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Developing a Conceptual Framework of Green Mining Strategy in Coal Mines: Integrating Socio-economic, Health, and Environmental Factors

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Abstract

Considering that mining has many environmental impacts from the exploration phase to production and finally closure, it is necessary to plan the activities so that the concept of green mining is realized in its true meaning. This means that mining is carried out in order to obtain the minerals that are used in various industries; however, by taking appropriate measures, the impacts of mining on the environment are reduced to a minimum level. Since there is little information about the environmental, ecological, hydrological, and hydrogeological status in most mining areas, a comprehensive study of the area's water, soil, plants, and animal species should be conducted. The existence of permanent and seasonal rivers in the vicinity of some mines, in some cases being located in protected areas of the Iranian Department of Environment, and the presence of vegetation near some mines are among the matters that cause many environmental challenges in the mining areas. For this purpose, a series of comprehensive studies are critical in the pre-mining, during mining, and closure phases of the mine life. In addition, detailed studies should be done on factories such as smelters located in the mining areas. Life cycle assessment (LCA) is widely used in order to determine the environmental status of these factories. Furthermore, the issue of process water and water recycling, as well as waste management, should be considered. Nowadays, the environmental monitoring technology is one of the widely used tools in many mines in the world. Moreover, these mining companies' green space management system should be given special attention according to the obligatory standards of the Iranian Department of Environment. In this paper, a conceptual framework for the green mining method will be introduced for the coal mines to consider the economic and social aspects, and we pay a special attention to the health, safety, and environmental requirements.

1. Introduction

Currently, the problems associated with energy and the environment have become a primary focus of global concern so sustainable development has become a popular theme in the today's world. Mining is carried out to produce energy and supply the raw materials required by various industries. However, the environmental impacts of mining have also attracted much attention in the recent times. Establishing an appropriate balance between energy production and environmental protection is a core principle of sustainable development, a matter that has received a special attention in the green mining technology.

Mining activities cause severe environmental problems, and mainly affect the ecological, hydrological, and hydrogeological conditions within the affected area [1]. In order to understand the environmental impacts of mining,

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comprehensive studies should be conducted on the surface and groundwater quality, soil, plant, and animal species in the study area. These studies include remote sensing/satellite imagery, morphology and topography, geology, tectonics, lithological status and hydraulic properties of rocks, natural waterways, hydro-geophysics, hydro-geochemistry, soil physical and chemical properties, hydrogeological studies, surveying of the plants and animals species, environmental impact assessment (EIA) studies [2-4] in the study area, proper site selection of physical elements, office buildings, workshops and factories, location of low-grade waste dumps, location of tailings dam, environmental and health effect of chemicals used in mineral processing, review of solutions to minimise waste [5], investigation of the possibility of the use of non-reactive waste for various purposes, especially for sealing of reactive hazardous waste, designing an appropriate mine reclamation plan, carefully studying the open-pit mine status/geometry map and its development plan, mine planning including drilling, blasting, loading and transportation, proposing a suitable solution/practice to reduce dust generation, slope monitoring in open-pit mines using geotechnical and hydrogeological databases to minimize water pressure behind the pit walls and maintain pit wall stability, water quality control and preventing water inflow to the mine, environmental monitoring of low-grade dumps, tailings dams, characterization of mine waters, mine drainage and waste effluents for designing suitable treatment systems (a short-term treatment system during mining and a long-term treatment system in a post-mining period), studies of pit lake formation [6] and implementing environmental and quality considerations after the mine closure, and finally, evaluating the suitability of post-mining areas for various activities such as tourism, recreation, natural reserves or land use change.

In addition, detailed studies should be carried out on the mining-related plants operating near the mining areas such as concentrates, pellets, sponge iron, steel mills, smelting, and refining plants (in the case of sulphide mines such as copper, lead, and zinc). Life cycle assessment (LCA) [7] is an important issue that is widely used in assessing the environmental impacts of these factories throughout their life cycle. In addition, the study of the process of water, water reuse, and recycling as well as the type of waste generated and issues related to waste management should be considered. A monitoring system as smart technology is currently designed and implemented by many metal manufacturing companies around the world due to the new technological developments. In addition, the green space management system of these complexes should be given a special attention according to the obligatory standards of the Iranian Department of Environment.

Figure 1 shows the different sources of pollution in the mine and mining industries. As shown in the figure, except for the mine, which is the first stage of the production process and can be the starting point for pollution generation, various plants in the mining area including concentrates, smelting and refining, pellets, sponge iron, and steel mills can result in environmental pollution and severe health problems. In addition, mine tailings and waste rock dumps are among the other sources that cause environmental pollution. Assessing the environmental impacts of each one of these sources separately is an important task that should be considered in a comprehensive green mining system.

Some people believe that mining is not environmentally friendly, and has substantial environmental impacts. They believe that one can never imagine a mine that does not harm nature and does not pollute the environment. However, green mining technology is the only way to implement a sustainable mining effectively. The main goal of green mining is to mitigate the adverse environmental and social impacts of the mining operations. Green mining is defined as the use of technologies, constructive solutions, and methods implemented to minimize the adverse environmental effects of mining and mineral processing operations. In the sense that there are several mining companies worldwide that manage the mining operations and look for proper ways to mitigate the environmental damage caused by mining and associated industries and offer constructive solutions and new ideas to protect the environment and control environmental pollution.

