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Introducing sustainable development and reviewing environmental sustainability in the mining industry

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Abstract

A comprehensive systemic approach is needed to make effective decisions for global sustainability. The system's points of view introduced sustainable development (S.D.) and sustainability in prior years. Sustainable development is expressed as a desire followed by humanity to live in a better condition considering all the limits that nature could have. Social, environmental, and economic responsibilities are the wide-ranging developmental characteristics that form sustainability. In this paper, with the help of search engines like Scopus and Web of Science, several documents related to environmental sustainability in the mining industry were studied. The principal investigated problems were tailings dam failure, forestland use in mining operations, social and environmental issues in crushed stone mining industries, landfill mining challenges, climatic problems, economic problems, and fatalities in artisanal and small-scale mines. Also, a table was designed to categorise these problems and determine the solution and primary goal. This study investigates the severity of mining operation conditions and environmental issues in this industry. The common environmental problems in the mining industry include soil degradation, deforestation, land subsidence, acid mine drainage, waste production, natural landscape destruction, coal production, carbon footprint, dust pollution, greenhouse gas emissions and climatic problems. To have a more sustainable mining industry, all the mining stages, from the exploration to the post-closure stages, must minimise resource and energy consumption and waste products.

Keywords:

sustainable development; sustainability; environmental issues; mining industry

1. Introduction

With demand rising for raw materials, the increase of human activities, and the reduction of mineral deposits over recent decades, mining as a mother industry has become an exciting area for the various sectors in the supply chain. On the contrary, the multiple harms of this activity from the perspective of human rights activists in various fields have raised the voices of some critics (**Silva et al., 2019; Küçükbay and Sürücü, 2019**). The studies reveal that operations and facilities in the mines are unique in their structure, function, and business position. Operational conditions (such as harsh environment, maintenance strategy, various managerial decisions, etc.) in the mining supply chain have significant effects on the systems and equipment in multiple ways, including increasing the energy consumption, power losses, greenhouse gas emissions from plants, and life cycle costs. Also, improper mining methods and technologies cause environmental degradation, increased waste production (**Charron et al., 2014**), and adverse ecological effects.

Moreover, the mines are mainly located in geographically remote and pristine areas, making this region vulnerable and more sensitive (**Dhar and Thakur, 1996; Mottahedi et al., 2021**). Hence, engineers and managers can no longer perform in isolation of a challenging mine environment with strict regulations and requirements for safety and environment and to reduce business risk; a sustainability analysis should be included in the effectiveness evaluation of the system output (**Barabadi et al., 2016**). In recent years, sustainable development (S.D.) has been considered a generally accepted target in human society. Moreover, measuring the companies' sustainability performance has been highlighted by many stakeholders (**Bossel, 1999; Fiksel, 2006; Asif et al., 2011; Dahl, 2012; Haapala et al., 2013; Shuaib et al., 2014; Sachs and Ki-moon, 2015; King, 2016; Suter et al., 2017; Pupphachai and Zuidema, 2017; Diaz-Balteiro et al., 2017, 2018; Gan et al., 2017; Leonard, 2019**).

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Sustainable development and mining activities have three pillars: society, environment, and economy. Three principles must be applied in the mining life cycle to incorporate sustainable development and for the mining industry to gain comprehensive development (**Asr et al., 2019**). Sufficient economics, a clean environment, and a responsible society are the main goals of sustainable mining development. All mining activities in large-scale mines (LSMs) and artisanal and small-scale mines (ASMs) (or open-pit and underground mining) are affected by environmental footprints.

However, open-pit mining has more environmental disadvantages than underground mines (**Famiyeh et al., 2021**). In this regard, the most noticeable problems in mining industries are environmental issues like soil erosion and degradation, natural landscape destruction, deforestation, overcutting of vegetation, effects on natural resources, pollution of toxic substances, land subsidence, mine fall, acid mine drainage, more ecosystem issues, etc. (**Asr et al., 2019**). Since deteriorating environmental circumstances in many regions of the globe indicate that its sustainability may be endangered, sustainable development has become a generally acknowledged aim for human civilisation (**Bossel, 1999**). Sustainability is the challenge of our time (**Sachs and Ki-moon, 2015**). Finding sustainable development for a community, such as the mining industry, necessitates understanding what is vital for the viability of the systems involved and how that contributes to it (**Bossel, 1999**).

It is inconceivable that a system could exist as a closed area with defined boundaries. It moves across space and time, throwing out changes in its subsystem. A system's components are continually "sacrificed" to ensure persistence and long-term viability. Some businesses are attempting to implement more sustainable systems. For example, Interface (a carpet tile producer) in developing a sustainable process reduced greenhouse gas and energy consumption, and through the reuse of waste material had diverted 84 million pounds. Approximately $300 million in garbage disposal expenditures were averted (**Fiksel, 2006**). Although, in recent years, numerous communities and organisations like the United Nations Development Programme (UNDP) and the International Council on Mining & Metals (ICMM) made the mining sector more sustainable by enhancing guidelines and frameworks (**Asr et al., 2019**). Thus, this paper will discuss sustainable development in the mining sector and highlight the problems throughout sustainable mining in different fields. The main objectives are listed as follows:

- To evaluate the definitions, concepts, and constraints of sustainable development;
- To review and evaluate the existing approaches for identifying sustainable development;
- A brief discussion of mine environmental conditions and challenges;
- To introduce environmentally sustainable development problems related to the mining field;
- To discuss the importance of sustainable systems in mining, some innovative methods, and solutions to the mining environmental and social problems.

The article's general framework is as follows: several definitions of sustainability are discussed in the first phase. The overall meaning is a dynamic notion that balances societal requirements with available resources. Different conferences and subsystems of sustainable development integrated into later phases describe sustainability aims and development. The difficult mining environmental conditions are shown, and innovative solutions to regulate them. The goal of a proper understanding of the mining environment and industry is to achieve long-term growth in the mine. Therefore, a sustainable development's idea and primary purpose must be grasped to correctly put this notion into practice.

To better understand the importance of environmental sustainability in the mining sector, the Web of Science and Scopus databases were used to investigate the documents related to this field. The ‹Analyse search results› in Scopus compares the number of environmental documents and the number of documents in other areas. The rankings revealed more articles related to this subject compared to others. Some latest articles related to the mining environmental problems and innovative solutions for mitigating them were reviewed. A table was designed to categorise the articles and determine the primary goal of each one. Some novel and future methodologies were studied in the final stage to discover possible solutions.

2. Sustainable development

The term "sustain" comes from the Latin word "sustenance," which means "to hold up" or "to support," and has been modified to mean "to continue" or "to extend" (**Sutton, 2004**). In the past, human society's sustainability was not in jeopardy: its environment's glacial change provided multiple opportunities for adaptive reaction and avoidance. To sustain means "to maintain; keep in existence; keep going; prolong". In an ever-changing world, sustainability can only imply sustainable development. The sustainability aim is more effectively translated as a goal of sustainable development (**Bossel, 1999**). Sustainable development is quite different from sustainability, which can be applied to maintaining an existing situation or system state. The "development" word points to directional and progressive change (**Gallopín, 2003**). According to the European External Action Service (EEAS), consumers benefit from sustainable consumption and production because it maximises company potential by turning environmental issues into economic possibilities (**EEAS - European External Action Service - European Commission, 2017**). The main goal of sustainable development is to guarantee that it contributes to a better quality of today's life, without compromising the quality of life for future generations and cannot mean merely the perpetuation of the existing situation. Development is about improvements in the quality of life (**Azapagic, 2003**). Environmental, material, ecological, social, economic, legal, cultural, political, and psychological aspects of quality of life need consideration. Responding to the challenges of S.D. requires insight into the characteristics of a sustainable system. As with a multi-component system, a system's vision is necessary for capturing and comprehending the critical linkages. Despite the ambiguity surrounding the path of sustainable development, it is essential to identify the essential components of systems and design indicators that can give vital and trustworthy information about the system's sustainability (**Bakshi and Fiksel, 2003**).

