The IMRE Journal Volume 6 (2) 2012
2012. TU Bergakademie Freiberg
http://www.wiwi.tu-freiberg.de/~urm/imre/ej

Formulation of Strategies for Implementing an Industrial Ecology Framework in the Colombian Mining Sector

Irma Jineth Rosero Reyes

Technische Universität Bergakademie Freiberg

Correspondence:
ijroseror@gmail.com

Revised: 16.11.2012
Online Publication Date: 06.12.2012

Abstract

At present, Colombia is facing increased growth in the mining industry; this has sparked a discussion around both positive and negative effects on Colombia's economy, environment and communities. Moreover, the Colombian mining sector has come under tremendous pressure to improve its sustainable development. The Industrial ecology (IE) framework provides a useful systems perspective and innovative solutions to support sustainable development. In this paper the current state and desired end state of the Colombian mining sector in terms of sustainable development are discussed. Besides, the role of the IE framework in meeting sustainable needs of the Colombian mining sector has been analyzed, and the critical factors for a successful implementation of industrial ecology have been identified. The paper provides ten strategies for implementing an IE framework to face the sustainable development needs of the Colombian mining sector.

Keywords: Colombia mining sector, industrial ecology, sustainable development, strategies.

Introduction

The mining industry is the supplier of primary materials for different industrial activities worldwide; as such, it has great importance in the world‘s economy. However, mining activities affect not only on the local economies but also the community welfare and the surrounding environment. It is therefore crucial for the mining industry, and desirable for the community, to move towards a sustainable development that will allow the development of the mining sector based on the wise use of economic, environmental and social resources.

The Industrial ecology (IE) framework provides a useful systems perspective and innovative solutions to support sustainable development. It is a broad, holistic framework for guiding the transformation of industrial systems from a linear model to a closed–loop model that resembles the cyclical flows of ecosystems and which makes a greater contribution to sustainable development.

This paper describes the implementation of an IE framework to face the sustainable development needs of the Colombian mining sector. Considering that a successful implementation of industrial ecology requires strategies that address its implementation, the main objective of this paper is to provide the strategies for implementing an industrial ecology framework in the Colombian mining sector. In addition to the primary objective, the paper focuses on the following three objectives: (1) To describe the current state and desired end state of the Colombian mining sector in terms of sustainable development. (2) To analyze the role of IE framework in meeting industrial sustainable needs. (3) To identify the critical success factors for the implementation of an IE framework in the Colombian mining sector.

1. Methodology of the Research

The methodology to achieve the objectives of the paper is shown in Figure 1.1.

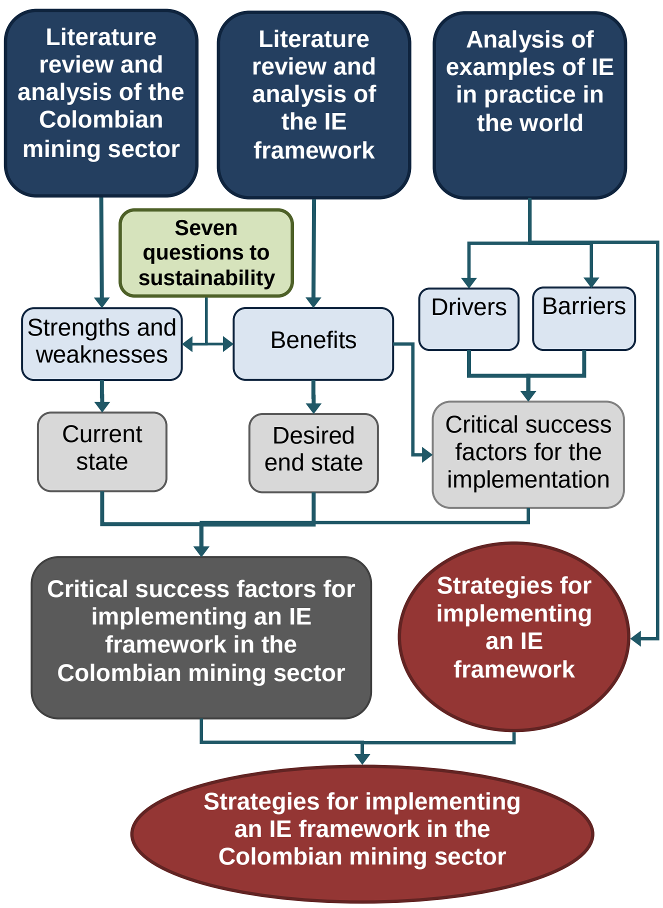


Figure 1.1. Methodology of the research. Source: Author

The strategies formulation process starts with a review of the information about the Colombian mining sector and its performance towards a sustainable development. Based on the "Seven Questions to Sustainability" (proposed by the Mining, Minerals and Sustainable Development Project in 2002, see Parks, 2006, p.25-29) this information is analyzed and the strengths and weaknesses of the Colombian mining sector in terms of sustainable development are identified.

From the strengths and weaknesses, the current state of the mining sector is analyzed with the aim of having a concise and clearer picture of the facts that help or limit (respectively) the progress towards sustainable development in the Colombian mining sector.

Analogously, a literature review of an IE framework is conducted. The analysis of the industrial ecology literature, guided by the "Seven Questions to Sustainability", allows for an identification of the benefits of implementing an industrial ecology framework. These benefits constitute the basis for describing the desired end state of the Colombian mining sector. The desired end state gives us a picture of what the Colombian mining sector can expect to reach in terms of sustainable development through the implementation of an IE framework.

The next step in the methodology is the identification of the critical success factors for implementing an IE framework. These factors help in selecting the strategies, from the wide range of strategies recognized in the examples of IE in practice in the world, for implementing industrial ecology in the specific case of the Colombian mining sector. The critical success factors are identified from the analysis of the benefits, drivers and barriers to the implementation of an IE framework.

The analysis of the gaps between the current state and the desired end state of the Colombian mining sector, allows reducing the list of the critical success factors into a shorter list. The shorter list contains those critical success factors that require high priority attention for reaching the desired sustainable development in the specific case of the Colombian mining sector.

Based on the shorter list of critical success factors, the strategies for implementing an IE framework to face the sustainable development needs of the Colombian mining sector are selected and formulated.

2. The mining sector in Colombia

The mining sector in Colombia has great importance in the country's economy since it provides the raw material necessary for the performance of diverse industries, contributes around 2.3% to the country's annual GDP and is a generator of employment. Although Colombia is not a world leader in mining, it is an important supplier of coal in the world; additionally, mining activities in Colombia have a big "footprint" in terms of their impact on the community's local economy and the environment.

General overview of the mining sector

The mining activities in Colombia date back to the pre-Columbian era, when indigenous ancestors mined minerals for jewelry used in rituals (Rodado, 2010). Since 2002, the Colombian mining activity has shown a significant growth in the production volume and value, as well as in its export quota, consequently, its contribution to the growth of the national economy has been sustained (UPME, 2006). The important performance of the mining sector is basically explained by three factors: (1) the growing development of coal, precious metals and ferronickel mining; (2) the mineral potential of the country that is held in a topography still largely unexplored and (3) a government that encourages mining and foreign private investment (Superneau, 2010).