Green mining depends on the economic cycle of the principles of the green industry, which creates a balance between mining operation and environmental protection. Green mining is a new mining technology that aims to provide low production, high efficiency, and low emission of pollutants. Green mining in a coal mine is the only procedure for the healthy development of the coal industry since it can mitigate the environmental problems caused by mining to gain the best economic and environmental benefits from the exploitation of coal deposits [8].

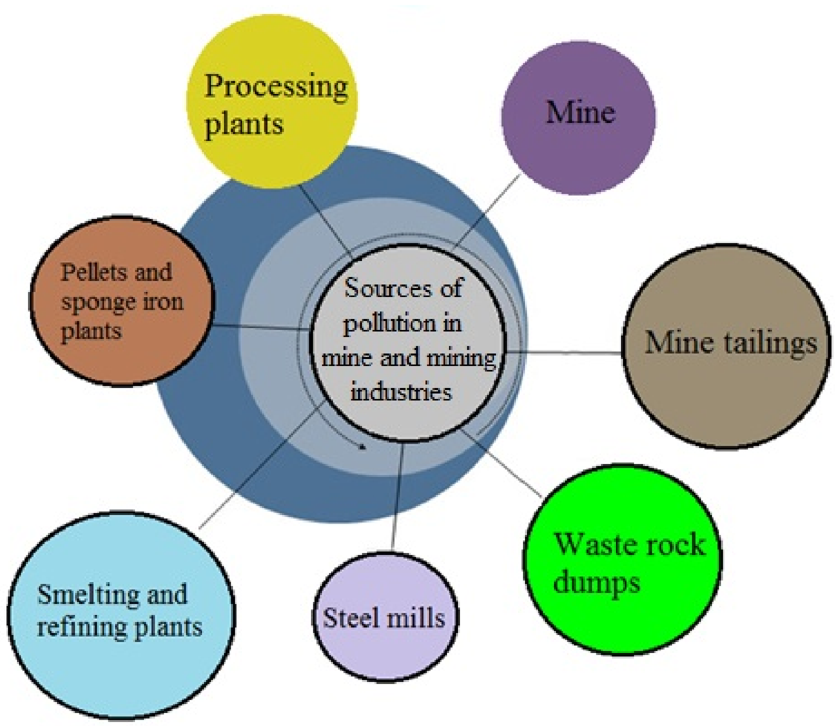

Figure 1. Various sources of pollution in mine and mining industries.

This article aims to develop a conceptual framework for green mining strategy and offer some insights and different solutions for the proper implementation of mining with a green and environmentally friendly concept that causes the least degradation of nature. The components affecting green mining will be described. The types of biological resources that should be studied in the green mining plan will be introduced. The implementation stages of the green mining technology will be briefly reviewed. Finally, a comprehensive green mining system will be provided for the coal mines and associated industries.

2. Environmental impacts of mines and mining industries

Mining at all stages (drilling, blasting, loading, transportation, and mineral processing) and the related industries such as iron smelting and steel manufacturing may negatively affect air and water quality and biodiversity. Open-pit mining is the most crucial method of extracting minerals near the surface of the Earth. Low-grade ores are usually stored in waste rock dumps, and high-grade ores go to the next stage for concentration and purification.

The primary pollutants emitted during processing, smelting, refining, manufacturing, and mining operations include the combustion products such as nitrogen oxide, carbon dioxide, carbon monoxide, sulphur dioxide, and dust from the mining activities. The main sources of emissions of combustion-related pollutants during the construction and operation stages are diesel generators, fossil fuel boilers, and traffic on the mine or plant sites. Pollutants emitted into the air have adverse effects on the human health and the environment. In order to prevent these effects, it is necessary to address these problems scientifically. It is essential to develop an air quality management plan in mining and the related industries to minimize the emission of harmful air pollutants. An effective dust control program is vital depending on the amount of dust generated by mining and the associated industries and its impact on the human ecosystems (including mine workers and indigenous communities) and natural ecosystems (including soil, plants, microorganisms, and animals).

Dust emissions usually occur during land clearing, ground excavation and from mining equipment and machinery traffic at the mine site. Dust in the mining area is caused by the loading and unloading operations, crusher, and conveyor systems. The significant health effects of air pollution on wildlife include direct mortality, diseases, and debilitating injuries from industrial activities, and physiological and psychological stress.

Mining often changes the physical, chemical, and biological environment in an area [9, 10]. The nature and extent will vary depending on the geographical location, the type of deposit, and the mining method. The mining operations can affect the hydrological and hydrogeological parameters, and deteriorate water quality in the mine site [11]. In addition, it can change the natural morphology, and lead to permanent changes in the topography of the mining area, destroy vegetation, and accelerate soil erosion caused by drilling and blasting by erosion agents such as wind and water.

Another impact of mining is the generation of large quantities of waste. Since many near-surface deposits have been mined, this increases the depth of mining, resulting in huge volumes of waste. Many mine wastes are toxic, and have direct and indirect adverse effects on the environment. Thus if the waste is not adequately controlled or adequately managed, the toxic and harmful substances will result in long-term contamination of surface water, groundwater, and soil.

Coalmine drainage pollution is commonly due to the oxidation of sulfide minerals, in particular pyrite. In coalmines, pyrite is generally found in either the coal seams or in mudstones with a marine origin. When pyrite is exposed to air and moisture, it rapidly oxidizes, which produces acidic drainage [12]. Such drainage containing high concentrations of iron, sulfates, soluble minerals, and various trace elements poses some problems. It has a detrimental effect on the surface and groundwater aquifers and soils [13].