Some famous world communities have adopted sustainable development concepts so far. Here are some of their results and achievements. The Brundtland Report has consolidated decades of work on sustainable development, the Rio Earth Summit has rallied the world to take action and adopt Agenda 21, the Convention on Biological Diversity has put the precautionary principle into practice, and the Kyoto Protocol has taken the first step toward stopping dangerous climate change. Social justice meets public health and environmentalism with the Millennium Development Goals; Al Gore has brought climate change to the forefront with an unpleasant reality, and Rio+20 has taken stock of two decades of attempts at sustainable development. Brundtland Commission by Gro Brundtland, former prime minister of Norway, has reported S.D. as a "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (**Brundtland et al., 1987; Daly 1990**).

This means that a sustainable system should demand inputs or supply outputs to or from our system that does not influence our capacity to provide comparable outputs or consume similar inputs in the future, according to the system's engineering life cycle (**Carson, 2016**). While this definition is admirable, Beloff opined that S.D. is a complex idea, and its concept is difficult for practical usage. Helping a company understand the "big picture" and define the meaning of sustainability within its corporate culture was the framework's objective (**Beloff et al., 2004**). Munier has determined that "sustainability is a process involving people, institutions, natural resources, and the environment" (**Munier, 2005**). U.S. Department of Commerce has presented a definition for sustainable manufacturing that involves "the creation of manufactured products that use processes that minimise negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound" (**International Trade Administration, 2009**). Turcu claims that there is no universally acknowledged definition of sustainability. S.D. refers to attaining long-term development that meets human requirements and improves people's quality of life. At the same time, natural resources should be used so that the ecosystem's regeneration ability can sustain them (**Turcu, 2013**). The Arctic-FROST network defines *sustainable development* in the Arctic as "development that enhances the health, human development, and well-being of Arctic communities and people while maintaining ecosystem structures, functions, and resources" (**Petrov, 2014**). Like the intangible concepts such as democracy, justice, and innovation, the essence of S.D. can be hard to define and maybe measure (**Suter et al., 2017**).

The SD of a system is based on the lack of sustainability in subsystems and borrows from the sustainability of a super-system. Thus, setting the boundaries and distinguishing system levels for meaningful analysis has become a formidable challenge. It should be underlined that assessing sustainable systems cannot be performed simply by connecting a collection of domain-specific models. New techniques are needed to determine higher-order interactions among interdependent systems. The emergent behaviours and dynamic interactions that define complex and adaptive systems like lake systems are captured by these technologies (**Cohen, 2003**), system dynamic modelling (**Sterman, 2000**), and Thermodynamic Life Cycle Analysis (**Ukidwe and Bakshi, 2004**).

Based on the abovementioned paragraph, systems must be viewed as both 'objective' (objects and their interactions existing in a context) and subjective (related to multiple 'framings' under varied viewpoints on the system and its surroundings) simultaneously. From the system's point of view, sustainable development consists of six essential systems: individual development, social system, governance, infrastructure, economic system, resources, and environment are crucial factors. The components of each system are shown in **Figure 1**. As can be seen, these six systems may be divided into three subsystems: human (dark-white background), support (white background), and natural (grey background). These three subsystems correspond to the three capital categories used in whole system analyses: human capital, structural (constructed) capital, and natural capital are, three types of capital (**Bossel, 1999**).

If the system responds to S.D., it can benefit. Cost-saving, production efficiency, and product quality enhancement lower costs of health and safety, labour-related costs reduction, innovative solutions, staff motivation increment, improvement of the response-ability to the legislative changes, improvement of the relationships with government, social and economic risks reduction, best practice, reputation, enhancing the access to capital/markets, etc. However, it is not simple to quantify them because pay-back times often may be longer than usual. Progressively, the central point that arises over time in this third industrial revolution is replacing cost vision with time vision in any process. Improving an enterprise's competitiveness necessitates implementing procedures that management and organisation prioritise time. Moreover, unsustainable systems have some potential threats and possible effects such as financial and environmental inefficiencies due to the old technologies, costs increment, poor environmental performance and more incidents, conflicts with communities, poor external appearance, loss of international customers, etc. (**Azapagic, 2003; Beloff et al., 2004**).

3. System sustainability performance

The concept of sustainability was first applied to forest management issues in the 18th century, and since the 1980s, there has been an explosion of scholarly debate on these topics. It lasted until the **1992** World Conference on Environment and Development in Rio. The United Nations held this conference. Moreover, 178 governments, heads of state, NGOs, civil society, and campaign groups joined together, which may have been the sustainability summit (**Carlowitz, 1713; Pretzsch, 2014**).

U.S. National Research Council has expressed the definition of sustainability as futurable continuous terms of human consumption and activities throughout the provision of products and services for people by the systems (**National Research Council, 1999**). Bakshi and Fiksel have defined *sustainability* for engineering products or processes as "making a respectable level of controlling resource exhaustion and waste generation and supplying a long-lasting economic value for the business enterprise" (**Bakshi and Fiksel, 2003**). Munier has defined sustainability as "a process involving people, institutions, natural resources, and the environment" (**Munier, 2005**). An applicable definition for engineering contexts has been suggested by Mihelcic et al. as the "design of human and industrial systems to ensure that humankind's use of natural resources and cycles do not lead to diminished quality of life due either to losses in future economic opportunities or adverse impacts on social conditions, human health, and the environment" (**Mihelcic et al., 2003**).

The Academic Advisory Committee for the Office of Sustainability presented the working definition of sustainability in 2010 at the University of Alberta: "Sustainability is the process of living within the limits of available physical, natural and social resources in ways that allow the living systems in which humans are embedded to thrive in perpetuity." Most definitions of sustainability imply that a system will continue to operate at a specific level, under certain constraints, indefinitely (**Voinov and Farley, 2007**).

