ceased in Roşia Montană, so there are no current carbon emissions caused by any mining activity. Considering that the Roşia Montană project is set to become one of the largest gold operations in Europe, a careful carbon footprint project is essential. The CO_2 emissions were estimated based on the planned equipment selection, the production schedule (Roşia Montană Project. Feasibility study – final) and using the industry norms (Table 14) (Bobar, 2009).

Table 14 Assumptions made in order to estimate CO_2 emissions (Bobar, 2009).

Emission source	Emission type	Volume/units
Electrical power	50 MWh	
Fuel	diesel	2.7 kg CO_2/L
	gasoline	2.3 kg CO_2/L
Energy Blend Type	Electricity EU	0.375 kg CO_2/kWh
	Electricity RO	0.737 kg CO_2/kWh
Concrete*	concrete use for initial construction period	36 795 m^3
	concrete use for sustaining construction period	1 665 m^3
	concrete use for closure construction period	640 m^3
Deforestation**	deforestation in yr 0	50 ha
	deforestation in yr 7	135.3 ha
	deforestation in yr 14	47.9 ha
	deforestation in yr 16	18.8 ha

*the ratio of cement is 300 kg per 1m^3 of concrete and 0.6 t CO_2 are emitted per tonne of cement
**1 ha of forest consist in 140 m^3 of wood and 0.5 t CO_2 are lost per m^3 of wood

5.4.2 Estimated CO_2 emissions

It is estimated that the Roşia Montană project will produce 241 856 t of CO_2 emissions a year (Bobar, 2009). These emissions were calculated by combining together all the carbon emitting activities including: the mining cycle (drill, blast, load, haul), processing cycle (crushing, grinding stages, onsite smelting) and transport and delivery of materials and goods; they do not include transport of the product (gold) once it leaves the mine site. The estimated CO_2 emissions are summarised in Table 15 and Figure 28:

Table 15 The CO_2 emissions during the mining and processing of 13,400 000 tonnes of ore per year (Bobar, 2009).

Resources	Annual avg. quantity	CO_2 emissions (t/year)
Mining		
Gasoline	820 000 L	1 886
Diesel Fuel	16 458 000 L	44 437
Deforestation	250 ha	17 637
Total		63 960
Processing		
Gasoline	500 L	1.15
LPG*	5 214 t	9 906
Electricity	410 000 MW	163 374
Reagent Transport	25 truck/day	4 615
Total		177 896.15

*LPG - liquefied petroleum gas

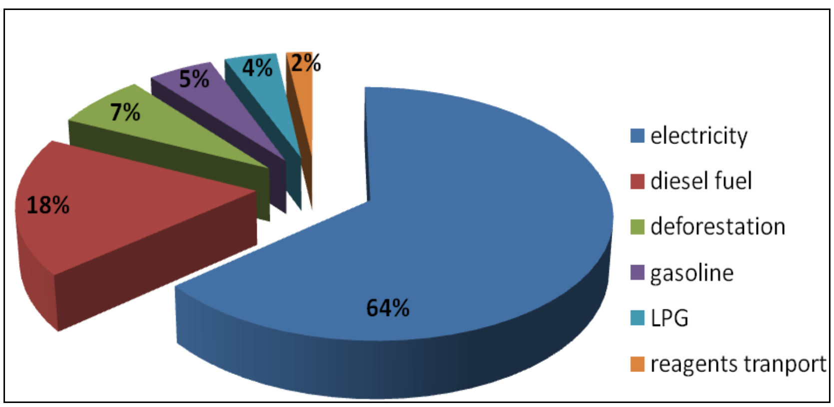


Figure 28 CO_2 emissions from different sources (Bobar, 2009).

5.4.2.1 CO2 emissions from mining activities

It was estimated that during Roşia Montană project, the mining activities will produce 63 960 t of CO_2 a year, which represents 26.4% of the project's total carbon footprint. The two major contributors, regarding CO_2 emissions caused by the mining activities, are the fossil fuel consumption (19.15%) by the heavy equipment (haul trucks, drill rigs, loaders and other) required for open pit operations, and the deforestation (7.25%).

