# SPACE TECHNOLOGIES ARE ENABLING A NEW ERA OF MINING

*Source: ESA (2019). https://business.esa.int/news/workshop-space-enabled-applications-for-mining-sector*

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## Disclaimer

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## Executive Summary

The global space economy is growing thanks to the shift of space business to the private sector and the increasing focus of markets on innovative technologies involving satellites. Competitive forces are rapidly changing forcing the global economy to adapt to the new environment. One of the industries that has been slow to adapt to changes in technology is mining; many mining companies have been slow to transform their business according to stakeholders' expectations, resulting in less than optimal financial performance. In the last fifteen years, total returns (dividend + capital gain) for mining company shareholders has been lower than for many other sectors due to a negative market outlook on the viability of the mining business model. In particular, mining investors perceive the following risks:

- *Environmental* – driven by the potential effects of climate change on mining operations (including water stress, heat waves, floods), and by social and environmental concerns about GHGs emissions, biosphere pollution and natural disasters.
- *Social* – related to the risk of losing the licence to operate, due to stringent government policies or community complaints.
- *Business* – caused by a combination of factors such as the high risk of worker injuries or fatalities, low level of talent attraction, reduced innovation development, and the need to fulfil the future mineral demand through difficult exploration scenarios.

This report focuses on the benefits obtainable by mining companies through collaboration in the development of technologies and services with the space industry. In particular, it has been found that through the employment of *Earth Observation*, *Satellite Communication* and *GNSS* satellite technologies, a set of ten *satellite-enabled activities* could be currently or foreseeably implemented by mining companies in order to address the issues listed above. It is suggested that the mining sector should conduct a strategic assessment regarding which of the possible activities fit their requirements the most and focus their efforts on them. For this reason, this report has assessed the *readiness of the technology* and obtainable *value added* of each activity and categorised the latter in the following groups.

- *Question mark activities*, low value added – not-ready technology: *Stakeholder Engagement*.
- *Common activities*, low value added – ready technology: *Weather Forecasting*, *Site & Logistic Management* and *Design & Survey*.
- *Developing activities*, high value added – not-ready technology: *Unmanned Vehicles & Machineries*, *Mineral Identification*, and *Employee Training, Support and Monitoring*.
- *Strategic-fit activities*, high value added – ready technology: *Data Communication & Transmission*, *Environmental Monitoring* and *Water Management*.

In conclusion, taking into consideration the findings in this report, it is possible to conclude that *"satellite technologies perfectly fit many of the mining industry's environmental, social and business needs, therefore close collaboration between the mining and space sectors in the development of technologies and services will lead to solid benefits for the players involved"*.

# 1. Introduction

## 1.1. Purpose of the research

The space industry value is projected to grow at a CAGR of 5.6% in the next few years causing the industry to expand from a value equal to USD 360bn in 2018 to USD 558bn by 2026 (Report Buyer, 2018). This result is principally driven by two factors - on the one hand the global privatisation trend of the space industry is enabling the development of new technologies, while, on the other hand the global market is increasingly demanding technologies able to foster innovation. As regards the latter factor, it is important to highlight that space technologies are fundamental for boosting the development of Internet of Things (IoT), Artificial Intelligence (AI), Augmented/Virtual Reality (AR/VR), and Big Data applications in a wide range of industries worldwide. Therefore, those industries that are struggling to adapt to new end-user needs, governmental regulations and investor expectations, have the potential to benefit from the ever-expanding range of available space technologies and services. In particular, one of the industries most affected by these changes in the business environment is the global mining sector. According to S&P (2019), the *metal and mining* sector is ranked (along with the oil & gas) as the riskiest industry from a social and environmental point of view. The increase of social and financial market concerns about climate change, natural disasters, and worker and community rights, together with the increase of site remoteness and shifts in customer demand, are pushing mining companies toward a phase of profound change that will force them to compete on the basis of developing key resources able to guarantee the sustainable development of their business minimizing environmental and social impacts, and maximizing the returns.