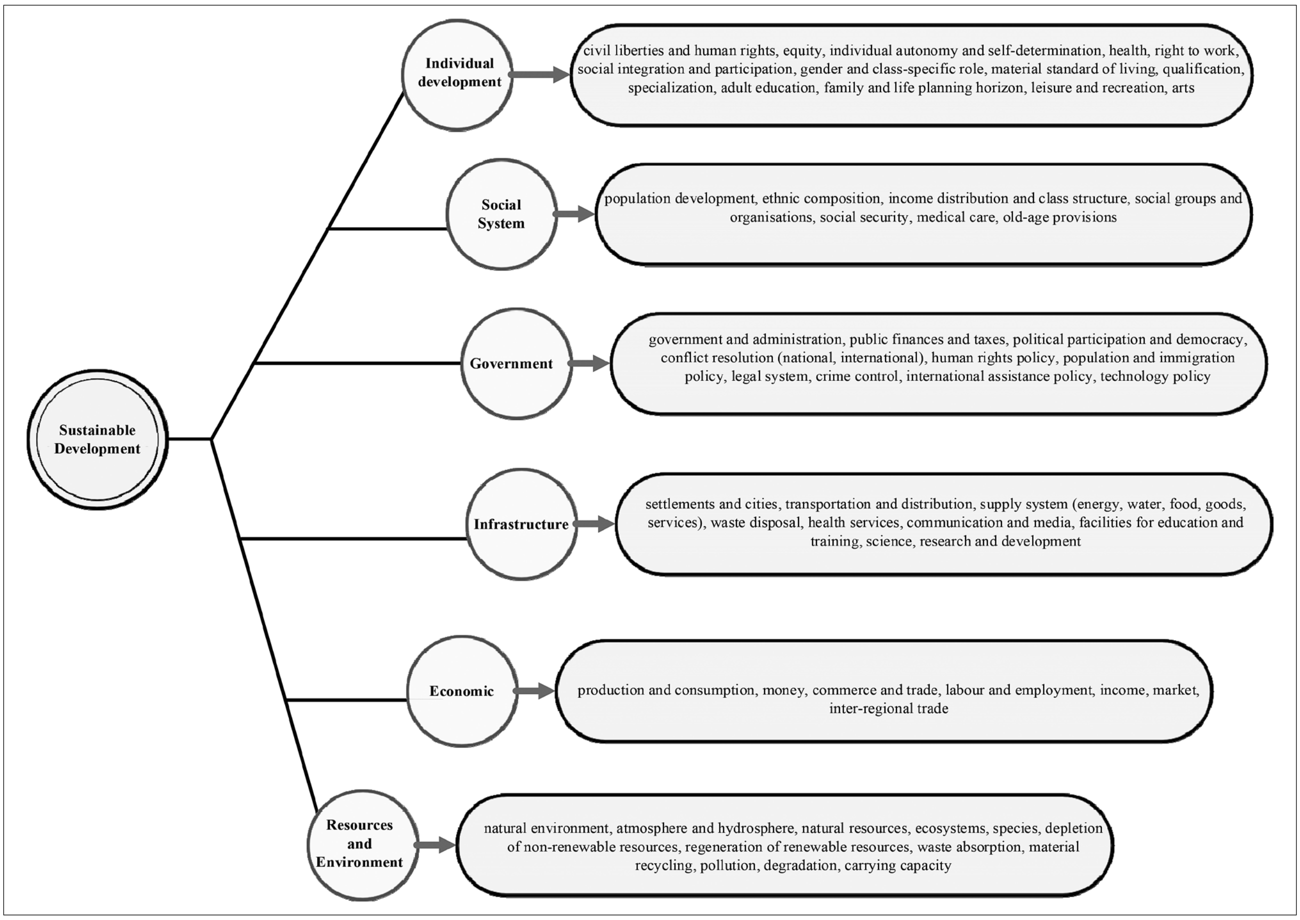

Figure 1: Subsystems and components of sustainable development

Sustainability goals must be described correctly to reach the goal of sustainable development (**Bossel, 1999**). Sustainability and sustainable development have a contrasting conception, which can be applied to maintaining an existing situation or system state. The "development" word points to directional and progressive change (**Gallopín, 2003**). Our Common Future (1987) described the meaning of sustainable development as the development that satisfies the current requirements without negotiating the future generation's capability to meet their needs. It involves combining a growing environmental concern with socio-economic matters and balancing social, environmental, and financial responsibilities (**Brundtland et al., 1987; Butlin, 1989; Ferrer-Balas et al., 2008**). In the report, some of the primary purposes were: preserving and boosting the resource base, innovative solutions, the combination of economics and the environment in decision making, reconstructing technology, managing risk, resuscitating growth, human health, education, and welfare.

The fundamental purpose of sustainable development is to ensure that it contributes to a better quality of life for today's generation, considering the coming generation's quality of life and cannot only mean maintaining the current situation. Development is about enhancing the quality of life (**Azapagic, 2003**). Material, environmental, social, ecological, economic, legal, political, cultural, and psychological aspects of quality of life must all be considered. Although the direction of sustainable development is not specific, recognising the critical components of systems and defining indicators for providing trustworthy and vital information about the practicality of the system is needed (**Bakshi and Fiksel, 2003**).

Design for sustainability guarantees that community and customer expectations are addressed while the ecology is protected (**Mayyas et al., 2012**). Incorporating environmental matters into a system development process that satisfies other requirements like high quality and leastways cost is needed (**Keoleian and Menerey, 1994**). Sustainable development should be formed so that the minimum energy and material be consumed in production and systems and brings non-toxic materials throughout their whole wheel of life. They should be designed for dismantlement and remanufacturing and be highly recyclable for the rest of their lives (**Mayyas et al., 2012**). However, the sustainability discourse may present an additional problem: the production of non-renewable resources is inherently unsustainable.

Nevertheless, it should be noted that if it has been done responsibly, consuming non-renewable resources could promote sustainable development and might lead to better social circumstances, a higher quality of life, and economic development (**Heininen, 2015; Tiainen et al., 2015**). Consequently, a company's fame and brand value could be upgraded by sustainability, leading to an increased worth for shareholders or cost savings due to minimising energy and material consumption. Furthermore, sales growth would be seen, or customers would be reinforced due to the growing number of people who prioritise environmentally friendly products and services (**Hopkins, 2002; Fuka and Lešáková, 2016**). The equilibrium must exist in all social equality, economic well-being, and a healthy environment to signify sustainable development; this is a vital task in sustainability (**Gutman and Teslya, 2018**). Using explanations of the concept of sustainable development, further studies of this issue enter into more detailed phases.

3.1. Sustainability assessment, measurement, and tools

Notwithstanding an exact definition or theory, many sustainability measurement tools are upgraded and used in numerous industries. Since recognising the notion of sustainable development as unrelated, from balancing environmental degradation and economic well-being creation in the 1960s and early 1970s, the number of methods, approaches, models, and assessments for evaluating sustainability increased. Calculating sustainability metrics should be manageable by accessible data, resealable for decision-making, replicable, scientifically meticulous, functional at numerous analytical scales, and expandable with improved understanding (**Bakshi and Fiksel, 2003**). As an ever-changing notion, sustainability can occur in society and incorporate all of the changes in many sections of a community. Bossel, 1999; Beloof et al. have provided a review of the leading sustainability approaches and framework for assessing and improving it (**Searcy, 2012**).

An all-inclusive evaluation of the overall product sustainability is considered, presented by Shuaib et al. The methodology's application has been expressed for a consumer electronics component that spans two generations (**Shuaib et al., 2014**). Additionally, in 2015, a systematic framework dealing with the critical decision-making factors was suggested for sustainability assessment by Sala et al. The way of moving from integrated assessment to sustainability assessment was indicated in this approach. The present framework provided the eight main sustainability assessment principles: crucial considerations, guiding vision, framework and indicators, sufficient scope, transparency, productive communications, wide-ranging participation, continuity, and capacity. These principles are important because they show the practitioner performing the assessment (**Sala et al., 2015**).

In the following, the description of the integrated management systems (IMS) approach was presented by Asif et al. for coordinating corporate sustainability and business processes together. Asif highlights, Corporate sustainability is a dynamic conception, and the particular economic, environmental and social features and precedences that are the focal points of an organisation will continuously alter (**Asif et al., 2011**). A novel rating system has been progressed for extensive industrial projects by Poveda and Lipsett. They have discussed and compared the different methods in a range of three main branches include (**Poveda and Lipsett, 2011**):

Measurement methods:

- Fundamental and generic approaches: the natural step, environmental impacts, financial approach, community capital, the driving force-state-response model, issues or theme-based frameworks, assessment method tool kits, accounting frameworks, integrated and holistic frameworks;
- Strategic approaches;
- Integrated approaches.

Assessment methods:

- Analytical effects of society, environment, and economy;
- Strategic environmental assessments;
- Analytical benefit-cost methods;
- Travel cost theory;
- Community impact evaluation;
- Contingent valuation method;
- Hedonic pricing method;
- Multicriteria analysis;
- Material intensity per service unit;
- The procedure of analytical network;
- Assessment of life process;
- Ranking systems for the environment and sustainability.

Rating systems and the credit weighting tools:

- Environmental plan and energy guidance;
- A complete assessment system for making the environment effective;
- Building research foundation environmental assessment technique;
- Green building tool;
- Green Star.

Dahl has provided an introductory paper that reviewed some of the achievements and lessons learned in sustainability indicator development used at the national level from 1992 to 2012 (**Dahl, 2012**). In another case, in the same year, by completing a literature study between 2000 and 2010, Searcy attempted to suggest future research directions in the design, implementation, usage, and evolution of corporate sustainability performance measurement systems (**Searcy, 2012**).

Despite advancements in decision-making and process- and systems-level research, there are still numerous problems and possibilities in this field. Haapala et al. published a review of research on concepts, methodologies, and tools for sustainable manufacturing in 2013. The link between sustainable manufacturing systems and manufacturing processes was demonstrated in their study (**see Figure 2**). As shown in **Figure 2**, process planning, production scheduling, and forward and reverse supply chains are critical components of a sustainable manufacturing system (**Haapala et al., 2013**).