The adverse environmental effects resulting from acid mine drainage are due to a poor management during the design, development, operation and closure of mining activities, and incorrect understanding of AMD in the past [14]. In other words, the concept of green mining was not included in the work plan of the miners. The destructive effects of acid mine drainage may remain for long after the cessation of mining work, so the environmental management is an essential task during mining operations. A basic strategy and plan must be developed for mine closure in order to prevent the subsequent generation of acidic acid drainages.

Acidic drainage generated from the oxidation of sulfide minerals that may contain high concentrations of some trace elements has many environmental effects. If acid mine drainage formation cannot be prevented, it should be treated with chemical or biological processes to eliminate or minimize their adverse effects on the environment. The acidity is neutralized in the treatment process, and the toxic metals are removed or reduced to acceptable standards for the discharged effluents. Heavy metals in acid mine drainage such as iron, zinc, copper, lead, cadmium, aluminum, and manganese become insoluble when react with a chemical agent and precipitate at a specific pH to form metal complexes. The mining industry is an essential and fundamental task for neutralizing acid mine drainage in the areas where it forms. In such areas, remediation technologies and chemical treatment facilities will be required before acidic drainage can be discharged into the surface and groundwater sources [1, 15].

Although temporary remediation methods may reduce the effects of acidic water on the environment, active and/or passive treatment methods need to be employed for an accurate and complete treatment of mine acid drainage. Active treatment methods often produce large amounts of gypsum sludge contaminated by some trace elements, which require additional treatment facilities, and are therefore costly [16]. In contrast, constructed wetlands and the use of the biological sulfate reduction process are often effective and inexpensive treatment methods, with low maintenance costs, for the treatment of acidic mine drainage [17]. The subsequent research work carried out by Skousen in 2000 has illustrated that wetland systems successfully remove metals from acid mine drainage but such systems are not always reliable to treat it in all seasons [quoted in 18]. Skousen *et al.* in 2016 presented a comprehensive review of the different types of passive systems for acid drainage treatment [19]. The main purpose of treatment systems is to remove the contaminants such as iron, sulfate, and trace elements from acid mine drainage and increase the pH. The treated mine effluents can then be directed to the receiving waters [18].

Evaluating the effects of mining activities on the surrounding environment or the environmental management of mining sites is of particular importance. The environmental management of mining areas includes an effective control of water pollution and disposal of mining waste, effluents and leachate from concentrate plants, hazardous wastes transportation and disposal, management of tailings from processing plants, and reclamation of mine lands. Indigenous and local communities near the mine site and processing plant should also be given a special attention. The economic, social, and cultural development of indigenous and local communities significantly impacts the constancy and sustainable lifetime of the mining activities and the prevention of social challenges.

Mine tailings management raises several issues related to water pollution control. The major potential environmental and social impacts of the tailings are as follow:

- Effects on surface water quality could arise from contamination by leakage, accidental release from the tailings dam.
- Seepage through the base of the tailings dam could affect the groundwater quality.
- Discharge from the tailings dam could potentially affect the local river.
- Radiation levels in plant effluent and tailings may be higher than the standard level.

Tailings dam failure can cause significant environmental, social, and economic impacts. The consequences of tailings dam failure cost a lot of money for the mining companies, and may result in an early mine closure.

The main short-term and long-term problems associated with tailings are:

- Safety incidents and instability problems
- Water pollution
- Air pollution due to dust emission
- Visual impact

The stability study of tailings dam at different stages from construction to closure, reclamation and continuous monitoring is vital for any mining area. Tailings dam stability study will provide the important data required to monitor long-term dam construction.

2. Environmental impacts of mining complexes and related industries

Reclamation of lands affected by mining activities and mine tailings is significant in controlling the environmental problems. Mine tailings are often transported to the tailings dam through pipelines. These pipelines sometimes cause environmental pollution due to breakage and leakage. Pipelines are required to be regularly inspected and maintained to ensure that the transport of materials is done properly. Based on the geographical location, the tailings dams may pose a long-term risk to the public and the environment if they break. Dams may fail in active earthquake zones and areas where landslides occur. Dam foundation condition is important in terms of safety, environmental protection, and reducing or preventing leakage rate of contaminated water from the dam to the surface and groundwater. Due to the fact that dams are usually designed for long-term use, appropriate measures need to be taken to have sufficient strength and maintain their maintenance costs to a minimum. In addition, they cause the least environmental pollution. In order to achieve this goal, before deciding on the location to construct a tailings dam, seismic surveys are used to identify the nature and subsurface characteristics of the area from a geotechnical point of view. By establishing the accurate water balance in the tailings dam system, water pollution can be reduced. These waters include process water, surface run-off, groundwater flowing into the dam, precipitation, evaporation, and seepage into the ground. In order to establish water balance in a tailings dam, it is necessary to determine the amount of water entering and leaving it accurately.

3. Green mining concept

Green mining is a technique to minimize the negative environmental and social impacts at all stages of mining operations. Simultaneously, the operation seeks to maximize social and local benefits. Green mining is a way to produce sustainable minerals and reduce the adverse impacts of mining operations. The green mining method utilizes constructive technologies and solutions to reduce the environmental consequences of mining activity. A comprehensive definition of green mining is provided, which is called the mineral extraction technology with the aim of "reasonable production, high efficiency, and low environmental consequences" [8]. Green mining has been proposed as a practical approach to make the mining and related industries more sustainable than the conventional mining method [20].

Table 1 presents the components affecting green mining. As it can be seen, the economic and social progress, technological development, and international laws and regulations affect green mining and its implementation. Education is also one of the parameters that can play an important role in the performance of the green mining system by developing a training culture and using proficient employees.