Fossil Fuel Consumption

The burning of one litre of gasoline produces 2.3 kg of CO_2, while one litre of diesel produces 2.7 kg CO_2 (Bobar, 2009). It was estimated that the mining activities will require an average fossil fuel consumption of 17 278 000 L/year (820 000 L/year for gasoline and 16 458 000 L/year for diesel). As such the fossil fuel burning will release 46 323 t of CO_2 per year, which represents 19.15% (0.78% for gasoline and 18.37% for diesel) of the project's total carbon footprint (Bobar, 2009; RMGC Staff, 2009). Both the lead up construction period and the actual mining operations will require heavy mobile equipments and vehicles which require fossil fuel. The initial construction period is expected to last two years prior to operations. The mobile equipments and vehicles required during the construction phase are listed in Table 16 (Bobar, 2009; RMGC Staff, 2009).

Table 16 Mobile equipment and vehicles for construction phase (RMGC Staff, 2009).

Type of equipment/vehicle	Units
IR 270 MP auger bit	2
Hydraulic Shovel	2
CAT 992 G Loader	1
CAT 758 C Tipping lorry	3
CAT D9R Bull Dozer	3
CAT 834G Loading Bull Dozer	2
CAT 16H Moto Grader	2
CAT 777D Water Tanker	2
CAT 988 Loader	1
CAT 773D Haul Truck	1
IR ECM 590 Drill	1
325 BL Hydraulic Shovel	1

The mining process will require a much broader range of equipment, which can be broken into five basic steps: drilling, blasting, crushing, handling, and transport. Proper grading of the landscape and dust control is also essential. Each activity will require various pieces of direct equipment as well as support equipment to complete the task at hand. The estimated mobile equipment required, their respective quantities and capacities are summarized in Table 17.

Table 17 Mobile equipment and vehicles for operation phase (RMGC Staff, 2009).

Type of Equipment	Units	Class/Capacity (preliminary data, subject to change)
Primary Equipment		
Drills	3	9-11 inch diameters
Hydraulic Shovel	3	19.5 m^3

Wheel Loader	1	22 t
Haul Truck	29	150 t
Track Dozer	3	354 kW/474 HP
Wheel Dozer	2	392 kW/525 HP
Motor Graders	2	198 kW/265 HP
Water Truck	2	70,000 L capacity
Wheel Loader	1	350-400 KW, 6-7m^3 bucket
Rock Drill	1	107kW/144 HP
Excavator	1	140kW/188 HP
Support Equipment		
Fuel Truck	1	10 t
Lube Truck	1	10 t
ANFO Explosives Truck	1	
Tire Handler	1	
Welding/Mechanics Truck	1	
Mobile Crane	1	~ 80 t
All Terrain Crane	1	~30 t
Boom Truck	1	12 – 18 t
Rough Terrain Forklift	1	
Equipment Trailer/Tractor	1	
Flatbed Truck	1	
Pickup	14	4 x 4 twin cab
Semi-Mobile Crushing Plant	1	
Portable Light Tower	6	

The haul trucks necessary will not be acquired all at once, it will follow the acquisition schedule from Figure 29.

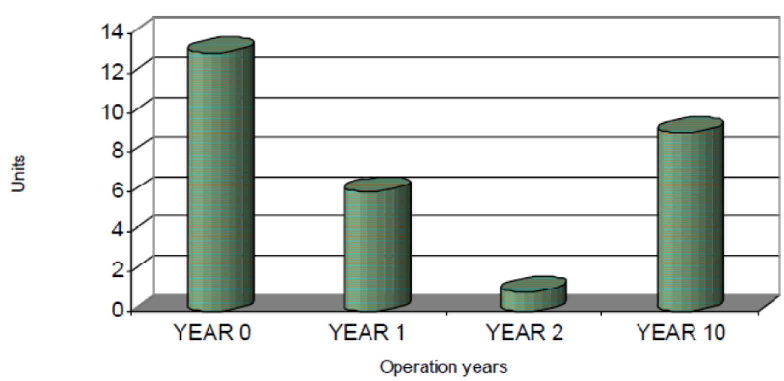


Figure 29 Haul truck acquisition schedule (Bobar, 2009).