As previously stated, two methods for assessing sustainability were introduced. Shuaib et al. established a product sustainability index, a complete examination of product sustainability. Sala et al. gave another assessment afterwards, providing eight fundamental elements for sustainability. Many studies have been done on sustainability indicators based on the literature. King has recently proposed a functional classification for sustainability indicators, including political and operational, recognition and awareness, justification, monitoring,

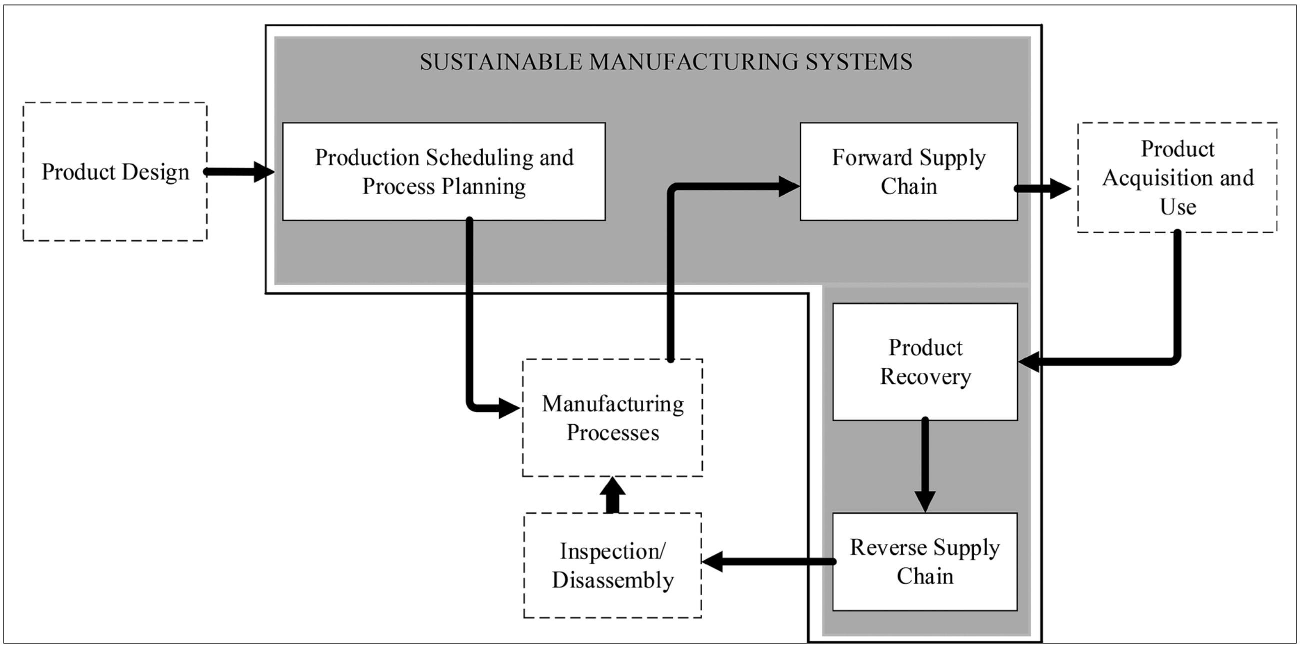

Figure 2: Parameters of sustainable manufacturing system (**Haapala et al., 2013**)

control, reporting, normative guidance, communication, and opinion formation. Furthermore, The Houston Sustainability Indicators program (HSI) was utilised as a case study to demonstrate the definitions and use of this categorisation (**King, 2016**). While it may not be entirely true that "if you can't measure it, you can't manage it," according to Carson, quantifying sustainability or measuring a notion like this fosters more debate regarding the term's meaning (**Carson, 2016**).

Balteiro et al. reviewed and evaluated the literature of 271 published ISI papers on the themes of multiple criteria decision-making strategies for system sustainability. The results revealed that Analytic Hierarchical Process and Weighted Arithmetic Mean were the two most employed approaches. On the other hand, it has been confirmed that multiple criterion decision-making approaches combined with group decision-making techniques have been prevalent during the last several years (**Diaz-Balteiro et al., 2017**). Recently, to respond to "how sustainability indicators (S.I.s) might become effective tools in supporting adaptive governance?", Pupphachai and Zuidema have recognised three conditioning factors for S.I.s. They have concentrated on policy performance and trend monitoring and whether or not these topics are being debated both within and outside government agencies. Moreover, Gan et al. have reviewed the most commonly used methods for weighting and aggregating S.I.s. They have also suggested an approach for choosing the appropriate methods (**Gan et al., 2017**).

Urbanisation is another area that has used S.I.s. It has characterised the human-ecosystem interaction. Using a literature search, Verma and Raghubanshi identified two broad categories of problems and three preliminary criteria for developing and implementing S.I.s in an urban environment in 2018 (**Verma and Raghubanshi, 2018**). One of the approaches for aggregating sustainability indicators to generate a composite index is to employ multicriteria distance function (MDF) methodologies. Multiple Criteria Decision Making (MCDM) approaches are being utilised to solve sustainability challenges, and multicriteria methods based on distance function reduction have taken the lead. As a result, Balteiro et al. have identified several critical issues relating to using various MDF methodologies for assessing natural system sustainability (**Diaz-Balteiro et al., 2017**).

There is little agreement on how a sustainability evaluation should be carried out in the mining industry. While the approaches and breadth of sustainability assessment frameworks differ, they all have the same goal of informing decision-makers about the consequences of mining on the environment and society. Leonard investigated civil society social capital interactions in South Africa in mining development for local sustainability in 2019. In this study, Leonard has tried to understand how civil society takes part in social capital to collectively organise against mining development and the potential challenges (**Leonard, 2019**).

Now, as a precise aim, worldwide developments are focusing on sustainability. However, for the notion to be operational, it must be translated into the practical realities of the actual world. We must detect the presence or lack of sustainability in the systems we manage and sustainability risks. We require appropriate indicators to offer this information and tell us about the sustainability target. First and foremost, we must give critical information to provide a picture of the system's current health and viability; second, we must provide adequate information about the system's contribution to the performance of other systems that rely on it. This is a recursive connection in existing complex systems: systems depend on other systems, relying on another set of systems (**Bossel, 1999**). As a result, a system sustainability performance study must identify critical systems for sustainable development. Then a strategy for determining indications of these systems' viability and sustainability must be devised. Finally, the data is utilised to evaluate the viability and sustainability of human growth at various levels of social structure. The overall system's survival is dependent on the subsystems' satisfactory operation.

Sustainability assessment and measurement involve a specific procedure. Variables relevant to sustainable development are discovered throughout the measurement phase, and data is gathered and evaluated using technically acceptable methods. The performance is compared to a standard for a criterion throughout the evaluation process (or for several criteria). Assessments are carried out in the context of the evaluation and decision-making, with stakeholders expected to participate. Sustainability is a dynamic target. Societies and their environs evolve, as do technology and cultures, values and goals, and sustainable society must enable and support this change. To be sustainable, the structure and form of society must allow for constant change; it cannot be planned or foreseen (**Bossel, 1999**).

Improved product sustainability has become a worldwide trend due to rapidly declining global resources, continuous climate change, growing environmental pollution, and increased customer awareness (**Sutton, 2004**).

4. The mine operation conditions

There are a wide variety of systems and system environments. Environmental reflections would orientate the structure and operation of systems and their behaviours. Furthermore, the systems might be successfully constructed in any environment by paying close attention to these essential orientations. To survive sustainably, systems must be compatible with their system environment and its attributes. The mines are challenging, frigid environments with ice in the winters, darkness during the night shift, and higher instability. Operators confront additional challenges since the environment is fragile, and the infrastructure for service, communication, and rescue operations has not evolved considerably. Since they are mainly located in remote areas, long distances and a lack of infrastructure may necessitate a superior range of duties and more expenditure. In winter and for field maintenance, the difficulty in navigating is caused by snow, gales, intense storms, and icing. Furthermore, the mining region's communication issues may need the installation of extra communication infrastructure that combines satellite and ad hoc field systems. On the other hand, climate-related health risks include increased morbidity and mortality due to increased extreme weather events and the incidence of injury and fatality linked with unpredictable circumstances (**ShakorShahabi et al., 2021**).

One of the problems which create some challenges for working conditions in mines during night shifts is darkness. Other environmental and conditional problems can include locating the reserves in forested areas, ground degradation, river channel relocation, sludge in river beds, and failure to manage the tailings dams appropriately. Dust and chemical substance impacts, inadequate ventilation and lighting, vibration and noise impacts, lack of sufficient roof supporting system in underground mines, job security, safety problems, especially in underground mines, and occupational health are examples of health, safety, and environmental (HSE) problems.