For these reasons, closer collaboration between mining and space industry is proposed as a way for the former to address some of its challenges in the new global socio-economic landscape. In particular, it has the potential to assist with the ability to efficiently support the search of new mining sites, to instantly connect remote operations, to provide an efficient and timely control system and to remotely manage resources and machinery.

With the aim of addressing these topics, the following research questions will be answered:

- RQ1 – *Which issues are mining companies currently facing?*
- RQ2 – *Which space-enabled activities are able to solve these issues?* And, *on which of them should mining companies focus on the most?*

## 1.2. Structure of the report

This report is composed by five chapters. The Introduction aims to illustrate the purpose of the research and the structure of the report. Chapter 2 provides an overview of the mining industry, addressing the main process stages, the industry's financial performance, and the issues currently faced by mining companies. Chapter 3 introduces space industry capabilities with a particular focus on satellite technologies' applications. Chapter 4 aims to describe the *satellite-enabled activities* useful for the mining industry and to provide insightful case studies, employing a "Satellite-enabled activities" framework.

The concluding chapter represents is a summary of ideas and concepts from the research conducted.

# 2. The Mining Industry

As reported by PWC (2019), the mining industry is currently suffering from the intensification of stakeholders' expectations regarding environmental and social concerns, and technological innovations. Therefore, with the aim of better understanding the issues faced by the mining sector, the following paragraphs will provide an overview of mining's business stages, will analyse the financial performance of the sector and will show the principal issues faced by mining companies.

## 2.1. Mining Business Stages

This section describes the mining sector's supply chain, breaking down the entire process into the following six stages, as defined by Hartman and Mutmansky (2002): *Prospecting*, *Exploration*, *Feasibility & Planning*, *Development*, *Operation*, *Closure & Reclamation*.

### 2.1.1. Prospecting

The aim of this stage is the identification of minerals deposits above or below the Earth's surface. In order to do so, two principal methods are employed: the *direct* and *indirect* methods. The former refers to the study of surface deposits through visual examination enabled by space imagery, geological maps, and structural analysis; while the indirect method employs geophysical knowledge in order to detect anomalies through physical measurements of the earth.

### 2.1.2. Exploration

The main object of this stage is to reveal the mineral deposit size and grade in order to estimate the total value of the project. During *Exploration*, the techniques employed are substantially similar to those used in the prospecting stage, but with a higher level of specificity.

### 2.1.3. Feasibility & Planning

This stage does not require "real" and "practical" actions on the site, but aims to measure the profitability and economic feasibility of the project - assessing the estimated revenues, direct and indirect costs, safety and socio-environmental impacts and risks in order to take business decisions regarding the development, sale or abandonment of the site.

### 2.1.4. Development

The objective of the *Development* phase is to prepare the site for operational activities. Therefore, it is principally focused on:

- the acquisition of mining rights and water resources;
- the construction of logistics (i.e. roads and railways) and power infrastructure, waste disposal areas, offices and other support facilities; and
- getting access to the deposit "by stripping the overburden, which is the soil and/or rock covering the deposit, to expose the near-surface ore for mining or by excavating openings from the surface to access more deeply buried deposits to prepare for underground mining" (Hartman and Mutmansky, 2002, p. 10).

### 2.1.5. Operation

Without any doubt, the *Operation* stage is the core phase of mining process and aims to recover minerals from earth. On average, it lasts from ten to thirty years, and therefore the mining companies' ultimate goal during this stage is to be able to manage the operations in the most profitable, most efficient and safest way.

According to Hartman and Mutmansky (2002), there are two principal exploitation methods: *Surface* and *Underground* mining. The former is widely used worldwide and is the main exploitation method, while the use of the latter is diminishing due to the high level of hazards (i.e. fire, flood, collapse, toxic contamination) that result in employing this method only in highly profitable cases.