Each piece of equipment has a known rate of CO_2 emission. In order to calculate CO_2 emissions caused by the activity of the 25 delivery trucks, it was assumed that the trucks travel a distance of 100 km/day, during 5 days/week, 52 weeks/year, generating 7.1 kg CO_2/km (formula 1). As such, the activity of 25 delivery trucks cause 4 614 t of CO_2 emissions a year (Bobar, 2009; RMGC Staff, 2009). It should be noted that carbon emissions related to workers transport are relatively negligible compared to other emissions (Bobar, 2009). As most workers are likely to live in the surrounding area and buses/personnel vehicles burn relatively small amounts of diesel, these emissions have not been accounted.

$$25_{trucks} \cdot 100_{km/day} \cdot 7.1_{kgCO_2/km} \cdot 5_{days/week} \cdot 52_{weeks/year} = 4615_{tCO_2/year} \qquad (1)$$

Mine Site Deforestation

In order to recover the ore, it is necessary to clear-cut a significant surface of forest. This will affect the amount of CO_2 that will be absorbed each year by the forest, increasing carbon footprint of the operation. It is estimated that approximately 250 ha of indigenous forest will be deforested during the project life (17 years) (Bobar, 2009). From 61 500 m^3 of investigated forest, approximately 35 000 m^3 will be gradually deforested in 4 steps: 50 ha (in yr 0), 135.3 ha (in yr 7), 47.9 ha (in yr 14) and 18.8 ha (in yr 16). This will decrease the carbon absorption with: 3 500 t CO_2/year in the first 7 years, 12 970 t CO_2/year between year 7 and 14, 16 320 t CO_2/year between year 14 and 16, and 17 630 t CO_2/year in year 16. Carbon sink was estimated considering that each hectare of indigenous forest contains 140 m^3 of wood and each cubic meters of forest can sink 0.5 t of CO_2. The new planted forest area is growing with 7.6 m^3/ha/year after year 5, based on the information obtained from forestry planning documents (Bobar, 2009).

5.4.2.2 CO2 emissions from ore processing

For the Roşia Montană project, the ore processing cycle will represent the important source of CO_2 emissions (73.6%) (Bobar, 2009; Keech, 2010). It is estimated that a quantity of 13.4 Mt of ore will be processed each year, resulting in 177 896.15 t of CO_2 emissions a year. The ore processing CO_2 emissions are related to the electricity consumption, gasoline and LPG consumption, and reagent transport.

Electricity consumption

It was estimated that the ore processing requires a total electricity consumption of 410 000 MW each year. This will produce 163 374 t of CO_2 emissions a year, which represents 64% of the project's total carbon footprint. The entire processing plant and administrative buildings will be run by electricity, except a small part which requires LPG. In Romania, the majority of the country's power supply is provided by burning coal, and each KWh produced from different sources (blends) releases an average of 0.737 kg CO_2 into the atmosphere (Bobar, 2009; Keech, 2010). This is nearly double compared to the EU average value of 0.375 kg CO_2 per KWh. In this case, RMGC is required to purchase energy which produces CO_2 emissions at nearly double the EU average (Bobar, 2009). The only way for RMGC to reduce the carbon footprint of its electricity consumption will be through emission reduction strategies.

Gasoline consumption

Gasoline consumption during the ore processing, produces a relatively small carbon footprint. The gasoline consume is estimated at 500 L/year, which will produce 1.15 t of

CO_2 emissions a year (0.0004% of the project's CO_2 emissions) (Bobar, 2009). The gasoline consumption is mainly due to the equipment and vehicles involved in the processing operation. Since all the equipment and vehicles use the best available techniques (BAT), gasoline consumption is not a priority in this case.

LPG consumption
5 214 t of LPG will be consumed by the processing plant each year, producing 9 906 t of CO_2 each year. The LPG will be used predominantly in the cyanide leaching process. LPG will be used in the heating and ventilation system of the onsite administrative building (Bobar, 2009).

Reagent transport
The mine site and processing plant do not have direct access to any ports or rail lines. As such, all the required reagents and major consumables must be transported to the mine site via trucks. It is anticipated that in order to meet these demands the processing plant will require 25 truckloads of supplies a day, 5 days a week. Assuming an average 100 km travel distance producing 7.1 kg of CO_2 per kilometers operating 52 weeks per year; this results in 4 615 t of CO_2 output per year (formula 1). This accounts for 1.9% of the project's total carbon footprint (Bobar, 2009; Keech, 2010). .