The mining sector in Colombia focuses on producing raw materials and does not typically engage in secondary mineral reprocessing activities. The main activities of this sector include mineral exploration, mining exploitation, beneficiation, smelting, refining and commercialization. Mining activities are typically conducted as a series of discrete steps, or unit-ops: drilling, blasting, cutting and excavating; ground control; loading and hauling and material processing. The ore bodies are mined by both underground mining and surface mining methods. However, a wide range of environmental, cultural, and socioeconomic resources can be potentially negatively impacted by mining activity (Hilson, 2000), which has generated pressure on the sector in issues related to sustainable development, employment, occupational health, safety, local development and rehabilitation of any environmental damage.

Strategic minerals in Colombia

The most representative minerals of the country in terms of volume, value and employment generation are coal, gold, ferronickel and construction materials (UPME, 2004). Colombia is the first coal producer in Latin America and the world's tenth. Colombia is the fourth largest exporter of Coal worldwide. It is estimated that its total reserves amount to roughly 17 billion tonnes of which 7 billion tonnes have been found. In the year 2009, 72.3 million tonnes of coal were mined (CIMC et al., 2010).

According to UPME (2004), the large coal mining industries in Colombia have shown a significant improvement in terms of technology, environmental and organizational concerns. The generation of employment in the coal mining industry is important and its activities are distributed in the respective coal areas across the country.

Gold production in Colombia comes from small and medium scale mining and the typical operations are carried out by one person or a small group of people. In most of the Colombian regions, gold mining activities are characterized by low technological levels, alluvial processes, poor planning, informality, and in some cases illegality. Additionally, because of the traditional methods of exploitation, resources are wasted and recovery rates are very low (50%), generating environmental and social problems (UPME, 2004). Nevertheless, gold mining has a big economic importance in the gold mining regions in the country. Production records suggest that the country's production capacity is between 40 tonnes (1986) and 47 tonnes (2009).
Colombia also stands out because of its production of high quality ferronickel in the Cerro Matoso mines. Ferronickel is the second largest source of export income from the Colombian mining sector (CIMC et al., 2010). The production of nickel in 2009 was 51.8 kilotonnes.

Construction materials mining is characterized by an abundance of resource reserves, mining operations located near urban centers or centers of consumption and short distance transportation due to the low value of the resource. Colombia exports ceramic products for construction. The composition of foreign sales of construction materials indicates that 97.7% of the sales are processed products, which are transported by road to the harbor in the North Coast of Colombia. Mining products account only for 2.3% of the construction materials (UPME, 2004).

Economic performance of the mining sector

The contribution of the mining sector to the Colombian economy is smaller than in other American countries with a well-recognized mining development such as Chile, Peru or México (UPME, 2006); nevertheless, the development of the Colombian mining sector has been growing since 2002. According to González (2011), the mining boom in Colombia can be associated with the international cycle of high prices and the generous conditions created by the Colombian Government for attracting foreign investors.

The mineral potential of the country is held in a topography still largely unexplored. Nevertheless, as a result of governmental initiatives, the exploration activities in the country have been growing since 2006. The progress in the geochemical exploration of the country has been significant. For example, in 2006, 22,130 square kilometers of territory were geochemically explored and by 2010 an area of 77,706 square kilometers was explored (Ministerio de Minas y Energía Colombia, 2011).

Likewise, the number of square kilometers of the country that has been geologically and geophysically explored has increased. According to the Ministry of Mines and Energy of Colombia (2011), in 2007, the progress in the geological exploration of the country was 22,130 square kilometers, and in year 2010 were explored 61.760 square kilometers. In the case of the geophysical exploration, the number of square kilometers explored in 2007 was 10,000 and in year 2010, 11,750 square kilometers were explored.

The increasing importance of the mining sector in Colombia is also reflected in its growing contribution to Colombia's GDP, see Figure 2.1.

Figure in billions of constant pesos as of December 31, 2005.
As 31 December 2005 the exchange rate of the Colombian peso is 2320 Colombian pesos to 1 U.S. dollar

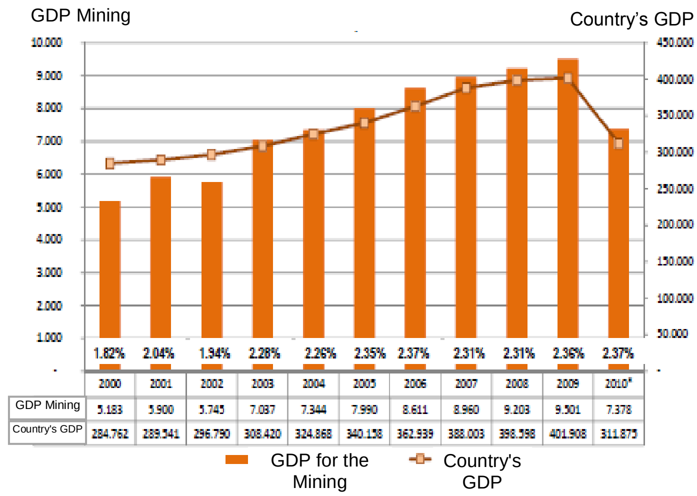
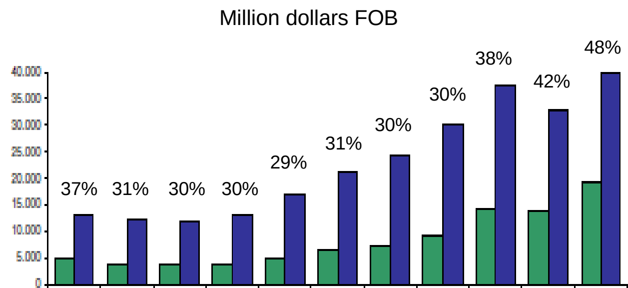


Figure 2.1. Share of mining sector in Colombia's GDP Source: Ministerio de Minas y Energía Colombia, 2011.

Figure 2 shows the contribution of the mining sector to Colombia's GDP since 2000 when mining activities accounted for 1.82% of the total GDP. By the end of 2009, the mining industry's contribution to gross domestic product accounted for more than 2.3% of total GDP. This means that, during this decade, the mining sector had a significant growth but it remains small in the whole of the country's productive activity.

According to the ex- Minister of Mines and Energy of Colombia, Carlos Rodado (Rodado, 2010), Colombian mining exports increased by more than 280% from 2000 to 2010. Figure 2.2 shows the value of Colombian mining exports for years 2000 to 2010 and the value of the total exports of Colombia for the same period of time.

Among Colombian mining exports, coal figures as number one, since coal exports have increased by nearly 500% from year 2003 to year 2009. In 2009, coal exports represented about 16% of country's total exports and amounted to 5.416 million U.S dollars (CIMC et al., 2010).



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Mining	4.900	3.784	3.564	3.886	4.811	6.523	7.415	8.971	14.268	13.786	19.147
Country	13.158	12.330	11.975	13.129	16.788	21.190	24.391	29.991	37.626	32.853	39.820

Figure 2.2: Colombian mining exports. Source: Ministerio de Minas y Energía Colombia, 2011.