### 2.1.6. Closure & Reclamation

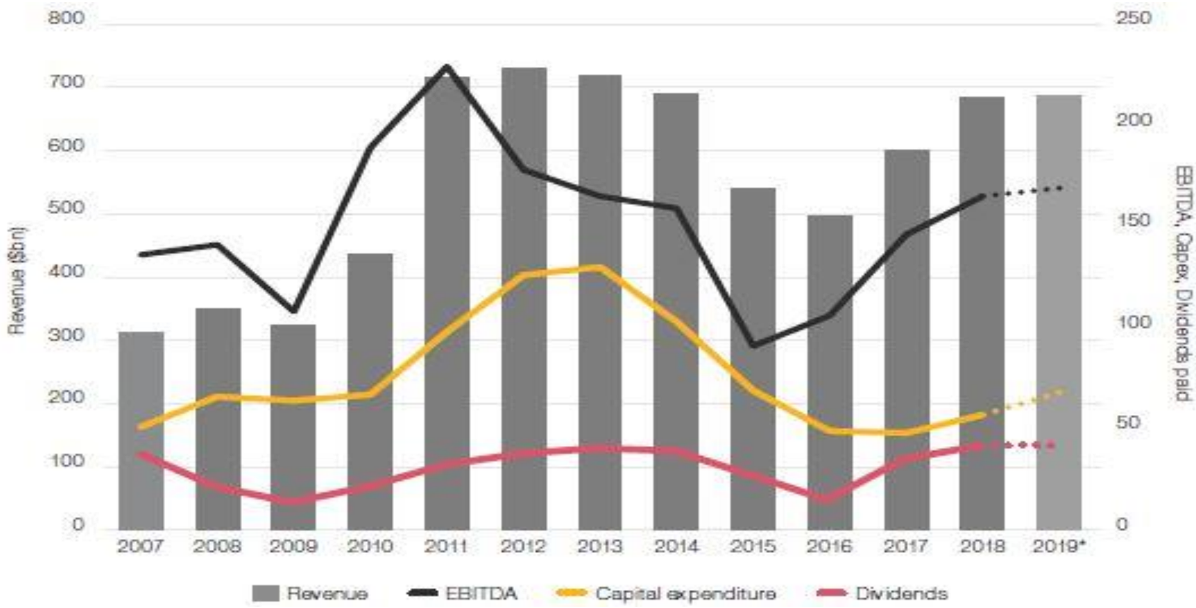
The *Closure & Reclamation* of mines is a crucial phase in the life of the mine with important implications in terms of short-term regulatory compliance and the long-term image and credibility of mining companies. Therefore, according to Hartman and Mutmansky (2002, p.13) "the best time to begin the reclamation process of a mine is before the first excavations are initiated" i.e. planning mining operations with the aim of maximising the efficiency of the production phase and also minimizing the intervention required during the rehabilitation phase.

This stage can be divided into four sub-phases (Hartman and Mutmansky, 2002, p.14):

- The first one addresses the removal of facilities and infrastructure removal.
- Then, it is important to "seal all mine shafts, adits, and other openings that may present physical hazards" and "any existing highwalls or other geologic structures may require mitigation to prevent injuries or death due to geologic failures".
- The third step is the "restoration of the land surface, the water quality, and the waste disposal areas so that long-term water pollution, soil erosion, dust generation, or vegetation problems do not occur".
- The conclusive phase refers to the transformation of operational sites into "wildlife refuges, shopping malls, golf courses, airports, lakes, underground storage facilities, real estate developments, solid waste disposal areas, and other uses that can benefit society".