Considering all these aspects it was estimated that The Roşia Montană project will produce 16.15 kg CO_2 per tonne of processed ore (Bobar, 2009; Keech, 2010). By comparing the CO_2 emissions from Roşia Montană with other international mining projects (which consists of similar gold deposits and size), it proves that CO_2 predictions were realistic and are relatively low (Figure 30). RMGC plans to minimise their carbon footprint to a level as low as it is reasonably practicable; with the stated aim of reaching carbon neutral by the end of the mine life (year 17).

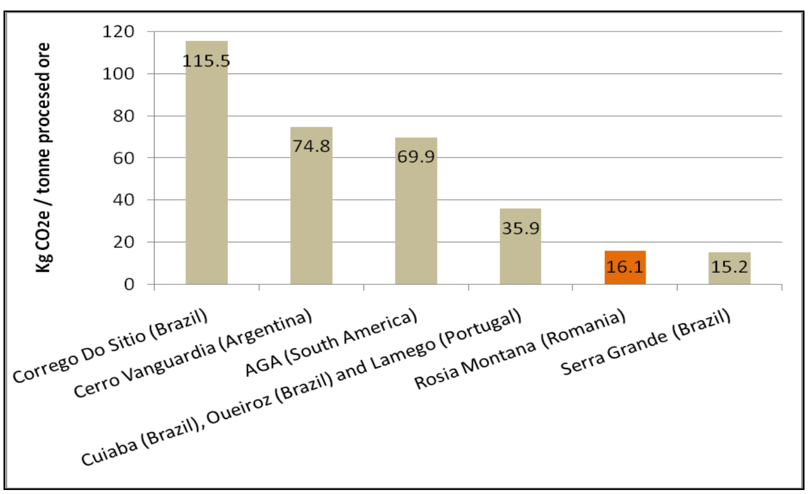


Figure 30 The emissions of CO_2 per tone of processed ore in several mining projects comparable (size and type) with Roşia Montană (Bobar, 2009; Keech, 2010).

5.5 Mitigation measures and CO_2 reduction strategies

Some of the possible CO_2 reducing strategies for The Roşia Montană mining project were detailed in this chapter. As it was mentioned in this chapter, the stated goal of RMGC is for the project to be "Carbon Neutral" by the end of the mine life (year 17). RMGC has explored three strategies in order to achieve this goal: (1) purchase green credits from emissions market (Carbon Trading); (2) invest in cleaner technology and "green energy" (wind, solar, hydro, etc.); and (3) develop a "carbon sink" reforestation programme in the project area (Bobar, 2009). Possible sites include the Apuseni Mountains.

At present, there is a weak carbon trading market within Romania. As a consequence this option is not feasible at this time for Roşia Montană project. At the moment, there are no opportunities to invest in "green energy" (wind, solar, hydro, etc.) in the Roşia Montană area. In order to reduce the CO_2 emissions, RMGC will invest in cleaner technology by using the best available techniques (BAT). On the other hand, the Apuseni Mountains area is heavily affected by the forestry industry, approximately 600 ha of forest are lost a year. As a consequence under the present circumstance surrounding The Roşia Montană mining project, reforestation represents the most feasible option for the reduction of CO_2 emission.

Different reforestation "carbon sink" scenarios for The Roşia Montană mining project were presented in Chapter 4. It was estimated that a total of 8 000 ha of "carbon sink" indigenous forest must be planted for the project to become carbon neutral by year 17. The estimated cost for this operation is of 5 million USD. Unfortunately at this time the reforestation of 8 000 ha is not feasible. On the other hand if the Romanian energy sector is able to align with the EU energy standards, in order to generate 0.375 kg CO_2 emission per kWh, the project will require only 5 000 ha of new indigenous forest; at a total cost of 3 million USD. RMGC has been committed to reforestation of 1 000 ha of land. Considering the Romanian power blend this will result in a period of 50 years until carbon neutrality is achieved. If Romania aligns to EU emissions requirements (0.375 kg CO_2/kWh) the time range will be shorter ~ 39 years (Bobar, 2009).

5.6 Impacts of Roşia Montană mining project implementation

5.6.1 The actual economical and social status of Roşia Montană

Apart from forestry, subsistence-level agriculture and tourism, mining is the main source of employment in Roşia Montană area. 57% of people in employment used to work in the extractive and processing industry (Richards, 2005). Incomes are generally low, even by Romanian standards, with average annual household monetary incomes of 1 805 USD, or 653 USD per capita (EGS International, 2003). Roşia Montană mine closed in 2006 leading to the loss of significant numbers of employees. The population is in a significant state of poverty and lack of financial capability to enable people to start businesses. The financial capability of the local public administration is low.