In the mining sector, foreign investment rose from 466 million dollars in 2002 to approximately 3.094 million dollars in 2009, an increase of 664% (Rodado, 2010). Figure 2.3 shows the value of foreign investments in the Colombian mining sector for the years 2002 to 209 and the value of the total foreign investment in Colombia for the same period of time. The largest investments have resulted in a remarkable growth in exports of the mining sector, as mentioned above (CIMC et al., 2010).

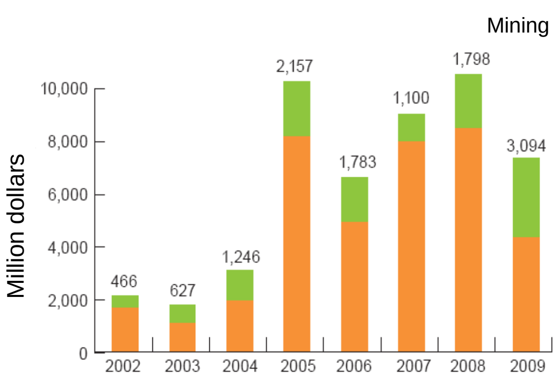


Figure 2.3: Foreign direct investment in Colombia, 2002-2009. Source: Banco de la República in Superneau, 2010.

Colombian mining royalties increased by 853% from 2002 to 2009 (Rodado, 2010). Mining royalties are rising in line with mining exports and foreign investments. Between 2004 and 2009, Colombia experienced a sustained upward trend in royalties from \$ 280 billion to \$ 1.527 billion. In 2009, approximately 87% of the 1.527 billion of mining royalties was generated by coal, 6.3% by nickel, and 5.5% by precious metals, among others.

According to the Ministry of Mines and Energy of Colombia (Ministerio de Minas y Energía Colombia, 2011), the payment of royalties to the central government has provided significant economic benefits to the country and the government expects an increasing on economic and social benefits through the mining sector's royalties.

Social performance of the mining sector

According to the National Administrative Department of Statistics of Colombia (DANE, 2011), employment in the mining sector amounted to about 770,000 persons, about 1.8% of the total population.

Within initiatives to solve social problems facing the mining sector, Colombia has two representative examples: in small scale mining the most significant case is the Green Gold (Oro Verde) program in Chocó. This is a program that promotes fair trade practices and the compliance with ten certification criteria, to ensure socially and environmentally responsible practices in the small scale mining activities. At large scale mining, Cerro Matoso in Cordoba is the outstanding project in corporate responsibility of BHP Billiton in the country (UPME, 2007). Other big mining companies like Mineros S.A. and Cemex carry on Corporate Social Responsibility Practices and are aware of the importance of investing in areas such as the social fabric and vulnerable populations (Pardo, 2011).

Adversely, according to Pardo (2011), the absence of the State in some regions of the country has led to the development of mining in conditions of illegality, which imply: improper mining practices, environmental impacts, lack of knowledge or ignorance of the rules on industrial hygiene and safety, employment of people without social security, child labor and presence of guerrillas and paramilitary groups.

Furthermore, according to Fasecolda (2010), mining is one of the sectors with the highest accident rate in the country. In 2010, 11,798 accidents were registered. Landslides are the main cause of injury, followed by oxygen deficiency, methane explosion and fire (see Figure 2.4).

However, nowadays the mining industry employers are looking at other countries, such as Germany, in order to import technology and processes for improving safety conditions for their workers.

As pointed out by González (2011), the growing of mining activities and the increasing land covered by mining concessions, result in territorial conflicts between different actors i.e. miners, ethnic groups, guerrillas and paramilitary groups, campesino and displaced families.

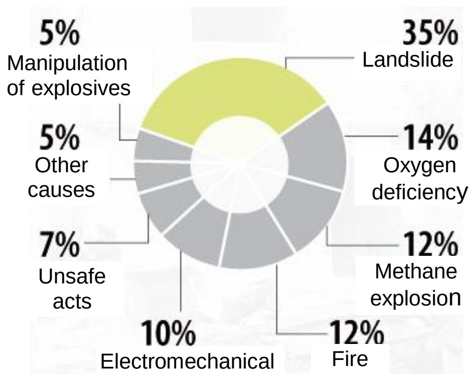


Figure 2.4: Causes of mining accidents 2005-2011. Source Portal de Información Minera Colombiana. (n.d.)

According to Sánchez (2011) the mining development model has attempted to maximize profits for the mining companies (i.e. Transnational corporations) to offset the risk of operating in the country, but much of the income obtained by the country through royalties, taxes and other equity has not been well invested due to corruption and poor governance and planning. Garcia et al. (2010) highlight the case of the department of La Guajira in Colombia where the most important coal mining activities are found. Despite having received more than 1 billion USD between 2002 and 2008, the department has basic education coverage of only 68%, 50% of water coverage and sewage coverage of 39%.

Finally, it should be mentioned that the mining sector is affected by a lack of dialogue between environmental authorities and mining companies, deficient information about the sector and absence of scientific studies about the impacts of the mining activities on the environment and communities of the country (Pardo, 2011).

Environmental performance of the mining sector

Colombia has about 10% of the world's biodiversity and is one of the countries with the largest number of endemic species around the world. Despite this, mining has been developed with poor planning, limited financial investment and without environmental control and remediation in the exploited areas, which has lead to the generation of serious environmental and social impacts (Garcia et al., 2010 and UPME, 2004).

Coal and construction materials are mined in Colombia on a large scale by open pit methods. In order to mine, trees and vegetation are cleared and burned, changing the appearance of vast areas, not to mention changing the ecosystem. When trees and water sources are changed, animal populations must migrate or die (UPME, 2004). The removal of vegetation increases erosion and landslides. Additionally, the clearing of forestland results in lower humidity in the air above the surface, as well as in reduction of regional precipitation, in rise in temperature and in desertification. Deforestation can cause the climate to become more extreme in nature; the occurrence and strength of floods and droughts could increase (Heilmeier, pers. comm.; Santos et al., 2003).

The environmental impact of mining on water sources is mainly connected to gold mining in the country. On the one hand, the mining industry uses large amounts of water in the extraction process, which threatens the availability of this resource for the local population and surrounding municipalities. On the other hand, the use of mercury and cyanide and the sediment generation increase the likelihood of contamination of rivers and watersheds. These facts have been repeatedly observed in mines in the departments of Tolima, Chocó and Antioquia (UPME, 2004 and García et al., 2010).

It is estimated that the annual mercury emissions/releases from gold mining in Colombia can be between 50 and 100 tonnes per year (Defensoría del pueblo Colombia, 2010). The environmental authority does not show up in the mining area, neither does it monitor the quality of water discharged by the mines (UPME, 2004).

The main sources of atmospheric pollution in the country are particulate matter emissions from coal, clay and lime mining; toxic pollutants from gold recovery, and the noise and vibrations caused by the use of machinery, equipment and explosives. Emissions of particulate matter from coal, clay and lime mining are the main cause of air pollution in the department of Boyacá, particularly in Sogamoso (a mining town in Boyacá) where chronic obstructive pulmonary disease was the second cause of death in 2007, with a number of 40 cases (Defensoría del pueblo Colombia, 2010).