## 2.2. Mining industry's Financial Perfomance

*Figure 1 - Top 40 Mining Companies Financial Performance Trends ($bn)*




*Source: PWC (2019). Mine 2019 Resourcing the future.*

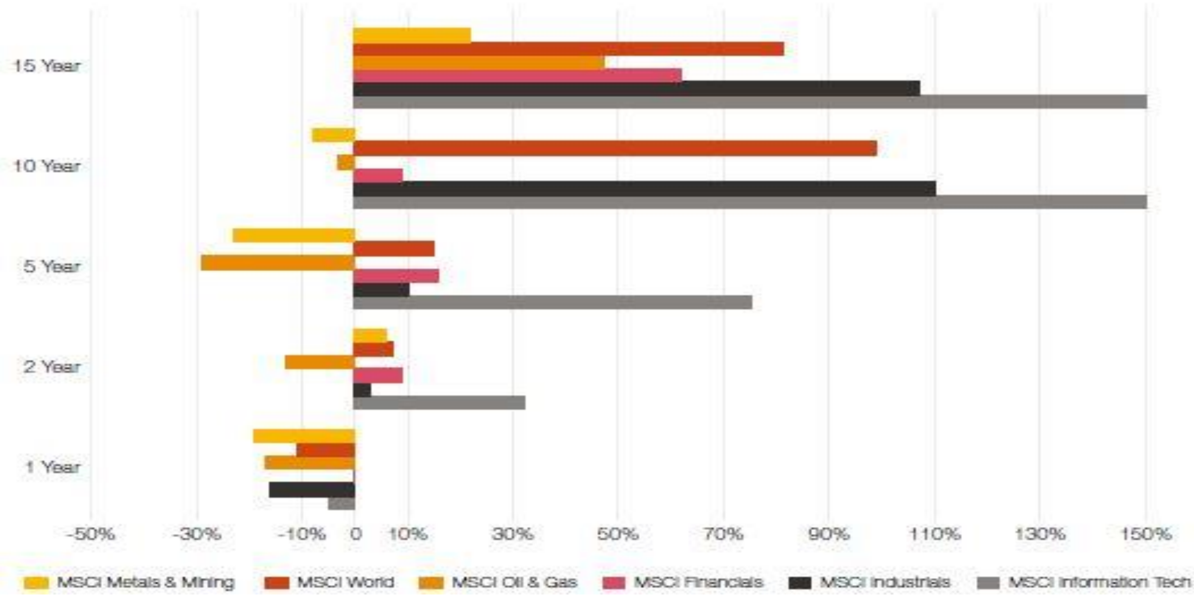
*Notes: 2019 values are outlook based on PwC Analysis.*

The graph above provides a financial performance overview of top 40 mining companies in the world by market capitalization as 31 December 2018. In particular, according to the data gathered by PwC (2019), the mining industry's financial performance in 2018 confirmed the revenues and profitability turnaround already shown in 2017 and enabled the first capital expenditure enhancement since 2013. The astonishing boost in total revenues[1] led to higher cash flows that have been widely employed in improving shareholders' remuneration[2]. Unfortunately, as is shown in the figure below, despite the strong financial performance of the sector, and the high amount of distributed dividends, the mining industry has a relatively low total shareholder return performance (along with oil & gas industry) in the global industry economic landscape.

[1] Principally driven by the increase in commodities price but also by a production increase equal to 2% (PwC, 2019).

[2] Total dividend equals to $43 bn in 2018 leading to dividend yield of 5.5% (PwC, 2019).

*Figure 2 - Relative Sector Total Shareholders Return Performance*




*Source: PWC (2019). Mine 2019 Resourcing the future.*

*Notes: total return = annual capital growth + dividend yield*

As already mentioned above, mining companies are struggling to adapt their business methods to the new *digital innovation* trend and *climate change* concerns. Therefore, investors tend to discount the mining companies' share prices to take into consideration perceived risks related to the *environmental*, *social* and *business* issues.

## 2.3. Mining Industry Environmental, Social and Business issues

This section aims to provide an overview of the environmental, social and business issues faced by mining companies according to reports released by PwC (2019), EY (2019) and McKinsey & Co. (2020).

### 2.3.1. Issue 1: Environmental

*Environmental* risks related to the mining industry are twofold:

- *Physical risk* - the industry will suffer from harsher climate conditions driven by climate change;
- *Stakeholder risk* - the industry is affected by stakeholders' expectation of carbon emissions reduction and environmental disaster prevention.