Table 1. Components affecting green mining.

No	Subject	Effective component(s)
1	Community and society	Job creation, sustainable livelihood, raising awareness, presence of people, building a culture of community, civic engagement, reporting to the public (people), demand of society, civil society organizations (CSOs)
2	Economy	Knowledge-based economy, regional economic mobility, and growth, rural economic development, monopoly rent-seeking, mining companies, economic transparency, segmental view, single window, investment opportunities, permits and inquiries
3	Education and cultural development	Educational beliefs, research and development parks, new definitions, transparency at work, educational culture, educational space, capable expert, up-to-date expertise, mining workshops, academic roadmap, cohesion and empathy, rethinking, practical intentionality
4	Laws and policy-making	Transparency of laws, comprehensive environmental law, daily policy-making, regulatory implementation strategies
5	International	International standards, passivity in global developments, global market
6	Technical	Latest technology

3.1. Green mining goals

Green mining in a mining area is the only way for the safe and healthy growth of the mining industry. This process can prevent or reduce the adverse environmental impacts of mines as much as possible. Green mining pursues the following goals:

- Green mining is an essential tool to create an innovative technology in sustainable mining.
- Green mining is a tool to increase the productivity of materials, water, and energy to reduce the environmental consequences.
- Green mining is a tool to recover the maximum amount of useful minerals and a way to minimize mine waste.
- In green mining, access to mineral resources is guaranteed for future generations.
- Green mining is a way to minimize the environmental and social consequences at all stages of mining.
- Green mining is a process to help organize the mining operations to create safe activities for the employees.
- Green mining provides a model for reclamation of the mining site after the abandonment of mines and mining industries.

3.2. Identification of biological resources and providing baseline reports

Green mining is a multifaceted issue. Therefore, all its aspects are required to be studied; otherwise, ignoring some components may cause irreparable harm to the environment and make corrective measures very complex and challenging. One of the most essential requirements of green mining is the environmental impact assessment of the mining projects. Figure 2 presents six biological resources that should be considered in the green mining plan as the preliminary studies. These include water and soil resources and plant and animal species in the area. In addition, the health of the employees of the mining complexes and associated industries and the health of the indigenous and local communities near the mine site should be monitored. These biological resources are always at risk of environmental pollution, and should always be monitored.

By carefully studying the area, sampling, analysis of samples, and necessary interpretations, the status of these resources and the amount of contamination in each of them and the source of these contaminants will be fully determined, which finally future planning can be done based on the results. Due to the relatively higher environmental sensitivity of the mining area and the adverse impacts of mining activities and related industries on the ecosystem of the region, it is necessary to conduct a comprehensive study of all environmental issues in the region, and finally, take into account all aspects and available information to assess the environmental impact of the region. It is important to note that the final environmental impact assessment will show what steps are required to be taken to reduce and prevent environmental pollution in the mine and related industries so that mining operations can be carried out with the objective of green mining to minimize the adverse environmental and social impacts in all stages of the operations. After conducting the essential studies, it is also necessary to employ an extensive reclamation planning scheme that meets the required standards.

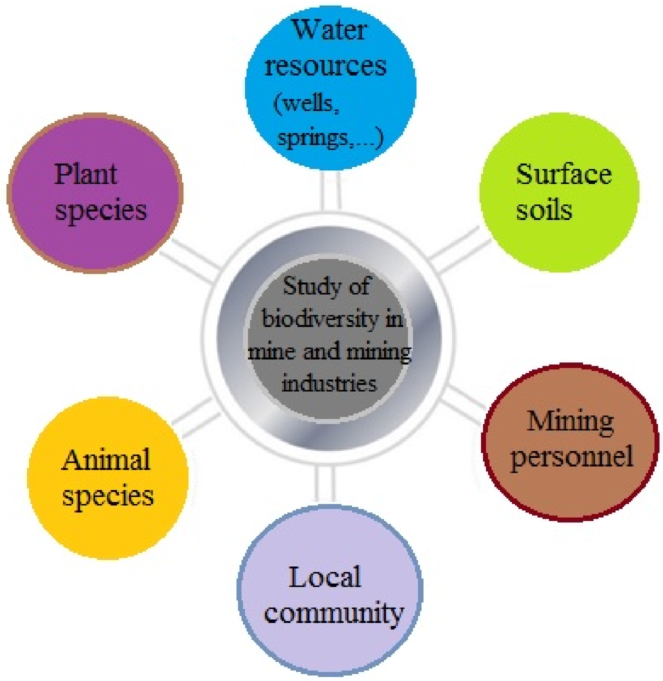

Figure 2. Biological resources that should be reviewed and monitored in green mineral plan.

3.3. Preliminary studies in green mining

The stages of green mining studies in terms of environmental considerations and assessment of the impacts in a mining area are as follow:

- **Data collection, control, and review of data**

This stage includes gathering all information on the geology, meteorology, tectonics, sub-surface lithology, hydrology, hydrogeology, environmental hazards, and health effects at a mining site.