The community includes 39% of the ‘active population’ (people who contribute to the registered economy) and 61% who are classed as ‘inactive’ (people who are not contributing directly to the registered economy, who are not registered as unemployed, who do not have official employment, who do not pay tax, who do not receive unemployment benefits, who may receive pensions or sickness-benefits, and who may be involved in unregistered economic activity). The population in the area is aged and has a high proportion of women compared to men (EGS International, 2003). There is tendency for a decrease in the overall population, a fact noticed at regional level as well.

In terms of the cultural and historical heritage, the economic decline of the area, that started a while back, got worse in the last years and it reached a peak once the mining activities were closed in 2006 and it had an evident impact on the status of this heritage. As mentioned before, the historical monuments at Roşia Montană are in various degradation stages, from minor cracks to pre-collapse stage. Under Law No. 422/2001, the responsibility to suitably maintain, consolidate, restore and use the historical monuments lies with the owner (http://www.kvvm.hu/cimg/documents/Kornyezeti_jelentes_angol_nyelven_a_verespataki_iparfejlesztesi_ovezet_modositott_ovezeti_telepules.pdf). Some of the heritage structures are abandoned and in most of the situations, the owners do not have the financial resources required to restore them.

5.6.2 Socio-economic impacts of RMGC Project implementation

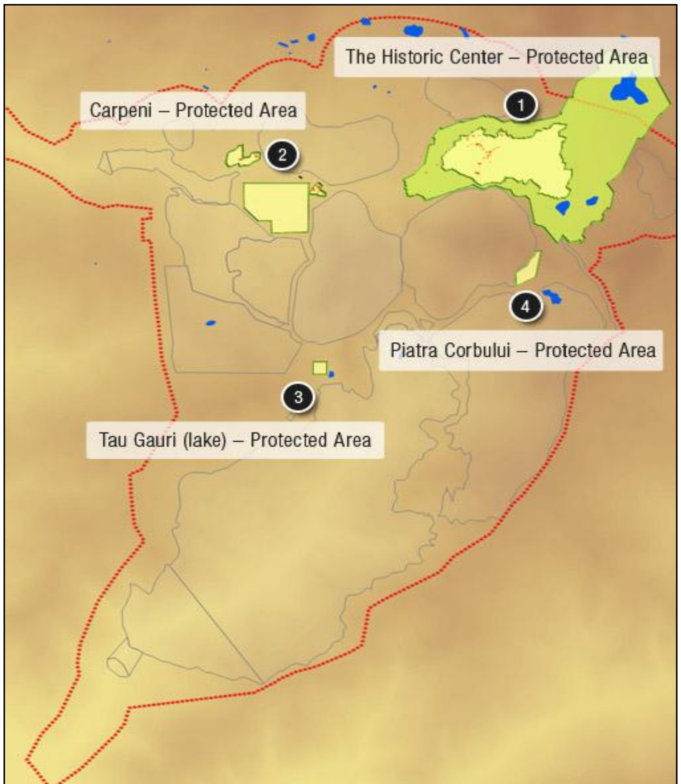
The mining project proposed by RMGC is not in contradiction with other economic development projects in the area - on the contrary, it may act as a catalyst for any such projects. The direct socio-economical impact of the project is felt notably in the communes of Roşia Montană and Bucium, as well as in the town of Abrud. These localities have a long-lasting mining tradition, and they are strongly affected by the current situation. In fact, the mining disappeared with the closure of the two state exploitations: RosiaMin and CupruMin, leaving over 1 200 people unemployed. As a result of the acute lack of jobs, people - especially the young ones – are leaving the area for developed urban areas in the country or abroad. Consequently, the area is going through a continuous depopulation and demographic ageing process.