Focusing on the former, there is a need for mining companies to mitigate the climate change risks for their assets improving the resiliency of their operations. In particular, heavy investments in water monitoring and management are required in the very near future. On the one hand, "climate change is expected to cause more frequent droughts […], altering the supply of water to mining sites and disrupting operations" (McKinsey & Co., 2020, p. 2) with a particular risk for already stressed area such as Chilean coast, eastern and western Australia, Central Asia, Middle East, Southern Africa and the western North American areas, but also for those regions not currently accustomed to water stress[3]. This phenomenon may lead to a multitude of negative effects for mining companies, indeed drought conditions could lead to costly short-term shut down[4], or it could reduce the likelihood of obtaining the *license to operate* due to the scarce nature of water resources.

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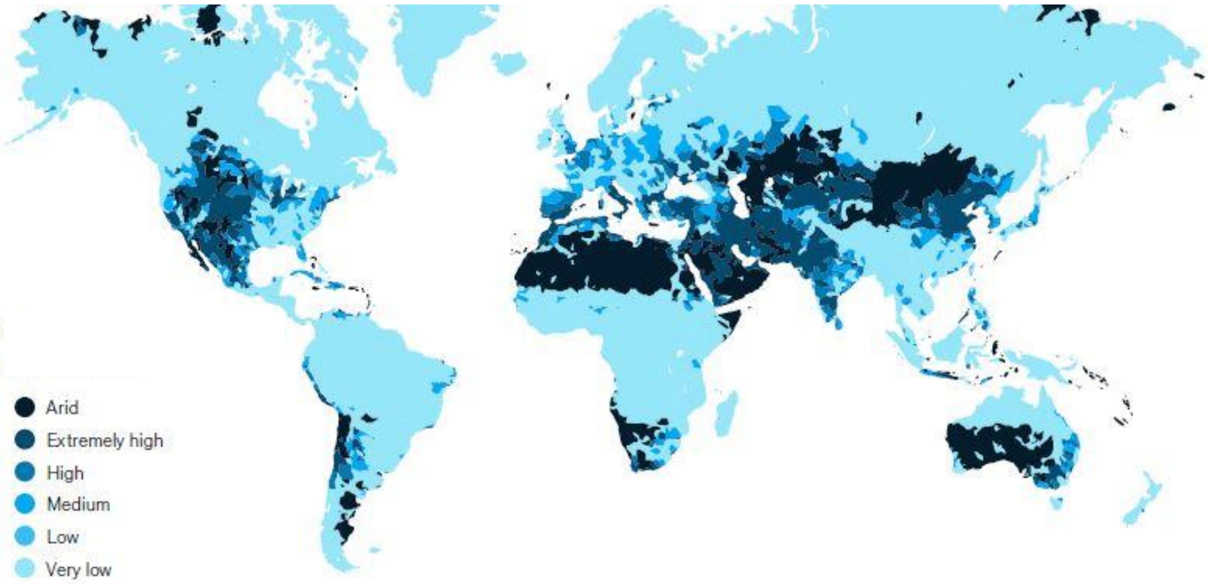
[3] Water stress is defined as the ratio of water demand to supply.

[4] "For instance, Leagold Mining recently shut down its RDM gold mine in Brazil for two months because of drought conditions, even though it had built a dam and a water pipeline. Even in areas with low water stress, certain water intensive mining processes are jeopardized. In Germany—not a country known for being vulnerable to drought—a potash miner was forced to close two locations because of severe water shortages in the summer of 2018, losing nearly $2 million a day per site".

*Figure 3 – Projected Global Water-Stress Level by 2040*




*Source: McKinsey & Co. (2020). "Climate risk and decarbonization: What every mining CEO needs to know".*

On the other hand, "flooding from extreme rains can also cause operational disruptions, including mine closure, washed-out roads, and unsafe water levels in tailing dams" (McKinsey & Co., 2020, p.3) with an annual production loss equal to 10% in particular regions such as south America, southern Africa, central and western Africa, northern Australia, India, Indonesia and Southeast Asia.