- **Climate and meteorological studies**

At this stage, the following studies are necessary:

- Identifying climatological stations in the region and collecting the meteorological data

- Determining temperature, evaporation, and long-term precipitation of the region

- Determining the climate of the study area using De Martonne climate classification and Amberg index

- Determining the critical seasons of the year in terms of rainfall

- Determining long-term average monthly and annual precipitation, temperature, and potential evaporation values

- Predicting the future climate patterns of the region

- Determining the environmental status of the mining area under the existing climatic conditions and investigating the environmental challenges related to the climate

- **Basin/watershed studies**

- Preparing a map of the basin and determining the sub-basins and the location of the mine

- Preparing a map of the mine catchment and determining the waterways within the catchment area at three different levels

- Performing the physiographic operations of the catchment area and determining the hydrological parameters of the sub-basins and waterways in the area

- Determining the water inflows and outflows of the study area

- Identifying waterways and surface run-off, determining their characteristics, and investigating the relationship between surface and groundwater in the study area

- Determining the characteristics of rivers in the basin

- Performing rainfall-runoff studies and preparing run-off hydrographs for rivers and waterways, and determining the potential for flood risk in the study area

- Assessing the water inflow to open-pits or underground mines during flood events

- Providing flood control solutions and preventing its consequences in the mine area
- Determining the boundaries of the catchment area and performing water balance calculation
- Determining the environmental hazards and risks in the study area at the catchment scale

- **Remote sensing and UAV studies and preparation of required maps**
  - Preparing and processing of satellite images to determine the digital elevation model (DEM) of the study area
  - Preparing accurate digital elevation model using UAV technology and taking aerial images of the study area
  - Determining soil type and its permeability in different places of the study area by combining UAV-based aerial imagery and satellite data
  - Determining the type and density of vegetation in the study area, applying satellite and UAV images to prepare run-off curve number (CN)
  - Determining land use potential map for the study area with the purposes of application in hydrogeological studies

- **Sub-surface geological studies related to water and the environment**
  - Geological investigation of the study area and identification of various geological formations
  - Assessing the tectonic activities, identifying the fractures and faults, and determining the surface flow paths in the study area
  - Determining the various geological units, tectonic activities and the role of each in the movement of surface and groundwater and the transport of potential pollutants through the groundwater flow system
  - The design and implementation of the geophysical sounding in the required number to determine the sub-surface geological structure and identify the groundwater aquifers

- **Investigation of the physical and chemical characteristics of water resources in the study area**
  - In-situ measurement of water quality parameters (pH, Eh, EC, salinity, temperature, and dissolved oxygen)
  - Sampling and determination of the concentrations of trace elements, anions, and cations in different types of water samples
  - Isotope studies and determination of the origin of different water samples
  - Determining the quality status of water resources using various hydrogeochemical diagrams

- **Investigation of the physical and chemical characteristics of soil in the study area**
  - Determining the soil type and studying its physical and chemical characteristics
  - Evaluation of the permeability of various rock units and preparation of a permeability zoning map
  - Sampling and determination of the content and type of trace elements, anions, and cations in different types of soil
  - Performing radiometric surveys in order to detect and map natural radioactive emanations from rocks and soils
  - Investigating the status of soil contamination in the study area and preparing a map of the distribution of various elements
  - Investigation and analysis of the environmental, health, and socio-economic impacts of soil pollution, the effects of mine opening, and pollution emission from the existing industrial plants

- **Study of the variety of plant and animal species and ecosystem of the study area**
  - Identifying the plant species
  - Sampling of plant species and determination of trace metals, major anions and cations in different plant species
  - Identifying the plant species absorbing pollutants, and introducing native plant species acting as a superabsorbent
  - Identifying the different types of animals, and the number and biodiversity and risk of extinction of each animal
  - Investigating the status of mining hazards and their damages on the existing plant and animal species and providing control strategies in order to reduce mining damage to the plant and animal ecosystem

- **Study of acid mine drainage production potential**
  - Assessment of the status of the study area in terms of potential for acid mine drainage production
  - Sampling of the existing geological units in the study area and determining the acid producing potential of different rocks based on the MEND approach

- Assessment of the physical, geo-chemical and mineralogical properties of waste rock, and study of the acid producing potential in waste dumps
- Applying the monitoring and control strategies to limit acid mine drainage production and proposing the operational procedures in order to minimize damage to the environment

- **Study of socioeconomic status and indigenous human communities in the areas under investigation**
  - Assessing the socioeconomic status of the local human communities
  - Gathering necessary information about occupations, population distribution, relative income and livelihood of local communities
  - Assessing the status of literacy and educational development among indigenous communities and assessing the current situation
  - Planning and providing solutions about constructive interaction between local communities and industrial and mining complexes

- **Preparation of comprehensive GIS-based water and environmental quality information database**
  - Collecting all the data layers required for the comprehensive green mining plan
  - Digitization of available information/documents
  - Transferring data to a GIS model/ software and preparing classified database
  - Database Management

- **Environmental hazard mapping and site selection for construction of waste dumps and tailings dams**
  - Zoning of the study area and conducting integrated studies to identify contaminated sites and other high-risk areas using Geographic Information System (GIS)
  - Mapping the environmental vulnerability of the study area using a fuzzy-integration-based approach, drastic model, and multi-criteria decision making (MCDM) methods
  - Investigating the current locations of waste and tailings disposal sites and identifying potential problems
  - Site selection for the construction of new waste dumps, tailings disposal sites and factories to be used in future using GIS-based spatial analysis

- **Investigation of pollutants formation in concentrate, pellet, smelting and refining plants according to process engineering models**
  - Investigation of components of concentrate and pellet processing systems and identification of sources of environmental pollution
  - Sampling at different points of the system, especially effluents and determining their pollution levels
  - Assessing the health status of employees at the factories in high-risk areas
  - Investigating the status of waste generation systems and waste disposal methods
  - Assessing environmental pollution potential in concentrate and pellet plants
  - Determining the status of noise, dust, man-made pollution, lighting in workplaces, and machinery movement in the study area and their potential environmental impacts