The department of Antioquia is the most polluted by mercury in the country. The usual levels of mercury downtown Remedios, Segovia and Zaragoza (mining towns in Antioquia) in front of gold shops range from 2000 to 10000 ng of Hg/m3 of air, when the World Health Organization established as 1000 ng/m3 the guideline for public exposure (Veiga, 2010). Miners are not used to wear relevant personal protective equipment, which results in a bigger negative impact of mining activities on the miners' health (UPME, 2004).

Waste products from the mining and processing of minerals accumulate and leach into the soil. Cyanide-contaminated sand is produced in the extraction of gold, which is deposited in the open field without any treatment (UPME, 2004). Additionally, the removal of vegetation results in rapid degradation of nutrient rich topsoil and in reduction in the retention of humidity in the soil. Heavy rainfall and high sunlight quickly damage the topsoil in clearings of tropical rainforests (Santos et al., 2003).

Mining concessions affect more than 600 thousand hectares of collectively indigeneously owned land and applications for mining concessions overlap with 3.5 million hectares of reserves (Hountong, 2010). Simultaneously, transnational corporations own over 43 thousand square kilometers in mining concession, which includes protected areas and environmental strategic reserves, such as moorland. According to Ingeominas, since 2004, the government has given 1,536 mining concessions to explore and exploit gold deposits and 7,770 mining concessions are in the approval process (Sánchez, 2011).

Wildlife, aquatic and terrestrial microfauna in the mining area are affected by the modification of the physical - chemical parameters of water. Birds, mammals and reptiles are under pressure from mining and human expansion in the region. Mining sometimes creates standing bodies of water that attract insects, mosquitoes etc. (UPME, 2004 and García et al., 2010).

Strengths and weaknesses of the mining sector for a sustainable development

In order to contribute to sustainable development, the mining sector needs to reduce its impacts on and preserve the natural capital, nurture its social capital and improve its economic capital (Parks, 2006). Therefore, the improvements of the sector towards sustainable development can be assessed in terms of its economic, environmental and social performance.

In the present paper, the strengths and weaknesses of the mining sector in Colombia for a sustainable development were identified following the "Seven Questions to Sustainability" (7QS). The 7QS break down the assessment of sustainability into 7 key questions, enabling a clearer identification of strengths and weaknesses of the mining sector towards sustainable development in each of four areas: economic, social, environmental and governance (see Figure 2.5).

Figure 2.5: Seven questions to assess the long-term net impact of an activity on sustainable development. Source: MMSD North America, 2002b, p. 1 in Parks, 2006, p. 26.

For each of the seven questions, the strengths and weakness of the Colombian mining sector that help or limit (respectively) a positive answer to the questions, were identified; in other words, the strengths and weaknesses of the mining sector that help or limit progress towards sustainable development.

The strengths and weaknesses constitute the basis for determining the current state of the mining sector in terms of sustainability. Determining the current state provide us with a concise and clearer picture of the sector concerning sustainable development.

3. Industrial ecology framework

In order to face the sustainable development needs of industry worldwide, different approaches have been proposed. One of the approaches that has been emerging since the early 1990s and if properly developed, will bring great benefits not only to industry but also to the environment is the industrial ecology framework which allows the two systems (industrial and natural system) to coexist without threatening each other's viability.

Definition of Industrial Ecology

Industrial ecology is a collection of concepts and approaches that seek to reduce the impact of industrial systems on the natural systems, primarily through the adoption of cyclical principles of resource use present in the natural systems (Kazaglis et al., 2008). The objective of industrial ecology is to understand better how we can integrate environmental concerns into our economic activities (White, 1994 in Ayres and Ayres, 2002)

Nevertheless, as pointed out by Basu and Van Zyl (2006), there is no single definition of industrial ecology that is universally accepted. Since Industrial ecology is a field that covers the study of physical, chemical and biological interactions and interrelationships, both within and between industrial and ecological systems, different disciplines have provided diverse definitions for industrial ecology.

However, no matter what definition we find most suitable, it is important to remember that more than a concept, industrial ecology represents a relatively new and leading edge paradigm for business. Industrial ecology involves identifying and implementing strategies for industrial systems to more closely emulate harmonious, sustainable, ecological ecosystems (Frosch, 1992 in Garner and Keoleian, 1995). It emphasizes the establishment of public policies, technologies and managerial systems which facilitate and promote production in a more co-operative manner (Peck, 1998).

Characteristics of industrial ecology

According to Jelinski, et al. (1992), industrial ecology has four characteristics:

1. Industrial ecology is proactive, not reactive: industrial ecology is initiated and promoted by industrial concerns because it is in the own interest of the industry and in the interest of those surrounding systems with which the industry interacts, not because it is imposed by one or more external actors.
2. Industrial ecology is designed-in, not added-on: this characteristic recognizes that many aspects of materials flows are defined by decisions taken very early in the design process and that optimization of industrial ecology requires to view industrial ecology with the same intensity that is brought to bear on product quality or manufacturability.
3. Industrial ecology is flexible, not rigid: many aspects of the process may need to change as new manufacturing processes become possible, new limitations arise from scientific and ecological studies, new opportunities arise as markets evolve, and so on.
4. Industrial ecology is encompassing not insular: in the modern international industrial world, it calls for approaches that not only cross industrial sectors but cross national and cultural boundaries as well.

Key concepts of industrial ecology

Additionally, the Industrial ecology framework provides key concepts to change the traditional ways of industrial thinking to more sustainable ways. According to Garner and Keoleian (1995) the key concepts of industrial ecology are:

• Systems Analysis: Critical to industrial ecology is the systems view of the relationship between human activities and environmental problems.

• Material and Energy Flows and Transformations: the study of material and energy flows and their transformation into products, byproducts, and wastes throughout the industrial systems.

• Multidisciplinary Approach: Since industrial ecology is based on a holistic, systems view, it needs input and participation from many different disciplines.

• Analogies to Natural Systems: Industrial ecology draws the analogy between industrial and natural systems.

• Linear (Open) Versus Cyclical (Closed) Loop Systems: Moving from linear throughput to closed-loop material and energy use are key themes in industrial ecology.

• Technological dynamics: It considers technological dynamics as a crucial element for the transition from the actual unsustainable industrial system to a sustainable industrial system.

Benefits of the implementation of an IE framework

Rather than focusing on environmental leadership in isolation, industrial ecology provides a variety of economic, social, environmental and governance benefits for the sustainable development of industrial systems. In the present paper, the benefits of implementing an industrial ecology were identified following the 7QS. Industrial ecology provides useful systems perspective to support the evolution of industrial systems that are increasingly environmentally and socially sensitive while assuring shareholder value creation.

The analysis of the benefits of implementing an IE framework is the basis for determining the desired end state of the Colombian mining sector. The desired end state gives us a picture of what the Colombian mining sector can expect to reach through the implementation of an IE framework.

4. Current state and desired end state of the Colombian mining sector

Table 1 shows the current state and the desired end state of the Colombian mining sector in terms of sustainable development. The current state is established through the analysis of the strengths and weaknesses of the mining sector for a sustainable development. Likewise, the desired end state is determined through the analysis of the benefits of the implementation of an IE framework[1].