Furthermore, other climate factors could affect mining operations such as the transportation infrastructure located near the coast threatened by *sea-level rise*, or *extreme heat* that could negatively impact worker productivity (McKinsey & Co., 2020).

As regards the *stakeholder risk factor*, it is important to note that, considering *Scope 1*, *2* and *3 emissions*[5], the mining industry accounts for 32%-39% of global emissions due to the employment of heavy vehicles and huge amount of electricity (1%), fugitive-methane

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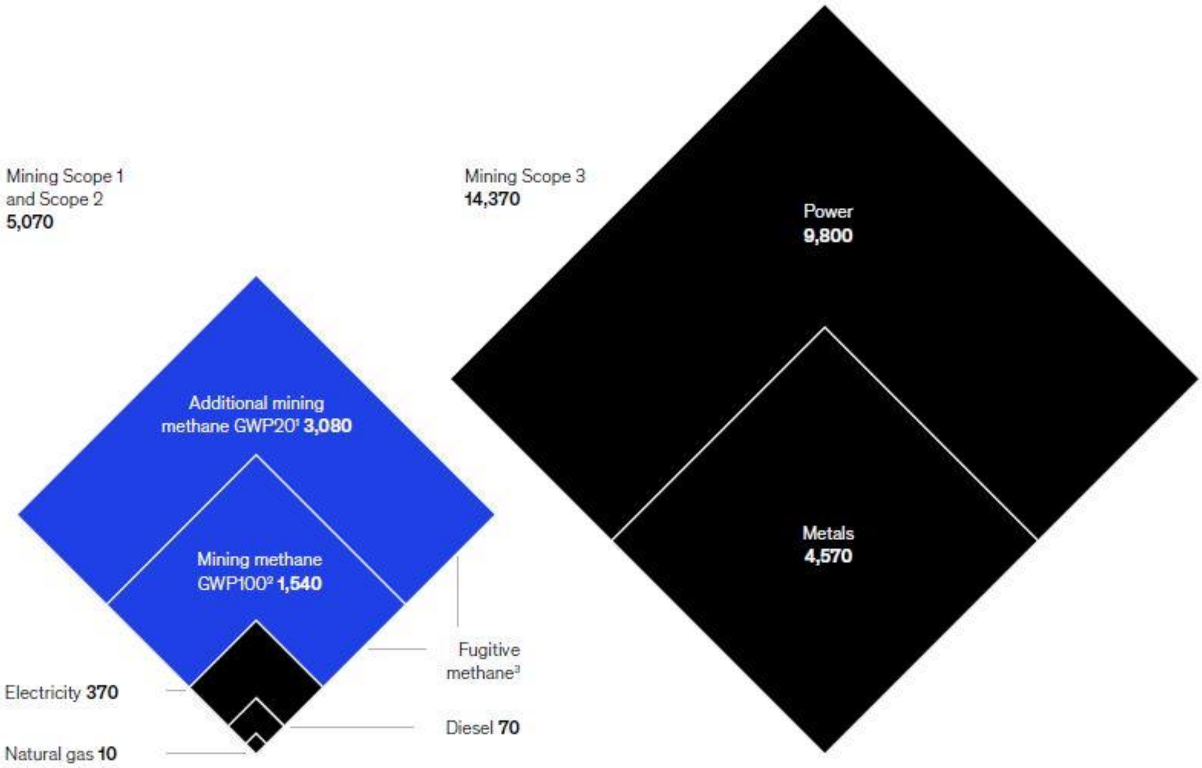
[5] According to GHG protocol, the Scope 1,2 and 3 emissions are defined as follows:

- "Scope 1 emissions are direct emissions from owned or controlled sources.
- Scope 2 emissions are indirect emissions from the generation of purchased energy.
- Scope 3 emissions are all indirect emissions (not included in scope 2) that occur in the value chain of the reporting company, including both upstream and downstream emissions".

emissions from coal mining (3%-6%) and *Scope 3* emissions related to coal-based power plant (20%) and coal use in industry (8%)[6].