- **Investigation of the green coverage ratio (green open space) in the mine and mining industries area**
  - Checking the status of the current green coverage ratio (green open space) in the mine zone, mining complexes, and associated industries
  - Providing solutions to improve the existing green coverage ratio according to the standards of the Iranian Department of Environment
  - Identifying suitable sites for the development of green spaces and mapping them
  - Identifying the types of plants best grown for the development of green spaces in mine site and concentrate and pellet plants according to the climatic conditions of the study region and the types of soil available

- **Environmental impact assessment (EIA) and calculation of a sustainability index**
  - Examining the current situation, preparing the Leopold matrix [21] for evaluating the potential impacts of a mining project, and explaining the severity and importance of the environmental effects of mines, concentrate, and pellet plants
  - Environmental impact assessment of the study area using the Folchi and modified Folchi methods [22]
  - Environmental impact assessment of the study area using the Pastakia (RIAM) method [23]
  - Environmental impact assessment of the study area using the data envelopment analysis [4]

- Assessment of environmental sustainability in the desired area using the Philips method, and determining a sustainability index [24].

- **Life cycle assessment (LCA) for all products and production systems**

LCA is a cradle-to-grave or cradle-to-cradle analysis technique for the systematically analysis and assessing the potential environmental impacts related to all the stages of the life cycle of mining projects [25]. The following goals are pursued at this stage:

- Defining the goal and scope of work, and creating a life cycle inventory
- Undertaking a field visit, and conducting necessary sampling
- Undertaking an LCA using the obtained data and results provided by an LCA software such as SimaPro [26]
- Delivering and evaluating the alternative scenarios

- **Data analysis, integration of findings and preparing six baseline reports**

At this stage, the data obtained is analyzed, the study findings are combined and integrated, and the baseline reports are presented. The baseline reports are summarized in Figure 3.

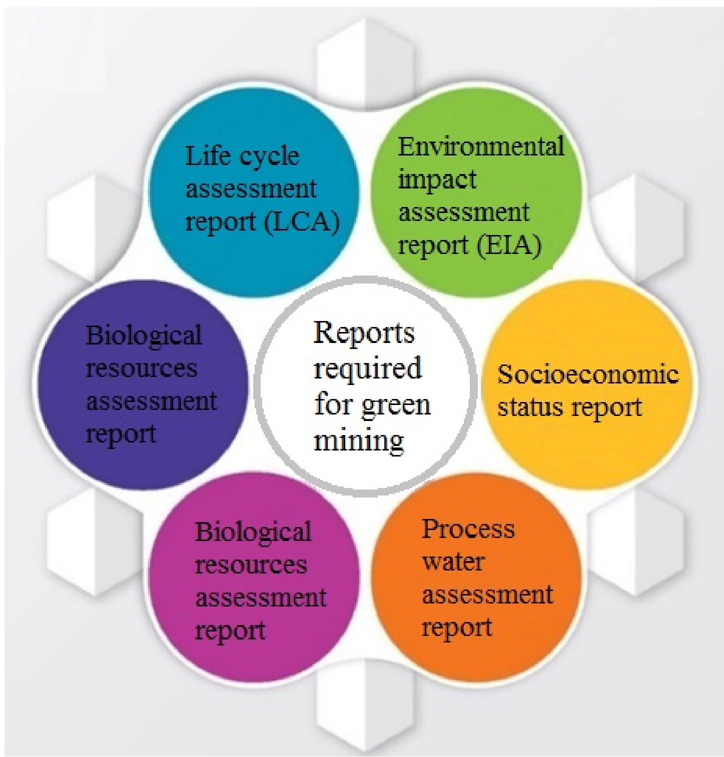

Figure 3. Baseline reports required in designing a green environmental management system (GEMS) for mines and mining industries.

3.4. Comprehensive green management plans (environmental management plan) in mines and mining industries

Up to this point, the studies were conducted in order to investigate the current situation and identify the problems and obstacles ahead in the design of the green mining technology. Figure 4 presents eight comprehensive plans that form the basis of the green mining technology. Further details of these plans are discussed below.

- **Developing a comprehensive water plan**

- Characterization of process waters of the mineral processing plant, evaluating the water and wastewater treatment methods, and planning to dispose of waste
- Sampling and determining the quantitative and qualitative characteristics of water entering the mines and factories
- Developing appropriate strategies to recycle water and increase the efficiency of process water

- Calculating the amount of virtual water for all products of mining industries
- Designing a comprehensive strategy for water consumption and water recycling/reclamation in the future

- **Developing a comprehensive waste management plan**
  - Accurate determination of all quantitative and qualitative characteristics of wastes produced
  - Determining the methods of industrial wastewater disposal and site selection for tailings and mine waste
  - Development of possible scenarios in order to deal with the potential health effects of waste
  - Designing and implementing comprehensive recycling, reuse, and rehabilitation of mine wastes

- **Developing a comprehensive corporate social responsibility plan (CSR)**
  - Determining the current status of the organization in terms of the degree of attention to social responsibility
  - Preparing a comprehensive plan for education and cultural promotion of the local communities
  - Examining the socio-economic situation and livelihood of local communities near mines and mining industries
  - Identifying and addressing mental health conditions in the employees
  - Assessing the status of work performance and the level of systemic corruption among the employees