Determining the current state provide us with a concise and clearer picture of the sector concerning sustainable development. The desired end state provides us a picture of what the Colombian mining sector can expect to reach in terms of sustainable development through the implementation of an industrial ecology framework.

From Table 4.1, it can be seen that there are significant discrepancies between the current state and the desired end state. According to the desired end state, the implementation of an industrial ecology framework contributes to face the sustainable development needs of the Colombian mining sector through, among other factors, cooperative partnership between business, academia, government and community. Cooperation and symbiosis linkages in the sector provide marketing and logistic advantages as well as economic and social benefits and a significant reduction of environmental impacts.

There are examples of industrial systems in the world which use the concepts of industrial ecology to produce in a more sustainable way. The analysis of the experience of these examples provides us with strategic information for the implementation of industrial ecology in the Colombian mining sector.

Table 4.1. Current state and desired end state of the Colombian mining sector in terms of sustainable development.

CURRENT STATE	DESIRE END STATE
Engagement: The mining sector promotes sustainable practices through the development of specific programs and plans. The organization forms of the miners are poor, weak and not very large; which, in addition to the resistance to change, the illegality, the informality and the lack of planning, coordination and cooperation hinders the development of engagement processes.	**Engagement:** The mining sector promotes sustainable development through cooperative partnership among business, academia, government and community. The commitment of stakeholders towards sustainable development strengthens the engagement processes in the sector and promotes sustainability as a business strategy with value added potential.
People: The mining sector has an important role in employment generation, but, only large companies and some specific programs carry out projects that contribute to the social welfare of the communities. In the small and medium scale mining exist: child labor, high accident rate, employment without social security, low levels of education and training, low use of mining health and safety equipment, security problems and territorial conflicts.	**People:** The mining sector is an important generator of employment. For the sector, labor law compliance and the health and safety of its workers are important, as well as the quality of life of the local community. The cooperation among the different actors of the sector improves safety and reduces the levels of territorial conflicts. Additionally, the sector provides education and training to managers and employees.
Environment: The mining sector possesses some mechanisms (e.g. guidelines, the CAMs, etc.) to promote sustainability and to comply with environmental criteria. However, there is a lack of environmental awareness (mainly at the small/medium scale) and the sector generates large quantities of pollutants which are released into the water, soil and air. Besides, the sector has poor environmental controls which, in addition to the poor adoption of clean technologies, the breach of environmental regulations and the improper operation of the CAMs, lead to the irrational use of resources.	**Environment:** There is a high level of environmental awareness in the mining sector. The material and energy exchanges between companies and other participants lead to better energy efficiency, resource conservation, reduction of emissions, waste/by-products recycling and improvement of land use planning, which result in significant reduction of environmental impacts. The sector uses sustainable technologies and carries out environmental controls and actions to ensure the integrity of the environment.
Economy: The mining sector is growing and increasing its contribution to Colombia's GDP. The country has a leading position in coal production and geological-mining potential. In addition, the government encourages mining industry and supports foreign investment in the sector. However, there is a drain of royalties from mining activities. The sector has deficient infrastructure and generates little value added. The large mining industry is basically owned/ operated by foreign capital. The small/ medium scale mining faces problems related to: high percentage of illegality and informality; low technological and productivity levels; low profit margins and low financial capacity.	**Economy:** The mining sector grows and the economy of the community and the country is better off as a result. The cooperation and linkages in the sector provide marketing and logistic advantages and economic benefits. The economic impulse in the sector brings industrial activities to the mining regions; additionally, the continual improvement of value chain management contributes to the generation of value-added in the sector. The innovation and technology development in the sector facilitate greater efficiencies and provide better profit margins.
Traditional and Non-market activities: The society has not participated in the discussions of formulation of mining policy as it should. Moreover, the government has lowered requirements for consultation and consent of ethnic groups to the mining projects.	**Traditional and Non-market activities:** There is an effective intercultural communication and participation among business, government and the local community, which supports cooperation and mutual agreement.
Institutional arrangements and Governance: The mining sector has a National Development Miner Plan which promotes sustainable development. The large mining companies and some specific programs carry out projects in corporate responsibility. Nevertheless, the sector faces institutional weakness, corruption, illegality, low incidence of training programs, poor governance, poor planning, and deficient research and regulation.	**Institutional arrangements and Governance**: The mining sector has a good reputation with stakeholders and a positive image thanks to its institutional strength and the participation of business, academia, government and community in the development of several policies, incentives, regulations, programs and capacities to address the sustainable development of the sector.
Synthesis and continuous learning: Large mining firms have shown a significant progress in technology, environment and organizational concerns. However, there is a lack of necessary information that enables the sector to have real statistics and assess its performance. As well, though the existence of the SIAC there is a lack of knowledge of environmental and social impacts of mining activities in Colombia.	**Synthesis and continuous learning:** The mining sector evolves and matures in an ecosystemic sense, and is increasingly environmentally and socially sensitive. The cooperation within the sector, improves the access to information and knowledge sharing. The periodic assessment of the mining sector performance helps to formulate new strategies towards sustainable development.

Source: Author

5. Formulation of strategies for implementing an IE framework in the mining sector in Colombia

Within the strategies formulation process, five examples of IE in practice in the world were analyzed. From the analysis of the five examples, 22 strategies for implementing an IE framework were identified, as well as the drivers and barriers to the implementation of an IE framework. Appendix 1 contains a table with the main characteristics of the five examples of IE in practice in the world.

The 22 strategies are the main input to the strategies formulation process. However, not all of the 22 strategies might be appropriate for the Colombian mining sector. It is then necessary to select the most suitable strategies for implementing an IE framework in the Colombian mining sector.

The selection of the most appropriate strategies is based on the appraisal of the critical factors of success for the implementation of an IE framework. The critical factors of success are key factors that have a direct and serious impact on the successful implementation of an IE framework, and therefore are the factors that industrial systems (i.e. mining sector) should focus on to be successful in the implementation of an IE framework.

The critical factors of success are identified from the analysis of the benefits, drivers and barriers to the implementation of IE framework. 23 critical factors of success are identified and they are classified into the six key concepts of the IE framework.

Selection of the critical success factors for implementing an IE framework in the Colombian mining sector

The factors that require particularly high priority attention for implementing an IE framework in the specific case of the Colombian mining sector are selected from the 23 critical success factors already identified; these will be the factors on which the strategies will focus.

The analysis of the gaps, between the current state and the desired end state of the Colombian mining sector, allows reducing the list of the 23critical success factors into a shorter list. Table 5.1 shows the 12 critical success factors for implementing an IE framework in the Colombian mining sector classified into the six key concepts of the IE framework.

Table 5.1. Critical success factors for implementing an industrial ecology framework in the Colombian mining sector.