Not allocating specialised experts, the limitation of using new technologies, access problems to infrastructures, such as water, electricity, road, and telecommunications, insufficient training for operators, insufficient and impermanent facilities at the mine site, absence of proper design and suitable complementary discoveries are placed in technical and technological issues. Also, the limitation of mineral resources in small-scale mines is considered one of the challenges that can bring problems for transferring minerals to faraway factories. Costly transportation systems, not having proper planning for establishing processing sectors near the mine sites, providing sufficient basis, and environmental problems are the challenging factors.

Management and economics constitute the most common problems in the mining sector. Fluctuations in mineral prices, demand reduction for minerals, and high expenditure for machinery maintenance are the problems in this field. Additionally, exploration operations require a high-cost budget, using modern technologies and comprehensive management. Financing has been recognised as one of the complicated factors in mining, especially in small-scale mines.

Publishing regulations for protecting natural resources, applying limits and penalties for the factories with unhealthy processes, and holding training workshops to improve the knowledge of all the members in a mining society (mine owner, miner, investor, and shareholder) about mining negative impacts on the environment are the actions must be taken to overcome the problems in mining operating conditions (**ShakorShahabi et al., 2021**). Learning modern mining skills, especially in mineral processing, can be considered one of the solutions. For instance, laying the groundwork for mobile mineral processing in small-scale mines can be the leading solution to this problem resulting in value-added mineral resources.

5. Sustainable development in the mining industry

Mining is one of the mother industry systems that promote the economy in our societies. Even though mining can spur economic development, but also has the potential to cause adverse environmental effects on communities and human lives. According to Tiainen's paper, mining could promote sustainable development if done responsibly. It could enhance social circumstances and the quality of life while promoting economic growth (**Tiainen et al., 2015**).

The relation between the S.D. and mineral processes in the mine life cycle (see **Figure 3**), such as exploration, environmental rehabilitation, and innovative technologies, is expressed by **von Below** (**1993**). The definition presented by **Allan** (**1995**) showed that a balance must exist between the mineral resources and the rate of the mineral usage. **Eggert** (**2006**) identified the requirements of sustainable mining development as an equitable society, developed economy, and suitable environment (**Asr et al., 2019**).

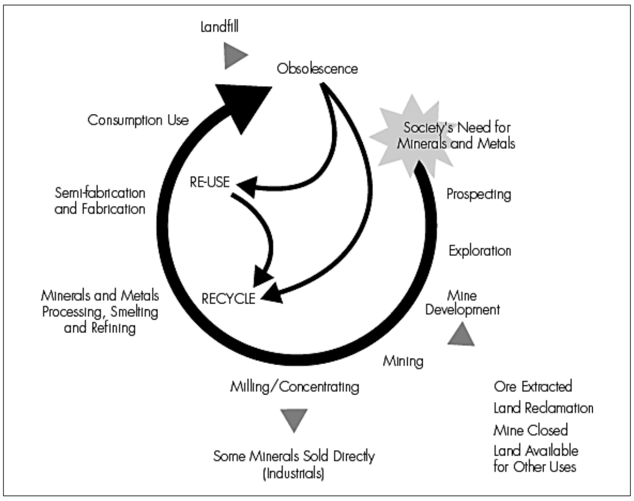

Figure 3: Life cycle of minerals (**Asr et al., 2019**)

Sustainable mining practices are divided into five proportions: economy, environment, efficiency, safety, and community. The principles necessary for the safety portion are providing educative plans paying attention to facilities and processes, and risk management plans.

Acid mine drainage and pollution control, having a social license for operational work (**Asr et al., 2019**). Arctic countries like Finland, Sweden, Greenland (through Denmark), and Russia have recently established national mining strategies to promote sustainability. Finland focused on industrial development and modernised its mining rules to achieve sustainability targets for the mining industry. The main focus is on operational factors, such as the growing need for transportation infrastructure and the significance of procuring sufficient labour, resources, and qualified supervision specialists. The Swedish Minerals Strategy with five general strategic objectives was published in 2013, emphasising sustainability, but not assessing Arctic mining. Mining, along with petroleum and forestry, is listed as an economic potential for the country. According to the Strategy, future extraction should be done sustainably. The Russian strategy, established in 2010, emphasises the importance of mining activities and the need to "move on to the next level" through sustainable natural resource management, negative environmental and social consequences, and operational risks. However, it lacks legislative support. Greenland updated its strategy in 2014 and has bolded the significance of sustainability. According to the document, mining advantages are distributed across society in the form of employment and higher revenue, with particular attention devoted to the demands of the industry in terms of operational conditions. S.D. also focused on environmental protection, labour market and employment, training, residents, and the local community and stakeholders (**Heininen, 2015**). Bolsunovskaya et al. also highlighted a long-term development strategy for the Arctic region's expansion and environmental, social, political, and industrial concerns and risks exacerbated by increased industrial operations. This paper presented a model concerning sustainable development for the Russian Arctic zone (**Bolsunovskaya et al., 2015**).

Multi-criteria decision analysis (MCDA) can assist realise policies and project proposals that reduce the possibility of environmental deterioration within a framework of optimising industrial, economic, and protection goals. It may help make judgments on Arctic sustainability based on various parameters. This method assessed the project's possible sustainability issues by combining divergent data sources, such as objective facts and subject expert opinion, to compare and contrast several options that achieve the same aim. Trump et al. have used MCDA in the industrial mining system of Greenland, where a decision-analytic approach might assist in improving and identifying methods that combine industrial aims with local and regional community sustainability issues. S.D. problems are common in the mining sector. Mining activity is described as a salvation and a curse for societies (**Trump et al., 2018**). Acid mine drainage, chronic chemical contamination of rivers and lands, and toxic gas and aerosol pollution are environmental issues. Economic concerns include employment, company development, multiplier effects, tax and revenue distribution, Occupational health and safety, and more considerable social disruption in the host community are social challenges linked with mining. A processing plant, slurry pipeline, dewatering, and storage facility, deep-water port site, fuel storage and pipeline, a small plant near the mine for explosives used in blasting, administrative facilities, worker housing, a potential airstrip, and access roads are some of the main subsystems of mine infrastructure (**Skorstad et al., 2018; Trump et al., 2018**).

In the following, some categories of environmentally sustainable development problems in the mining sector are introduced:

- **The impact of Mine tailings dams:** waste materials are collected from mining activities and form tailings dams. Substantial tailings and waste stones are generated from the mining sector, which form a considerable hazard to the environment (**Qaidi et al., 2022**). Solid waste brings severe environmental safety, stability, and storage (**Hefni et al., 2021**). Tailings dams may affect the areas that are far from themselves. Human mortality is another problem in storing mine tailings. In some countries like Indonesia and Papua New Guinea, the oceans and rivers are polluted by disposing of tailings waters (**Islam and Murakami, 2021**). The failure of tailings dams can also result in the death of nearby people in some countries. In recent years, these countries are Romania, the Philippines, Russia, Hungary, Canada, Brazil, China, and India. One beneficial way is to reuse tailings in mine backfill. This would diminish the expenditure on mining waste disposal in dumps (**Ivannikov et al., 2019**). To obtain sustainability in the mining field, effective tailing management is vital. Categorisation and characterisation are significant factors in mining waste management (**Jawadand and Randive, 2021**). As another solution, the polymerisation technique can transform wastes into value. Geopolymers are used as an appealing alternative in recovering mine wastes and producing sustainable construction materials. Techniques for transforming mine tailings into value: concrete aggregate, chemical products, valuable components, backfilling, glass wool, foamed ceramics (**Qaidi et al., 2022**)
- **Acid mine drainage:** AMD impact could be categorised into several items: salinisation problems, acidity, sedimentation processes, and toxicity of metals. AMD occurs in the mine closure. By stopping operational works in mining, pumping leads to control, and during some chemical processes, Acid Mine Drainage occurs. One of the significant problems that threaten species is the decline of fish. It has a severe impact on croplands and the food chain, too. Two kinds of treatments are identified for AMD passive and active treatments. Passive treatment is divided into two individual types biological and geochemical. Natural treatment is conducted with bacteria, and geochemical treatments work with alkanoic materials (**Rezaie and Anderson, 2020**).