- **Preparing the comprehensive green spaces management plan**
  - Checking the existing green spaces in the mine area
  - Checking the existing green spaces in the mining complexes and associated industries
  - Reviewing the existing green space improvement strategies according to the standards of the Iranian Department of Environment
  - Identifying suitable areas for the development of green spaces
  - Identifying the types of plants best grown for the development of green spaces

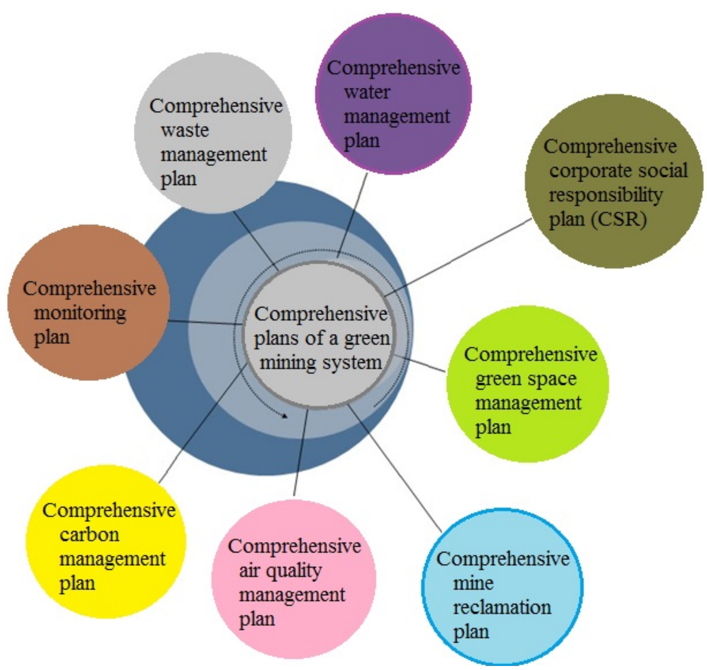

Figure 4. Comprehensive plans of green mining system for mines and mining industries.

- **Preparing the comprehensive air quality management plan**
  - Evaluating the meteorological condition of the upper and lower atmosphere and the status of wind vanes
  - Investigation of the topographic features of the study area and surface reflection
  - Evaluation of the specifications of emissions from all chimneys in different units and the types of fuel used

- Investigation of the type of pollutants (gases and particulate matter) and their impact
- Assessment of the emitting gases, particulates, and/or mixtures of these into the atmosphere, and comparing them with the recommended values
- Assessment of pollutant accumulation and determining their radius of influence around the existing mining complexes and associated industries
- Prediction of the risks from toxic air pollutants on mine personnel and nearby communities
- Comparison between the predicted results using the AERMOD or CALPUFF models and field measurements
- Preparation of pollution zoning maps in and around the mining complexes and associated industries

Important note: The study period was one year, and the measurements were carried out in all seasons.

- **Preparing the comprehensive mine reclamation plan**
  - Assessment of the environmental, ecological, hydrological, and hydrogeological problems of all abandoned mines in the study area
  - Investigation of the status of waste dumps and mine tailings after mining and production stages
  - Investigation of the geo-mechanical safety and stability of mine waste dumps and tailings dams
  - Designing appropriate mine drainage and wastewater treatment systems in the mining area after the cessation of mining operations
  - Estimation of the costs of mined land reclamation after mining activities
  - Preparation of a comprehensive plan on how to carry out reclamation operations in detail for all mines and related industries, waste rock dumps, and tailings sites
- **Preparing the comprehensive carbon management plan**
  - Identifying all sources of CO_2 and other GHGs
  - Determining the amount and type of gases produced in different sectors of mines, processing plants, and coal washing plants
  - Assessing the potential risks and health hazards of gases produced in the surrounding environment
  - Comparison of the current situation of GHG emissions with national and international environmental standards, under the provisions of the Paris Agreement
  - Modelling CO_2 distribution in the environment, and determining its concentrations
  - CO_2 sequestration via carbonate precipitation, and finding technical and industrial applications of CO_2 released into the atmosphere
- **Preparing the comprehensive monitoring plan**
  - Providing the necessary consultation regarding the installation and commissioning of a comprehensive monitoring system in the mining complexes and processing plants
  - Designing a central control system as a "management control system" (for example, in Tehran) as well as a separate control network in mining units
  - Identifying the type and installation location of all available sensors for monitoring
  - Providing monitoring results and challenges for a period of one year
  - Creating a training program for the employees to learn how to use monitoring systems in all mining complexes and associated industries

4. Developing a conceptual framework

The studies presented here provide an extensive "green mining system" that promote and pursue sustainable mining integrating socio-economic, health, and environmental factors. A comprehensive green mining system includes the following:

- Examining 6 biological resources for mining complexes and associated industries independently, and submitting the necessary reports
- Preparing 6 basic reports separately in each mining complex
- Providing 8 extensive green management plans for the whole mining complex
- Summarizing all the obtained results, presenting the environmental status chart of mines and associated industries, and presenting the final summary taking into account all the aspects of the green mining plan
- Providing green management solutions in all mining complexes
- Providing protection recommendations for water resources, soil, and plants and animal species in the area
- Providing sustainable solutions for pollution control in different parts of the mine, mineral processing, smelting, and refining plants, separately

Figure 5 shows a conceptual framework for implementation of green mining strategy in coal mines and associated industries.