KEY CONCEPTS	CRITICAL SUCCESS FACTORS
Systems Analysis	1. Environmental and resource conservation awareness. 2. Commitment and coordination among companies, government, university and community.
Material, Energy and Information Flows and Transformations	3. Use of concepts, methods and tools that support industrial ecology. 4. Industrial value chain analysis and management.
Multidisciplinary Approach	5. Capacity building, training and education. 6. Consideration of local conditions, culture and legal context. 7. Institutional strength and governance
Analogies to Natural Systems	8. Formation of sustainability partnerships.
Linear (Open) Versus Cyclical (Closed) Loop Systems	9. Motivation to exchange material, energy and information among firms and other participants. 10. Existences of a coordinative function.
Technological dynamics	11. Development or/and adoption of technologies, processes and products that maximize economic and environmental efficiency.
Others	12. Policies, regulations, control and rules to make industrial ecology economically attractive.

Source: Author

As can be seen from table 2, for each key concept of the industrial ecology framework, at least one critical success factor was selected.

Strategies for implementing an IE framework in the Colombian mining sector

Based on the 12 critical success factors shown in table 2, the strategies for implementing an IE framework in the Colombian mining sector are selected. Only the strategies which deal with more than one critical success factor are selected for implementing an IE framework in the Colombian mining sector.

The strategies are classified into four groups: Proactive not reactive; designed-in, not added-on; flexible not rigid; and encompassing not insular. These groups correspond to the four characteristics of the IE framework.

Proactive not reactive

Strategy 1: Education of managers and employees on waste minimization, reusing, remanufacturing, recycling materials and on industrial ecology concepts.

Target groups: Managers and employees.
Objective: Without knowledge of the industrial ecology concepts and without environmental awareness, the mining sector hardly will approach industrial ecology in a proactive manner. Therefore, the aim of this strategy is to provide education, training and information necessary to support the change of the companies toward sustainable development and to actively promote the implementation of industrial ecology as a framework to produce this change.
Responsible: Government, CAMs, SIAC, mass media, companies, universities
Term: Short term (approx 1-3 years)

Strategy 2: Development of tools and methodologies to assist companies in the identification of potential synergies and exchange of material, energy and/or information.

Target groups: Companies
Objective: To enable companies to actively identify and develop synergies, as well as exchanges of material, energy and/or information. The tools and methodologies can include: (1) forming reconnaissance teams to identify industrial areas likely to have a baseline of exchanges and mapping their flows accordingly; (2) develop a product, by-product and resource register of industries to assist in identifying synergies; (3) creation of a geographic information system to map the various sites and to record the by-products arising there, and what inputs they required; (4) development of surveys, plant visits and interviews, among others.
Responsible: Ministry of mines and energy, CAMs, Companies, universities and research institutes.
Term: Short-term (approx 1-3years)

Strategy 3: Reinforce the CAMs and give them the regional coordinative function to promote industrial ecology implementation in the mining districts and to foster positive interactions between member companies, government and community.

Target groups: Mining Environmental Centers (CAMs)
Objective: Strengthening the CMAs not only as key institutions which regulate environmental impacts of mining activities, but also as institutions which facilitate and organize symbiotic linkages within the mining sector. This implies a consolidation of the coordinative function within the CAMs to: support the management of intercompany information flows; foster positive interactions between member companies, government and the broader community; improve internal and external communication; provide data to local firms about waste and energy linkages opportunities; support networking opportunities; etc.
Responsible: Ministry of the environment, housing and territorial development; Ministry of mines and energy; and autonomous regional corporations.
Term: Medium term (approx 4-7years)

Strategy 4: Development and implementation of policy-based incentives or market-based policies that help stimulate the market to drive industrial ecology.

Target groups: Companies and community
Objective: To make industrial ecology economically more attractive through the development and implementation of policy-based incentives or market –based policies that reflect the real cost of environmental degradation in marketing pricing. These policies could include: fees and taxes for pollution,

ecological tax reform, taxes on virgin raw materials, tradable permits to incorporate environmental externalities into prices, product certification programs, among others. The mining industry might respond favorably to market strategies that make it more profitable to be less polluting.
Responsible: Government, Ministry of mines and energy; Ministry of the environment, housing and territorial development.
Term: Medium term (approx 4-7years)

Designed-in not added-on

Strategy 5: Establishment of site standards for the construction and operation of facilities increasingly environmentally sensitive.

Target groups: Mining districts.
Objective: To provide specifications and design procedures to ensure that mining facilities are environmentally friendly. The site standards allow the mining sector to take a leading role in improving protection of environment and in developing and maintaining best practices.
Responsible: Government, Ministry of the environment, housing and territorial development; Ministry of mines and energy; and autonomous regional corporations.
Term: Medium term (approx 4-7years)

Strategy 6: Design, development and /or adoption of eco-efficient technology and eco-efficient processes.

Target groups: Universities, research institutions, companies.
Objective: Modernization of traditional mining processes through the design, development and/or adoption of eco-efficient technology and eco-efficient processes that minimize the environmental impact of mining activities, reduce resource use and provide high economic performance. The eco-efficient technology and eco-efficient processes have an important role to play in facilitating industrial ecology linkages.
Responsible: Universities, research institutions, companies.
Term: Long-term (approx 8-10 years)

Flexible not rigid

Strategy 7: Use of industrial symbiosis method to create the exchange of wastes, energy and by-products between companies.

Target groups: Mining districts
Objective: To engage traditionally separate companies, within the mining districts, in a collective approach to competitive advantage involving physical exchange of wastes, energy and by-products between companies. The feasibility assessments of the potential exchanges comprise detailed evaluations of the by-product and waste streams (volumes and composition), reviews of potential uses, evaluations of possible processing and source treatment needs, concept designs, and assessments of the economic, technical, environmental, and social aspects.
Responsible: Companies, CAMs.
Term: Long-term (approx 8-10 years)

Strategy 8: Integration of the mining industrial chain.

Target groups: Mining industrial chain.
Objective: To force attention to the interdependence of various parties in the production process and identifying the potential for synergies among the companies. Integration of the mining industrial chain refers to connection, reorganization, cooperation and coordination for all nodes of the industrial mining chain, in order to improve overall operating efficiency of the industrial chain, seek greater market forces and more profits.
Responsible: Companies, Ministry of mines and energy.
Term: Long-term (approx 8-10 years)

Encompassing not insular

Strategy 9: Formation of sustainability partnerships among companies, government, university and community.

Target groups: Companies, government, university and community.

Objective: Foster a spirit of long-term cooperation among businesses, government, university and community which will help the sector to: define common goals, facilitate the sharing of information, develop collaborative projects, combine strengths and create networks and linkages. Some of the possible mechanisms to promote sustainability partnership include: forums where companies, government, universities and communities can develop agreements; policies that encourage partnership-building; continued dialogue between all stakeholders; delineation of responsibilities of different actors; periodic meetings; commitment agendas to enhance the mining activity within a sustainability framework, etc.
Responsible: Companies, government, university and community.
Term: Medium term (approx 4-7years).

Strategy 10: Formation of eco-industrial parks in the mining districts.

Target groups: Companies and community.
Objective: To create a network of companies working together to improve their environmental and economic performance. The companies, located together in the mining district exchange and make use of each other's by-products, waste, or energy. By working together, the network of companies seeks a collective benefit that is greater than the sum of individual benefits each company.
Responsible: Companies, government, CAMs and autonomous regional corporations.
Term: Long-term (approx 8-10 years).