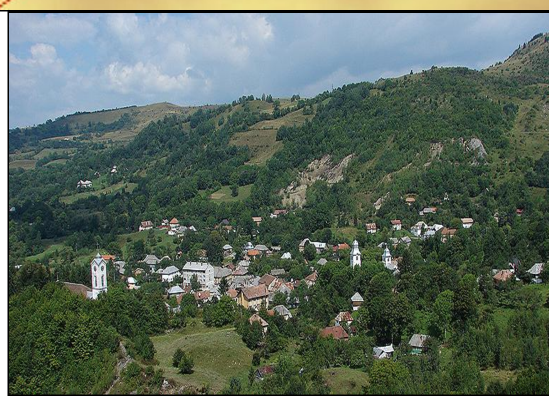
The business plan of the mining project provides for total benefits of approximately 4 billion USD for the Romanian economy. Out of this amount, 1.8 billion USD will go directly to the State budget (http://en.rmgc.ro/rosia-montana-project/economy.html). These funds include the dividends obtained by the Romanian State, which holds 20% of the RMGC’s assets, royalties paid by RMGC, as well as other taxes and duties paid directly to the local, regional and national State budget. The remaining 2.2 billion USD will be spent in Romania for human resources, construction, electricity, materials, reagents transport, spare parts and others (http://en.rmgc.ro/rosia-montana-project/economy.html). These amounts are a direct investment in the Romanian economy and will reach the workforce, the entrepreneurs and the Romanian companies which will provide products and services for RMGC, during the construction and the operation phases (http://en.rmgc.ro/rosia-montana-project/economy.html).

At the community level, The Roşia Montană Project will generate the following benefits http://en.rmgc.ro/rosia-montana-project/economy.html; http://en.rmgc.ro/rosia-montana-project/community.html; http://en.rmgc.ro/rosia-montana-project/patrimony.html):

- The mining project will create over 2300 direct jobs during the mine construction phase, 800 direct jobs during the exploitation and 3000 jobs in total during operation.
- The revenues to be earned by the employees will be twice as high as the average salary earnings at the level of the national economy.
- New jobs will be created by the development of businesses in the area as a result of the acquisition policy pursued by RMGC, the outsourcing of services and the increased buying power of the population.
- Granting of substantial dollar compensations much above the previous market value for the properties acquired by the Company. With the obtained money, people can not only rebuild their households, but also start up their own businesses.
- Major contributions to the local and state budgets, which will help develop public utility investments in the area. The total amount of the taxes, duties and dividends to be paid during the project exploitation period exceeds 1.8 billion dollars.
- Development of a modern infrastructure, which can also be utilized after the end of the project. The logistic facilities necessary for the project, respectively roads, infrastructure, houses, schools, public utility services, are built by the investor and belong to the community.
- Micro-crediting facilities and proper training programmes meant to foster entrepreneurship in the area.
- In supporting the local investors, RMGC has also created Roşia Montană MicroCredit, a micro-financing institution aimed to support entrepreneurship at the local level. However, due to the present stage of Roşia Montană Project, the MicroCredit activity has been temporarily suspended but will be resumed when the time is right.
- Conservation of the historical and cultural heritage as a result of the archaeological research programmes financed by the Company.

The cultural patrimony in Roşia Montană can bring numerous visitors in the area, as long as it is well preserved, restored and displayed. Nowadays, the Roman galleries are unsafe and difficult to access, whilst the historical buildings badly need repairing. In the future, with massive investments in infrastructure and patrimony rehabilitation, financed by the mining project, Roşia Montană will be able to finally take pride in its cultural heritage (Figure 31).





Historical centre – protected area

Carpeni - protected area (Roman building)

Figure 31 Important protected patrimony area in Roşia Montană (http;//en.rmgc.ro/rosia-montanaproject/patrimony.html).

5.6.3 Environmental rehabilitation

An important aspect of RMGC project is the environmental protection, for both past and future mining activities. Currently, the Roşia Montană area is quite severely contaminated by acid mine drainage flowing from approximately 150 km of underground workings, waste rock piles, and tailings. Abandonment of the Rosiamin mining operation would likely exacerbate this problem, because workings would be allowed to flood and waste impoundments, which are already of dubious stability, might not be maintained (Richards, 2005). The RMGC mine plan includes provision for "management of site water, including historically contaminated run-off and seepage in Roşia Montană Valley by development of a water catchment dam and then pumping of the water to a treatment plant, for treatment and discharge" (Richards, 2005). Mine tailings will be impounded in a specially designed facility in the Corna Valley (250 Mt capacity), and waste rock will be piled close to the mine workings. Waste rock piles will be progressively rehabilitated during mining, and tailings will be stabilized and remediated upon mine closure. The costs related to the rehabilitation and closure of the mine from Roşia Montană will be fully incurred by Roşia Montană Gold Corporation (RMGC). At the beginning of each year of mining operation, RMGC will deposit the entire amount estimated for environmental rehabilitation and long-term monitoring in a specially established account – Financial Guarantee for Environmental Rehabilitation (FGER), so even before the mining operations begin, environmental rehabilitation is guaranteed. This account can only be accessed by the competent governmental authorities and with the purpose of environmental rehabilitation. In addition, in response to specific concerns about the use of cyanide in processing, the mine plan has recently been revised to include cyanide-detoxification in the waste water circuit (http://en.rmgc.ro/rosia-montana-project/environment/closing-and-rehabilitation.html).