*Figure 4 – Mining Industry Emissions (megatons per years of $CO_2$ equivalent)*




*Source: McKinsey & Co. (2020). "Climate risk and decarbonization: What every mining CEO needs to know".*

*Note:*

1. *GWP20 = global-warming potential on a 20-year time frame;*
2. *GWP100 = global-warming potential on a 100-year time frame;*
3. *Fugitive methane is converted to $CO_2$ on both GWP100 (conversion factor 28) and GWP20 (conversion factor 84).*

As it is possible to see, a drastic reduction on coal production and usage will surely lead to enormous benefits to the environment, but, according to McKinsey & Co. (2020, p.2), excluding *Scope 3* emissions, the mining industry still must reduce the GHGs emissions "by 41 to 72 percent […] for a 2.0°C scenario and a 78 to 89 percent […] for a 1.5°C scenario". Therefore, current commitments to reduce emissions in the range of 0%-30% are not

[6] *Source: McKinsey & Co. (2020).*

enough, and there is a lot more to be done in terms of efficiency improvements, including vehicle and equipment electrification, and employment of renewable energy sources.

Another important *environmental* risk caused by mining activities is related to the impact on the ecosystem of areas surrounding mines. According to M.J. McKinley (2006), "on a long-term basis, mining can increase the acidity of water in streams; cause increased sediment loads, some of which may be metal-laden, in drainage basins; initiate dust with windborne pathogens; and cause the release of toxic chemicals, some contained in exposed ore bodies and waste rock piles and some derived from ore-processing reactions. Contaminants containing such toxic chemicals as cyanide and lead may be transported far from a mining site by water or wind, polluting soils, groundwater, rivers, and the atmosphere. These toxic chemicals can be remobilized intermittently (e.g., by intense wind or rain storms) and eventually distributed over vast regions". Furthermore, a giant threat is driven by *tailings dam collapse* with deadly consequences for workers, communities, rivers and forests in an area even wider than 1,000 kilometres. For example, the Brumadinho dam disaster in Brazil (2019) caused 270 deaths, the destruction of roads, railways, villages, and the pollution of over 300 kilometres of river.

### 2.3.2. Issue 2: Social

According to EY (2019), the 44% of their survey respondents rated the risk of losing the *license to operate* at the top of the list of mining sector business risks. This was due to the uncertainty brought about by the political environment, and demand from investors, communities and consumers demand for transparent ethical supply chains and lower environmental impacts. Even if the contemporary meaning of *social licence to operate* was coined by the vice-president of the Canadian mining company Placer Dome Inc. in 1997, in the last few years, the importance of ensuring an appropriate level of acceptance by local communities and stakeholders has taken a pivotal role in the mining sector. The level of *legitimacy*, *credibility* and *trust* expected nowadays are much higher than in the past and mining companies need to take serious actions in order to limit their impact on surrounding areas, and to improve the disclosure of the consequences of their activities.

Environmental disasters and carbon emissions are the main threats for the community, but it is important to highlight that mining projects are giant operations that employ hundreds of workers and that have a strong impact on local economy and on the lives of a large number of citizens.

**Box 1. Glossary**

*Social legitimacy* "is legitimacy is based on established norms, the norms of the community, that may be legal, social and cultural and both formal and informal in nature. Companies must know and understand the norms of the community and be able to work with them as they represent the local 'rules of the game'. Failure to do so risks rejection. In practice, the initial basis for social legitimacy comes from engagement with all members of the community and providing information on the project, the company and what may happen in the future and then answering any and all questions".

*Social credibility*, "is largely created by consistently providing true and clear information and by complying with any and all commitments made to the community. Credibility is often best established and maintained through the application of formal agreements where the rules, roles and responsibilities of the company and the community are negotiated, defined and consolidated. Such a framework helps manage expectations and reduces the risk losing credibility by being perceived as in breach of promises made, a situation common where relationships have not been properly defined".