6. Conclusions

The ten strategies encompass all twelve critical success factors for implementing industrial ecology in the Colombian mining sector, as well as they reflect the characteristics of the industrial ecology framework.

To support the sustainable development of the Colombian mining sector, the strategies focus on the development of cooperative partnership between companies, academia, government and community as well as on the development of networks and symbiosis linkages between companies and on the development of efficient technology and processes.

The strategies are a combination of short term, medium term and long- term goals. The implementation of each of the ten strategies requires the participation and commitment of different actors of the mining sector (i.e. companies, government, universities, CAMs, community, etc.).

The information flow has an important influence on strategy formulation within the industrial ecology framework. In the paper, the information generated by the analysis of literature and the examples of industrial ecology in practice in the world was used for the formulation of strategies for implementing an industrial ecology framework in the mining sector in Colombia. It shows how the information generated by analyzing existing industrial ecosystems flows within the industrial ecology framework and is passed back to the strategy formulation process through feedback loops and becomes an input for the next round of strategy formulation.

The next step towards the implementation of an industrial ecology framework in the Colombian mining sector is to implement the strategies. This step involves developing specific projects and allocating budgets to make the strategies operational and to reach a sustainable development.

Notes

1. To gain a better understanding of how the analysis has been done please refer to the longer version of the paper: Rosero, I. J. (2011). Formulation of strategies for implementing an industrial ecology framework to face the sustainable development needs of the Colombian mining sector (Master's thesis). Technische Universität Bergakademie Freiberg. Freiberg. Germany.

Appendix 1. Main characteristics of the analyzed five examples of IE in practice in the world

EXAMPLE OF IE IN PRACTICE	COUNTRY	DISTINGUISHING FEATURES	STRATEGIES FOR IMPLEMENTING AN IE FRAMEWORK IDENTIFIED IN THE EXAMPLES
Kalundborg eco-industrial park	Denmark	- Kalundborg is the archetypal example of industrial ecology in practice in the world. - Kalundborg boasts an unusual eco-industrial park that since 1972 has evolved from a single power station into a cluster of companies that rely on each other for material inputs. - The eco-industrial park development involved multiple public and private organizations.	- Use of industrial symbiosis method to create the exchange of wastes and by-products between companies. - Formation of partnerships between stakeholders of the eco-industrial park. - Use of eco-efficiency concept to contribute to waste reduction and resource savings. - Move gradually to more exchanges of material and energy within the industrial system. - Formation of an eco-industrial park.
Harjavalta eco-industrial park	Finland	- The area of the park is almost 300 hectares, has over 1000 employees and over 100 subcontractors. -Design and development of clean technology for copper and nickel smelting process. -The development of the eco-industrial park has involved multiple private organizations and the Harvajavalta city	- Design and development of eco-efficient technology (Flash smelting technology). - Use of industrial symbiosis method to create the exchange of wastes, energy and by-products between companies. - Use of eco-efficiency concept to reduce energy use and environmental impacts. - Formation of an eco-industrial park
Kwinana Industrial Area (KIA)	Australia	- KIA is the most notable example of industrial ecology in practice in Australia. - Considerable supply chain integration has occurred between the industries in the area. A number of companies produce essential raw materials for the manufacturing and refining processes of other nearby enterprises. -In 1991, the Kwinana Industrial Council (KIC) was established to manage environmental impacts of the KIA. - A number of tools and methodologies are being applied to assist with the identification and development of synergies.	- Creation of a member-based industry organization (Kwinana Industries Council) that fosters positive interactions between member companies, government, and community. - Development of tools and methodologies to assist in the identification and development of synergies. - Development of industrial facilities that further enhance synergy developments. - Identification of opportunities in four areas: large volume inorganic process residues; nonprocess waste; energy and greenhouse gas, and water conservation. - Pursuit of supply chain integration. - Use of industrial symbiosis method to recycle back water, energy, by-products and waste streams into the industrial area.
Burnside eco-industrial park in Dartmouth	Canada	- Burnside is considered a living experiment in transforming an existing industrial park into an eco-industrial park. - Burnside encompasses about 970 hectares of land. 17,000 people regularly work in the park and there are more than 1,000 employers. - Many of Canada's small and medium sized business sectors are represented in the park bringing in a large variety of materials and products and generating various wastes - In the year 1995 the Burnside Cleaner Production Centre (BCPC) was established to provide information on waste minimization, pollution prevention, and cleaner production to the park's approximately 1,500 businesses.	- Establishment of site standards for the construction and operation of facilities increasingly environmentally sensitive. - Production and use of environmentally friendly products to reduce the environmental impact of goods and services provided from the park. - Education of managers and employees on waste minimization, reusing, remanufacturing, renting and recycling materials and on industrial ecology concepts.. - Creation of the Burnside Cleaner Production Centre (BCPC) to promote industrial ecology at an existing industrial park. - Identification of potential exchange opportunities among firms through surveys, plant visits, and interviews. - Development of strong links to university research community.
Falconbridge and Noranda (F&N)	Canada	- F&N are major copper, nickel, zinc, and aluminum producers managing a diverse set of Canadian and international sites. - F&N also control significant smelting and processing facilities and they have extensive recycling and reprocessing capacity. - In the year 2005 F&N became the world's largest recycler of electronic waste and one of the world's largest recyclers of batteries and copper.	- Control of smelting and processing facilities parallel to mining activities. - Development of extensive recycling and reprocessing capacity. - Design and use of smelting facilities that can be used eventually for recycling. - Design and development of eco-efficient technology (reactor that captures SO_2 emissions as a byproduct of the copper recycling process). - Development of loop closing networks through the formation of recycling partnerships and the creation of waste disposal agreements.

Source: Author, based on information from Ehrenfeld, 2006; Peck and Associates, 1997; Heino and Koskenkari, 2004; Van Beers et al., 2007 and McKinley, 2008.

References

Allenby, B. (2000). Industrial ecology, information and sustainability. Camford Publishing Ltd. Foresight. The journal of futures studies, strategic thinking and policy. Vol.02, no.02.

Ayres, R. and Ayres L. (2002). A Handbook of Industrial Ecology. Edward Elgar Publishing Limited. United Kingdom.

Basu, A. and Van Zyl, D. (2006). Industrial ecology framework for achieving cleaner production in the mining and minerals industry. Journal of Cleaner Production 14 (2006).p. 299-304.

Branch, J.; Arango, M. and Pérez, G. (2008). Colombian mining sector modernization: opportunity identification from asystemic approach. Boletín de Ciencias de la Tierra. May/Aug. 2008, no.23, p.85-92

Chertow, M. (2007). “Uncovering” Industrial Symbiosis. Special feature on industrial symbiosis. Journal of Industrial Ecology. Massachusetts Institute of Technology and Yale University. Volume 11, Number 1. Pgs. 11-30

Consejo Intergremial de Mineria de Colombia (CIMC); Asociación Colombiana del Petroleo; Asociación Nacional Comercio Exterior; ANDI Cámara Asomineros and Cámara Colombiana de Servicios petroleros. (2010). Sector minero y petrolero en Colombia. Bogotá. Colombia.