- **Landfill mining:** solid waste is one of the subjects associated with global warming issues. Some preparatory works could combat this problem as reduction, prevention, reusing, or recycling. Landfill mining (L.M.) was introduced to tackle climate change within waste management as a solution. An example of the global issue amid reaching the SDG is the waste disposal problem. The main target is to make a productive material cycle that brings social, economic, and environmental equity together to reach SDG. Recovery of wastes like metals or rare-earth elements, which is worthy, could bring progress in green technologies and magnification of economic development (**Calderón Márquez et al., 2019**). Organic compound recovery is a related technique that aims to conserve garbage dumps and landfills (**Calderón Márquez et al., 2019**). L.M. can be correlated with SDG. For example, SDG 3 describes health factors and welfare, and SDG 6 relates to sanitation and clean natural resources, so concentration on hazardous waste impacts the environment is needed.
- **Artisanal small-scale mining (ASM):** artisanal mining is the only livelihood for some low-paid societies. Both large-scale and small-scale mining lead to a risky process that can threaten the miners' health. The causes of the disease among miners could be contamination by dust, pressure from the workplace, and other influential factors. The government and industry should provide functional solutions. All the communities must participate in providing solutions. Artisanal small-scale mining has more difficulties in comparison to large-scale ones. Some health problems are seen in gold mining, for instance, respiratory and skin diseases. In addition, accidents and suffering are more frequent in the mining sector (**Stewart, 2020**). The noise pollution in ASM, studied by just one research, results in miners and other residents in artisanal mining experiencing 24-hours noise exposure (**Gottesfeld and Khoza, 2021**). Neurologic and kidney dysfunction symptoms were observed in about 25-33% of artisanal gold miners. A study was conducted through 258 Brazilian artisanal miners, and the results were shown 10% exposure to silicosis (**Gottesfeld and Khoza, 2021**). ASM requires more attention to health and safety to reach sustainability.
- **Forestland use in mining operation activities:** sustainable forest management has been studied globally, but forestland use has been paid low attention (**Yıldız, 2020**). Sustainability in forestlands is reached by applying rehabilitation activities. Rehabilitation activities must operate during mining activities as soon as the end of mine operations.
- **Coal production:** the open-pit mining method produces plenty of large wastes that pollute the soil. For instance, in the Baganuur Coal Mine, environmental degradation was recognised in the continuing process of coal exploitation, so planning sustainable goals needs to identify the current ecological impacts (**Park et al., 2020**). One of the most critical factors in the sustainable development of the coal industry is geological conditions. Methane gas emissions, complicated geological structures of the coal mine, faults and high water content are the harsh working conditions in coal mines (**Que et al., 2021**). Accelerating renewable energy development has a good point on sustainability promotion in the coal industry. Reusing recyclable resources like extracted gas, emissions control, and innovative technologies are also solutions (**Tao et al., 2022**). The following are the most critical environmental impacts of coal mines: climate change, marine ecotoxicity, fossil depletion, freshwater eutrophication, and human toxicity. By boosting energy transformation and expediting the development of renewable energy, the sustainable development of the green coal industry will be improved (**Tao et al., 2022**).
- **Carbon footprint:** carbon emissions would be generated by the production procedure of raw materials and concrete, cement, and bolts (**Guo et al., 2022**). The fundamental principles for green coal development and mitigation of carbon emissions are carbon neutrality, resource recovery and environmental protection. To achieve the goal of carbon neutrality and ensure energy security and economic development in China, adequate, secure and green and low-carbon progress and coal consumption over management and technical innovation are vital. Carbon emissions could be reduced by speeding up technological innovation in full-face intelligent, fast excavation and intelligent coal mining and washing technologies, which reduce energy consumption from the source (**Li, 2021**). **Progress in carbon capture technologies:** a helpful way for solving the climate change problem and long-term storage of carbon dioxide is carbon capture utilisation and storage (CCUS) through mineral carbonation (**Jiskani et al., 2021**). Carbon capture and storage separate carbon dioxide produced in transportation and industrial sectors into a regulated place for storage. The leading phases that constitute carbon capture and storage application are carbon dioxide separation from the power plant stream, transportation of the captured carbon dioxide, and carbon dioxide sequestration. The ecological problems of carbon capture and storage should be respected. Releasing wastewater, one of the environmental concerns of carbon capture plants, threatens marine life. The new carbon capture and storage technologies need high energy, providing a serious challenge. Due to the high cost of carbon capture and storage technologies, future research must be conducted to reduce the present cost (**Wilberforce et al., 2021**).

- **Greenhouse gas emissions:** in iron mines, one of the causes of greenhouse gas emissions is diesel consumption in the loading and hauling process. in gold mining, greenhouse gas emissions are because of crushing and grinding processes. Reducing greenhouse gas emissions from metal mines is a compliant solution for climate change. Smart mining, using renewable energy, battery electric vehicles, and electric mining tools are the possible actions through the reduction of greenhouse gas emissions. Mining equipment automation and intelligence can also reduce greenhouse gas emissions (**Guo et al., 2022**).
- **Dust pollution:** dust pollution is one of the crucial problems in attaining green mining in open-pit coal mines. Dust pollution has always been a severe challenge connected with green and climate-smart open-pit mining and other ecological issues. The environment, biodiversity, the areas inside the mine and the workers' safety are threatened by dust pollution. In cold regions of China, open-pit coal mining is in the company of complex dust pollution, causing an environmental burden to mining. China has tried to control open-pit mine dust pollution by advancing green and climate-smart mines and building an ecological civilisation. In the planning and design stages, avoiding and controlling the source of dust generation is the best possible way of managing dust in mines. Artificial intelligence is also used in open-pit mining to study dust pollution and predict dust concentrations. Additionally, the dilution of dust concentration by meteorological factors could lead to the mitigation of environmental damage and green and climate-smart mining promotion in the mining areas (**Wang et al., 2022**).
- **Deep-sea bed mining sustainability:** the deep sea attracts the mining industry's attention for extracting metals like cobalt, nickel, copper, silver, zinc, lithium, and gold. Deep seabed mining requires dredging or transportation systems to transfer these materials

Table 1: Methodologies for recognising and reducing environmental impacts in mining sustainability

Method	Case study	Problem	Solution	Main Goal
The Gray water footprint (**Islam and Murakami, 2021**)	Mapping tailings dams in several countries	Tailings dams failure, Environmental and social issues, Water pollution	Monitoring tailings dams before failure	Investigating the environmental pollution of tailings dams
"Survey Monkey" Program (**Yıldız, 2020**)	Turkey	Forestland used in mining operation, Throughout sustainable natural resources	Providing comparison between land use and the operating license areas, Analysing the land used for each mineral group	Determining the use of forest lands for mining, Information about operating license areas, Identifying the amount of area which is used by the mining operation
Visiting three crushed stone mining industries and systematic research (**Monteiro et al., 2019**)	Monsenhor Gil, Piauí, Brazil	Environmental problems: Social impacts	The SDG service, such as: Providing occupational opportunities (SDG1)	Investigating the relationship between Mining and SDG
Reports and Scientific publications data (**Calderón Márquez et al., 2019**)	Data from L.M. projects of 21 countries worldwide since 1953	Landfill mining challenges, as: Solid wastes, Climate change	Landfill mining: By promoting soil and water resources protection. Fulfilling at least 11 of the 17 SDGs.	Recovering Excavated wastes, Urbanization, Environmental protection
Fuzzy Delphi Method and a systematic research approach (**Jiskani et al., 2022**)	A Chinese Mining Industry	Climatic and Environmental impacts, The atmosphere and Ecosystem pollution, Technical and operational challenges	Advancement of Green and climate-smart mining (GCSM)	Investigating the relationship between Mining and sustainability
Inside-out) and (outside-in) innovation concepts, Secondary Research, Questionnaires, Interviews (**Endl et al., 2021**)	14 European countries	Economic and Societal needs (in the mineral Extraction phase)	Applying Innovation concepts in Economic and social sectors	Set innovative ways to combat challenges, Investigating current and future mining innovations for achieving the SDGs
The media Reports, Web Search Engines (Stemn **et al., 2021**)	Gold Mines in Ghana	Fatality and accidents in (ASM)	Providing Health and safety to reach SDG	Investigating the number and causes of fatality in (ASM)

to the surface. In contrast with usual earthling mining, deep-seabed mining produces less overburden, and there is no need to use continual mining infrastructures (**Levin et al., 2020**). Exploring deep-sea bed mining is limited due to vulnerable operating conditions like low temperatures, darkness, and high pressure. Deep-sea bed mining brings biodiversity issues like migration or species extinction (**Levin et al., 2020**). By looking at the problems through terrestrial mining, Deep-sea bed mining could be an alternative for obtaining minerals.