During the mining project, the best available techniques (BAT) in all the operations and activities it will be used in order to enhance environmental protection (including low carbon footprinting) in all the operating phases of mine and make sure there are sufficient financial resources to fulfil all of environmental obligations and commitments, including re-integration of the exploited areas in the natural circuit. RMGC project will try to maintain, to the extent possible, the continuous landform features and minimise topographic changes, landslide-stop, will improve the hydro regime in the area (irrigation, drainage, measures against erosion). It will arrange green spaces and buildings to achieve continuity of the natural landscape and create aesthetic structures.

5.7 Conclusions

Since 2006, Roşia Montană mine is closed, so there are no current carbon emissions caused by the mine activity. Considering that Roşia Montană project is set to become one of the largest gold operations in Europe, a careful carbon footprint project is essential.

The activities that generate significant CO_2 emissions during the construction, operation and closure of Roşia Montană project include: the electrical power demand for ore processing, the fuel consumption for the heavy equipment used for operation, deforestation of 250 ha in order to make space for the industrial project, the supplies transport for construction and operation stages, the use of concrete, mainly during the construction of the project (Bobar, 2009). It was estimated that the carbon footprint caused by the mining and mineral processing operations as well as supply transport, will be 241 856 t of CO_2 emissions a year, that is 16.15 kg of CO_2 per tonne of processed ore. Processing and transport account for 73.6% of total CO_2 emissions, while mining activities account for 26.4%. The indirect emissions, due to purchased energy, accounts for 64% of total CO_2 emissions (Bobar, 2009).

At present, CO_2 emissions produced per kWh in Romania (0.737 kg CO_2) are nearly double that of the European Union average (0.375 kg CO_2). The main goal of the RMGC is for the project to become carbon neutral by the end of the mine life (year 17). The company has investigated three means of achieving this goal: (1) purchase green credits from emissions market (eg. Carbon Trading), (2) invest in cleaner technology and “green energy” (wind, solar, hydro) and (3) develop a “carbon sink” reforestation programme in the project area (Bobar, 2009).

RMGC has been committed to reforestation of 1 000 ha. Considering the Romanian power blend (0.737 kg CO_2/kWh) this will result in a period of 50 years until carbon neutrality is achieved. If Romania aligns to EU emissions requirements (0.375 kg CO_2/kWh) the time range will be shorter - 39 years (Bobar, 2009).

RMGC project represents the first major mining investment in Romania in 30 years. The mining project has the potential to generate significant wealth for the region and country, both directly through royalty, tax, and salary payments, and indirectly through the generation of secondary businesses and investment. An important aspect of RMGC project is the environmental protection, for both past and future mining activities.

Chapter 6 Conclusions

Whilst all mines are similar in premise: valuable material is removed from the ground, processed and sold; each mine is unique. Unlike other industries, where factories and plants are designed and built to a certain specification, we have to mine minerals in the conditions they are foundem. This may be the far north of Canada, where materials can only be brought in and out for a few months of the year and temperatures dip below – 50^0C, or Western Australia where access to water is limited for much of the year and temperatures soar above 40^0C. This means that the carbon footprint of each operation is unique to that operation and mitigation measures will also have to vary. Every case must be considered individually;, there is no broad stroke solution to mining GHG emissions, and no one size fits all answer. Rather each case must be carefully analysed and then the most effective solutions applied.