DANE. Departamento Nacional de Planeación (2011). Comunicado de prensa. Retrieved March 30, 2011 from http://www.dane.gov.co/index.php

Defensoría del Pueblo Colombia. (2010). La Minería de hecho en Colombia. Defensoría Delegada para los Derechos Colectivos y del Ambiente. Imprenta Nacional de Colombia. Bogotá. Pgs 46-64.

Ehrenfeld , J. and Gertler, N. (1997). Industrial Ecology in Practice´The Evolution of Interdependence at Kalundborg. Journal of Industrial Ecology. Volume 1. Number 1. Pgs. 67–79.

Ehrenfeld, J. (2006). Industrial Ecology. Environmental and Economic Boon. Communities &Banking. Retrieved March 2, 2011 from http://www.bostonfed.org/commdev/c&b/2006/fall/ industrialecology.pdf

Fasecolda. (2010). Retrieved January 20, 2011 from http://www.fasecolda.com/fasecolda/.

Garner, A. and Keoleian G. (1995). Industrial Ecology: An Introduction. Pollution Prevention and Industrial Ecology. National Pollution Prevention Center for Higher Education. Retrieved January 15, 2011 from http://www.umich.edu/~nppcpub/resources/compendia/INDEpdfs/ INDEintro.pdf

García, J.; Hincapié, L.; Ortiz, J.; Rodríguez, M. and Yáñez, S. (2010). ¿Bendición o maldición? Colombia de cara al boom minero-energético. Revista económica supuestos. Universidad de los Andes. Facultad Economía. Bogotá.Colombia.

González, C. (2011). La renta minera y el plan de desarrollo 2010 – 2014. Instituto de estudios para el desarrollo y la paz – INDEPAZ. Bogotá D.C. Colombia. February of 2011. Retrieved March 2, 2011 from http://www.indepaz.org.co/attachments/580_Renta%20minera%20Colombia%202011.pdf

Heino, J. and Koskenkari, T. (2004). Industrial Ecology and the metallurgy industry. The Harjavalta industrial ecosystem. In: Pongrácz E. (ed.): Proceedings of the Waste Minimization and Resources Use Optimization Conference. June 10th 2004, University of Oulu, Finland. Oulu University Press: Oulu. p.143-151.

Hilson, G. (2000). Sustainable development policies in Canada’s mining sector: an overview of government and industry efforts. Elservier. Environmental Science & Policy 3 (2000) p. 201–211.

Jelinski, l.; Graedel, T.; Laudise, R.; McCall, D. and Patel, C. (1992). Industrial ecology: Concepts and approaches. Colloquium Paper. Proc. Nati. Acad. Sci. USA. Vol. 89, pp. 793-797.

Kazaglis, A.; Fagan, J. and Giurco, D. (2008). Identifying and assessing industrial ecology opportunities in Melbourne. Retrieved March 20, 2011 from http://www.isf.uts.edu.au/publications/kazaglisetal2008industrialecology.pdf

McKinley, A. (2008). Industrial Ecology: A Review with Examples from the Canadian Mining Industry. Canadian Journal of Regional Science/Revue canadienne des sciences régionales, XXXI: 1. (Spring/printemps 2008), 163-174.

Ministerio de Minas y Energía de Colombia. (2011). Retrieved March 5, 2011 from http://www.minminas.gov.co/minminas/minas.jsp?cargaHome=3&id_categoria=108

Pardo, Á. (2011). Una incursión al Far West de la minería colombiana revela un modelo insostenible, falta de transparencia, diálogo de sordos y mucha plata… (Parte 1). Razón Pública. 13th February 2011. Retrieved March 25, 2011 http://www.imcportal.com/contenido.php?option=shoshown&newsid=5946&render=page

Parks, L. (2006). Examining Sustainable Development Challenges and the Role of Company-Consultancy Partnering in Creating Value: The Case of the Canadian Mining Industry. A Major Paper submitted to the Faculty of Environmental Studies in partial fulfillment of the requirements for the degree of Master in Environmental Studies York University. Toronto, Canada.

Peck, S. (1998). Industrial Ecology: From Theory to Practice. Retrieved March 5, 2011 from http://newcity.ca/Pages/industrial_ecology.html

Peck, S. and Associates. (1997). EIP Development and Canada: Final Report. Retrieved March 20, 2011 from http://www.p2pays.org/ref/10/09934.pdf

Portal de Información Minera Colombiana. (n.d.) Retrieved March 25, 2011 from http://www.imcportal.com/contenido.php?option=shoshown&newsid=5946&render=page

Rodado, C. (2010). El sector minero Colombiano. Fuente de Oportunidades. Ministerio de Minas y Energía Colombia. Presentation in Feria Internacional Minera. Medellín. Colombia October 6th of 2010. Retrieved January 20, 2011 from http://www.minminas.gov.co/minminas/downloads/archivosEventos/6556.pdf

Sánchez, J. (2011). Colombia. Un país minado por el despojo minero. Retrieved February 18, 2011 from http://www.humboldt.org.co/iavh/oportunidades/item/166-un-pa%C3%ADs-minado-por-el-despojo-minero

Santos, J.; Paulino, E. and Paiva, J. (2003). Evaluation of the anthropogenic impacts on the water cycle in Amazonia. Retrieved march 29, 2011from http://www.bvsde.paho.org/bvsacd/cd29/cycle.

Serrano, I.; Torre, I. and Eguren, J.(2005). Desarrollo de un método para la implantación de Ecosistemas Industriales a nivel comarcal. IX Congreso de Ingenierá de Organización. Gijón. September 2005.

Superneau, L. (2010). La oportunidad del auge minero en Colombia. Retrieved February 10, 2011 from http://member.bnamericas.com/cgi-bin/getreports?document=MISRE62010E.pdf

Tibbs, H. (1993). Industrial Ecology. An environmental agenda for industry. Global Business Network. United States of America. Retrieved January 15, 2011 from http://www.hardintibbs.com/wp-content/uploads/2009/05/tibbs_indecology.pdf

UPME. Unidad de Planeación Minero Energética. (2004). Plan de acción para la sostenibilidad y creación de Centros ambientales mineros - CAM, Cadenas Productivas y Plan Padrinos.Informe final. Bogotá. Colombia.

UPME. Unidad de Planeación Minero Energética. (2006). Colombia país minero. Plan Nacional para el desarrollo minero. Visión al año 2019. Bogotá. Colombia.

UPME. Unidad de Planeación Minero Energética. (2007). Plan Nacional de Desarrollo Minero. 2007-2010. Gestión Pública para propiciar la actividad minera. Bogotá. Colombia.

Van Beers, D.; Corder, G.; Bossilkov, A. and Van Berkel, R. (2007). Industrial Symbiosis in the Australian Minerals Industry. The Cases of Kwinana and Gladstone. Journal of industrial ecology. Special feature on industrial symbiosis. Massachusetts Institute of Technology and Yale University. Volume 11, Number 1. Pg. 55-72.

Veiga, M. (2010). Antioquia, Colombia: the world's most polluted place by mercury: impressions from two field trips. University of British Columbia. Retrieved March 5, 2011 from http://redjusticiaambientalcolombia.files.wordprewo.com/2011/05/final_revised_feb_2010_veiga_aantioqui_field_trip_report.pdf