- **Climatic problems:** green and climate-smart mining (GCSM) can change the traditional way of mining into a more sustainable form by decreasing the environmental footprint, preserving the ecology, and supporting clean mineral production. Reaching cleaner mineral production with the lowest environmental cost and low energy and resource consumption, and fast reclamation are the main goals of GCSM. Climate-smart mining makes extraction and mineral processing more sustainable and supplies clean energy technologies for minimising the climate and material footprint across the value chain. Green technologies are being used by green mining to maintain the mining industry's competitiveness through the whole life process of a mine and enhance environmental effectiveness. Replacing old equipment with new ones that produce less pollution and waste is one of the best ways to reach green and climate-smart mining. A systematic, extensive and eco-friendly mineral exploitation is also needed for the practice of GCSM. GCSM requires powerful and effective management (**Jiskani et al., 2021**).

Some methodologies for recognising and reducing environmental impacts in mining sustainability are explained in **Table 1**.

6. Methodology

The methodology and novelty of our work are explained in the following way: first, the keywords sustainable development, mining industry, environmental sustainability, and environmental impacts were used to discover the related documents in this field. The search engines used in this work were Scopus and the Web of Science. Documents, articles, books, and reviews were investigated to find recent information related to the subject. The "Analyze search results" in Scopus were also used to see all the related documents per year. The environmental issues in all the papers were investigated. The problems were classified according to their ecological impacts. A suitable solution for each problem was found by studying more articles. The primary goal of each article was also discovered. Seven articles were selected, and a table was designed for categorising the articles. The investigated problems were tailings dam failure, forestland use in mining operations, social and environmental issues in crushed stone mining industries, landfill mining challenges, climatic problems, economic problems, and accidents in artisanal and small-scale mines. A graph was also made with the help of Analyze search results sector in Scopus to know about the popularity of this subject in the last few years. The methodology of the selected articles is described in the following section:

- **The Gray Water Footprint:** in this study, Google Earth (G.E.), The SNL databases, and Mindat were used as online databases to find the mines' locations. Furthermore, some reports and literature were used in this methodology. Tailings dams that failed were mapped in Google Earth. The area of each tailings dam was evaluated throughout this methodology. The Gray water footprint method identifies the pollution released into the environment. The primary goal of this method is to demonstrate the intensity of dam failures. Tailings dams have social and environmental impacts. The provided database is also helpful for future research and decreases the risk of dam failure (**Islam and Murakami, 2021**).
- **"Survey Monkey":** "Survey Monkey" is the program in which the Turkish mining enterprises responded to some questions about mining activities in forestland. The questions included: mining production amounts, the amount of land used for mining activities in forestland, operating license areas, etc. The results show that the sustainability of the forestland use in mining activities has changed positively in Turkey during the last decade. Moreover, it is predicted that the need for land will decrease because of the future reduction of open-pit mining methods. It leads to a decrease in forestland overlaps. Additionally, the results aim to environmental sustainability promotion in forest areas (**Yıldız, 2020**).
- **Crushed Stone Mining Industries**: in Brazil, the process of three crushed stone mining industries was observed to know about the social and environmental impacts of the mining activities. Additionally, systematic research was conducted using Scopus and the Web of Science databases to determine the relationship between sustainable development goals (SDG)s and mining activity. The results have shown the opportunity for jobs and income in the visited industries. Reducing poverty, providing inclusive occupations, enhancing the cooperation for using clean energy and decreasing the environmental footprint on natural resources are the responsibilities of mining companies (**Monteiro et al., 2019**).
- **Landfill Mining Projects:** landfill mining (L.M.) is a strategic tool that can lead to sustainable development and climate change mitigation through waste management public policies. The study investigated landfill mining projects in four areas of the world since 1953 to find out the role of this methodology in reaching sustainable development goals (SDGs) (**Calderón Márquez et al., 2019**).

- **Fuzzy Delphi Method:** a three-phase systematic research approach was conducted to establish a decision support system and eliminate the problems associated with environment and climate change. This research leads to implementing and improving Green and climate-smart mining (GCSM) and connecting the mining industry with sustainability science. The fuzzy Delphi method is the first phase of this research, recognising nine pathways to solve twenty-four challenges. In addition, a case study of the Chinese mining industry helped to verify the practicability of this method (**Jiskani et al., 2022**).
- **Inside-out and outside-in:** this paper analysed current and future mining innovations to achieve sustainable development goals (SDGs) in Europe. First of all, to identify significant challenges in the mining sector and existing European mining innovations, desk research was carried out. In the second step, the innovations were classified into eighteen individual groups. In conclusion, two unique groups named: ''inside-out'' and ''outside-in'' were made for organising these innovative concepts. Generally, many innovation concepts positively affect the environmental sustainable development goals (SDGs) (**Endl et al., 2021**).
- **Mining accidents in Ghana:** the reports of artisanal and small-scale mining (ASM) accidents and fatalities were analysed to comprehend the safety performance of these mines in Ghana. The most common causes of the accidents and fatalities included: mine collapse, blast fumes and unsteady working areas. The results suggest that the health and safety of ASM need higher focus to achieve sustainability. The web search engines like Google, Bing, Ask.com, etc., were used to gather data on ASM accidents (**Stemn et al., 2021**).

7. Discussion

Sustainable development could be a co-existence procedure for interrelating systems in a typical environment. Each system goes its way of self-organisation concerning the problems of its specific environment. Presently, many companies can measure not the "sustainability" of a system but its "competitiveness" (or some features of competitiveness, such as economic profitability and profit rate). As previously mentioned, sustainable development can be defined as maintaining an existing situation or system state. The primary goal of sustainable development is to make sure that it contributes to a better quality of today's life without compromising the quality of life for future generations. Understanding the features and characteristics of a sustainable system is required for responding to the challenges of sustainable development. Recognising the essential parts of systems and designing indicators for trustworthy and vital information about the system's sustainability is necessary. After getting an overview of sustainable development, the mining conditions and environmental challenges were introduced. The circumstances for having a more sustainable mining industry were also discussed. According to the 'Analyse search results' in Scopus, in the last ten years, environmental science devoted the most documents about sustainable development compared to other fields like social science, energy, agricultural and biological science, and others. It is also the same for mining sustainable development (**Scopus**).

Further, the Web of Science provides several rankings for categorising documents (**Web of Science**). The results show the dramatic growth for the documents related to sustainable environmental development between 2013 and 2021 (see **Figure 4**). Environmental Sciences and Green Sustainable Science Technology are the two popular subjects in sustainable mining development. So we can assume that the main problem of having a sustainable mining operation is related to the environment. An origination of skilled engineers capable of adopting a comprehensive view of processes rooted in more extensive systems is required for sustainability. Industrial processes, ecological systems, and human beings must be integrated for performing engineering works. The primary objective of sustainable development is to create an equilibrium between three baselines, including economic, environmental, and social features. In the current system, the social part proposes social steadiness, the fair allocation of natural resources available for each citizen, cultural and human protection, and enhancement. The economic feature affects technological resource-saving methods, natural resources management, toxic waste disposal, and recycling. Preserving ecosystems and a variety of living organisms is mentioned in the environmental quality.