For operations to deal successfully with the issue of GHG emissions the first step is the development of effective carbon footprint management policy and best practice guidelines. Multinational mining companies have operations all over the world differing in everything from: geographical location, deposit type, mining method, material being mined, and geopolitical climate. Each mine will probably have to meet different standards, answer to different regulatory bodies, and comply with different legislation. In addition to this, each site will be most amenable to different techniques and renewable energies. Just as a conveyor system won't work in northern Canada, a haul ramp would be inappropriate in a 3 km deep South African gold mine. For any organisation to succeed in reducing its carbon footprint, its plan of action must be able to adapt effectively to individual projects. As mentioned in chapter 1 while there is no definitive set of standards or best practice guidelines regarding carbon footprint management, , one of the most effective tools is ISO14000. This allows companies to develop a practical and effective environmental management system, which is flexible enough to adapt to the regulatory expectations of a given project; be it in Zambia or Sweden. ISO14000 stresses high standards and constant re-evaluation and improvement. It allows an environmental management system to adapt to changing regulations and expectations as well as changing technological advances.

Despite actions like the Kyoto protocol, it is in unlikely that in the near future there will be an international set of guidelines or expectations enforced by governments outlining the best practices of carbon footprint management. Expectations and standards must therefore be industry lead. Only major corporations and leaders in the industry (such as the members of ICMM) can commit to responsible carbon footprint reduction both in countries that demand it and those that do no't. As more companies begin to employ low emission technologies, costs will decrease and the availability will increase, encouraging smaller and less influential companies and organisations to meet higher expectations of GHG reduction.

The Roşia Montană project provides an excellent case study to examine the carbon footprint of a proposed mining operation. Roşia Montană is a world class gold deposit in a historic mining area that is currently in the predevelopment stage. It provides an excellent example of a company that has fully examined the extent of its potential carbon footprint and investigated potential mitigating factors. As mentioned in chapter 5, the Roşia Montană project is expected to produce 241,856 tonnes of CO_2 per annum, which equates to 16.15 kg of CO_2 emission per tonne of processed ore. Roşia Montană is in Romania, an EU member nation that must comply with EU standards and regulations, but also a nation only recently out of the communist regime and still attempting to 'catch-up' in a democratic society. It provides the unique opportunity of examining a, until recently, developing nation reaching to meet developed world standards. An example of this is the fact that the project must still purchase all electricity from government owned coal plants which produce CO_2 emissions at nearly double the EU standard. This in turn accounts for 64% of the project's CO_2 emissions, providing unique challenges to reduction strategy. One of the few GHG reduction options available to RMGC is reforestation. Other options such as 'green energy' and carbon trading are not available in Romania at this time. RMGC has committed to planting a 1000 Ha of trees in attempts to offset carbon emissions; this means that it will take the mine 50 years to become carbon neutral. The Roşia Montană project is an excellent example of a company willing to take measures to reduce their carbon footprint but restrained by outside forces. That said Roşia Montană is yet to begin production meaning that if the RMGC continue a proactive approach to CO_2 emissions reduction and develops an effective environmental management system there is reason to believe significant improvement can be achieved.

GHG reduction technologies range from the expensive and complex (e.g. Solar power and the organic rankine cycle), to the simplistic and inexpensive (e.g. planting trees). It is essential that the needs of the individual project be fully understood and that the most appropriate measures be taken to manage GHG emission correctly. As no two projects are the same, each will require its own unique combination of reduction strategies. Whilst large scale solutions such as wind turbines produce largereductions and receive much publicity, their sheer size and the investment required makes them unattainable for all but the largest companies. In the future we are likely to see a combination of small-scale cost effective GHG reduction methods working in unison to reduce the carbon footprint of a project. These small but effective methods are within the means of all but the smallest operations and have the ability to significantly reduce GHG emissions. As more companies make GHG reduction a priority, and as governments tighten regulation, emission-reducing technologies will improve and prices will fall. Given a proactive approach and innovative thinking the mining industry has all of the resources available to significantly reduce GHG emission on a global scale and control carbon footprints.

6.1 Recommendations for Further Research

This report has provided a broad overview of carbon footprint in the mining industry and raises various questions. An area with particular room for growth is that of GHG reducing technologies. Whilst renewable energy and emissions reducing technology have been widely studied and written about, there is still limited information available concerning the application of these technologies to the mining industry. Further research could be completed on any one of the technologies discussed in chapter 3.

Areas of particular interest would be how that particular emissions reducing method performs over the long term and a full cost benefit analysis. Another interesting study would be to compare how the GHG emission reduction strategy for the Roşia Montană project performs and changes after production begins. This would provide information on how to improve GHG emissions projections and plans when projects are being designed.

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