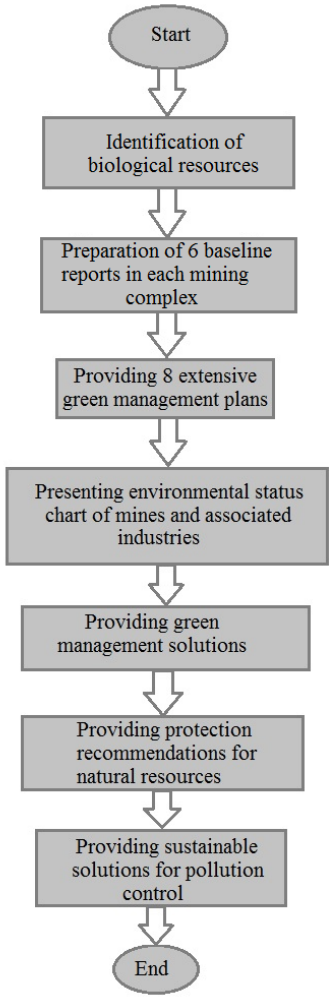

Figure 5. A conceptual framework for implementation of green mining strategy in coal mines.

5. Conclusions

Conducting mining and associated industrial activities using conventional techniques has many environmental impacts. In order to balance the mining area and the surrounding unmined lands, huge costs are required to be allocated. Considering all the environmental considerations, mining with the concept of sustainable development that produces the lowest adverse environmental impacts may not be possible. Implementing green mining technologies eliminates the idea that mining and environmental protection are two completely opposite concepts. Implementing green mining technologies would cause the least damage to the environment. In this mining technique, a sustainable production of minerals is expected so that the least adverse impacts of mining operations will affect the environment. In green mining, new technologies, and constructive solutions and methods for mineral extraction and processing will be employed that have the least adverse environmental problems. At the same time, the operation seeks to maximize the social and local benefits. For a proper implementation of mining with a green and environmentally friendly concept, the mineral extraction technology is used in order to achieve reasonable production, high efficiency, and low environmental impacts. Green mining is an exploitation technology that aims to reduce emissions of pollutants. Green mining in a coal mine is the only method for sustainable mining. The adverse environmental effects of coal mining are reduced, and the greatest economic benefits are obtained. The most significant achievements of green mining include providing green management solutions in coal mines and related industries, providing protection recommendations for water and soil resources at the mine site, and providing pollution control strategies in various parts of the mine and related industries.

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تدوین یک ساختار (مدل) مفهومی برای اجرای روش معدنکاری سبز در معادن زغال سنگ: تلفیق عوامل اجتماعی-اقتصادی، بهداشتی و زیست‌محیطی

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چکیده:

با توجه به اینکه معدنکاری از مرحله اکتشاف تا تولید محصول و نهایتاً متروک شدن، تبعات زیست محیطی فراوانی را به همراه دارد، لذا لازم است برنامه‌ریزی انجام فعالیت‌ها به صورتی انجام شود تا مفهوم معدنکاری سبز به معنای واقعی خود تحقق یابد. به این معنی که معدنکاری جهت دست‌یابی به مواد معدنی مورد نیاز صنایع انجام شده ولی با اتخاذ تدابیری مناسب، تبعات ناشی از معدنکاری بر روی محیط زیست به حداقل ممکن کاهش یابد. با توجه به اینکه در اکثر مناطق معدنی اطلاعات اندکی از وضعیت زیست محیطی، اکولوژیکی، هیدرولوژیکی و هیدروژئولوژیکی وجود دارد، ابتدا می‌بایست مطالعات جامعی در خصوص وضعیت آب، خاک، پوشش گیاهی و گونه‌های جانوری منطقه انجام شود. وجود رودخانه‌های دائمی و فصلی در مجاورت برخی معادن، در مواردی قرار گرفتن در مناطق حفاظت شده سازمان حفاظت محیط زیست و همچنین وجود پوشش گیاهی در نزدیکی بعضی معادن از جمله مواردی است که باعث ایجاد چالش عدیده زیست محیطی در منطقه معدنی می‌شود. بدین منظور یک سلسله مطالعات جامع در مراحل قبل از معدنکاری، در حین معدنکاری و در مرحله متروک کردن معدن ضرورت دارد. همچنین، در مورد کارخانه‌های موجود در محدوده‌های معدنی مانند کارخانه‌های ذوب، باید مطالعات مفصلی انجام گیرد. ارزیابی چرخه حیات (LCA) در تعیین وضعیت زیست‌محیطی این کارخانه‌ها بسیار مورد استفاده قرار می‌گیرد. بعلاوه، بحث آب فرآیندی و بازیافت آب و همچنین مدیریت باطله‌ها باید مورد توجه اساسی قرار گیرد. طراحی سیستم پایش از جمله مواردی است که با توجه به پیشرفت تکنولوژی امروزه در بسیاری از معادن در جهان استفاده می‌شود. بعلاوه، سیستم مدیریت فضای سبز این مجموعه‌ها با توجه به استانداردهای الزام آور سازمان حفاظت محیط زیست باید مورد توجه ویژه قرار گیرد. در این مقاله، یک مدل مفهومی برای اجرای مناسب روش معدنکاری سبز برای مجموعه معادن زغالسنگ معرفی خواهد شد تا ضمن لحاظ جنبه‌های اقتصادی و اجتماعی، الزامات مرتبط با بهداشت، ایمنی و محیط‌زیست مورد توجه ویژه قرار گیرد.

کلمات کلیدی: اثرات سلامتی، مولفه‌های معدنکاری سبز، ارزیابی اثرات زیست محیطی، ارزیابی چرخه حیات، طرح مدیریت سبز.