There has been much work put into developing sustainability indicators. Still, they are diverse and, in many cases, qualitative, which makes it challenging to define a universal metric to evaluate and compare the sustainability of systems. We believe that the effective pursuit of global sustainability necessitates a systematic approach to policy and intervention strategy creation. When using a system to examine sustainability, a few things to keep in mind are included:

- The system's established bounds: because most data used to study sustainability is collected for politically defined systems, political borders may be unnecessary or misleading for sustainability research. Furthermore, ecological and political boundaries seldom coincide;
- The data included in the analysis: all indexes or techniques are problematic if data is unavailable, which is now a frequent shortcoming in all sustainability efforts, regardless of scale or publicity;
- Weighting and normalising methods: sustainability analysis involves extensive data with varying values and measurement units. As a result, some ag-

gregation methods' results must be standardised such that their range of variability remains consistent. Furthermore, allocating equal weight to all practical elements presupposes that they all have the same impact on sustainability;

- The aggregation method: different aggregating methods can achieve significant disparities in results. While adding indicators may seem like a simple aggregation strategy, an additive connection may not reflect real-world sustainability situations adequately;
- The comparability of results across systems.

So we can conclude that a few actionable research priorities for future research can be suggested as follows:

- Current and novel data incorporated analysis, consisting of lengthwise (back and forward) and comparable syntheses, using current case study research and powering through these studies;
- The remaining refinement of incorporated sustainability indicators connects ecological and social procedures advancements and systems better;
- Taking into account the whole system;
- Examination of sustainable development as the process;
- Evaluation of the sustainable development and climate change association;
- Institutional function examination related to sustainable development;
- Recognizing and altering existing power relations (such as age, gender, culture, and other differences) on sustainable outcomes and processes;
- They studied the connectivity in various scales and their way of interaction instead of ecological, cultural, economic, atmospheric, climatic, and further procedures;
- Reconsideration and possibly re-conceptualization of relationships between sustainability research and sustainable development applications;
- Having a multi-dimensional concept of value that considers cultural, ecological, social, health, and economic values;
- Develop the new field of sustainable industrial systems design;
- Concentration on the socio-environmental system as the primary unit of analysis.

8. Conclusion

Sustainability explores risk management, cost reduction, creation of modern goods and society's structural and cultural changes. Nevertheless, incorporating sustainability thought and functional practice into the organisational construction is not considered little work; leadership, commitment, and vision are required. Additionally, a systemic approach is needed with a proper management framework, allowing company sustainability policies to manage, design, and communicate. *Sustainability* is a systemic issue that necessitates cooperative solutions. The methodology of sustainable assessment is a supportive way for policy and decision-makers, which suggests suitable actions to have a more sustainable society. Over recent years, sustainable development (S.D.) has been considered a generally acceptable target in human society. Sustainable development is quite different from sustainability, which can be applied to maintaining an existing situation or system state. Sustainable development and mining activities have three pillars: society, environment and economy. These principles must be applied in the mining life cycle to incorporate sustainable development. Sufficient economics, a clean environment and a responsible society are the main goals of sustainable mining development. The mining operation is accompanied by many environmental footprints such as waste production, acid mine drainage, land subsidence, deforestation, carbon footprint, dust pollution, soil degradation, water contamination, landscape destruction, etc. By investigating the works done in the mining sector to obtain more sustainable development in this field, we can conclude that

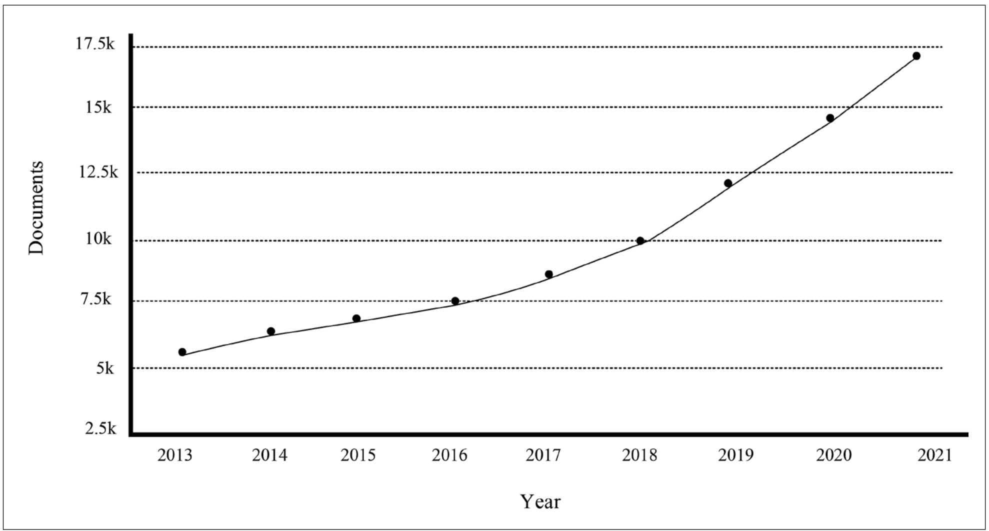

Figure 4: the dramatic growth of the documents related to sustainable environmental development between 2013 and 2021 (**Web Of Science**)

technological developments and safe and clean production methods are required to reach mining sustainability objectives. Accordingly, innovative attempts in clean production must concentrate on reducing the amount of waste generated and greenhouse gas emissions using renewable energy production systems. Extending mining activities in previously remote and unapproachable environments like the ocean floor and ice-covered regions are possible future trends for exploring new deposits. These remote areas require advanced machinery and equipment with a specialised and trained workforce. Modern mining methods should be developed with technological advances and the minimum use of resources to achieve maximum advantages (**Aznar-Sánchez et al., 2019; Asr et al., 2019; Endl et al., 2021**). All the mining stages must minimise resource and energy consumption and waste products from the exploration to the post-closure stages. The mining industry should promote renewable energy utilisation and reduce raw material and energy usage to comprehensively utilise mineral resources (**Jiskani et al., 2021**).

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SAŽETAK

Pregled održivoga razvoja i održivosti okoliša u rudarskoj djelatnosti

Za donošenje učinkovitih odluka u sklopu globalne održivosti potreban je sveobuhvatan sustavan pristup, što posebno dolazi do izražaja prethodnih godina. Održivi razvoj izražava se kao želja čovječanstva za životom u boljim uvjetima uzimajući u obzir moguća ograničenja prirode. Društvene, ekološke i ekonomske odgovornosti ubrajaju se među brojne karakteristike razvoja koje čine održivost. U ovome radu, uz pomoć tražilica poput Scopusa i Web of Science, proučavano je nekoliko dokumenata vezanih uz održivost okoliša u rudarskoj industriji. Glavni fokusi studija vezani su uz probleme kao što su klizanje jalovišta, korištenje šumskoga zemljišta u rudarskim radovima, socijalna i ekološka pitanja u eksploataciji i proizvodnji tehničko-građevnoga kamena, izazovi eksploatacije na odlagalištima, klimatski problemi, ekonomski problemi i smrtni slučajevi u privatnim i malim rudnicima. Također, osmišljena je tablica koja kategorizira te probleme i njihova rješenja te primarni cilj. Ova studija istražuje važnost radnih uvjeta u rudarstvu i probleme okoliša u rudarskoj industriji. Uobičajeni ekološki problemi u toj industriji uključuju degradaciju tla, krčenje šuma, slijeganje zemljišta, odvodnju kiselih otpadnih voda iz rudnika, proizvodnju otpada, degradaciju prirodnoga krajolika, proizvodnju ugljena, ugljični otisak, onečišćenje prašinom, emisije stakleničkih plinova i klimatske probleme. Kako bismo imali održiviju rudarsku industriju, sve faze rudarstva, od istraživanja do faza nakon zatvaranja, moraju minimizirati potrošnju resursa i energije te otpadne proizvode.

Ključne riječi:
održivi razvoj, održivost, problematika okoliša, rudarska djelatnost

Author’s contribution

Ali Nouri Qarahasanlou (Assistant Professor): initialised the idea, completed a literature review, and participated in all work stages. **Dina Khanzadeh** (BSc student): arranged and edited the paper. **Reza Shakoor Shahabi** (Assistant Professor) managed the whole process and supervised it from first to the end. **Mohammad Hosein Basiri** (Assistant Professor) rewrote and reviewed the article and acted as a co-supervisor.