*Social trust*, "or the willingness to be vulnerable to the actions of another, is a very high quality of relationship and one that takes both time and effort to create. True trust comes from shared experiences. The challenge for the company is to go beyond transactions with the community and create opportunities to collaborate, work together and generate the shared experiences within which trust can grow".

*Source: Shinglespit Consultants Inc., 2018*

### 2.3.3. Issue 3: Business

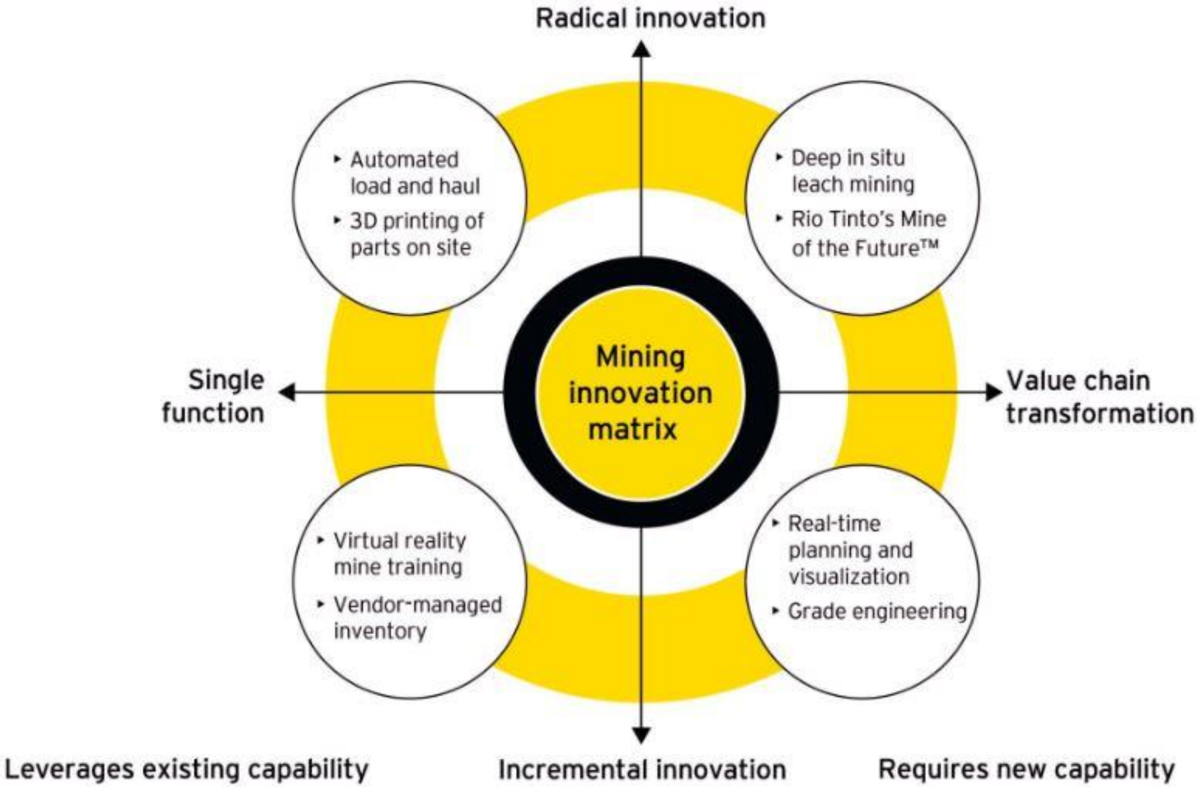
Giant environmental disasters such *as tailing dam collapses* are not the only source of risk for mining workers. Day-to-day activities have led to a significant amount of injuries and fatalities. In 2018, the 26 members of ICMM[7] (30% of total mining market share) reported a total of 50 fatalities. This was an improvement over previous years (a 33% reduction in

[7] International Council of Mining and Metals.

fatality frequencies rate since 2012), but this is a small part of the entire industry. In specific regions, such as eastern Asia the number of deaths is in the order of hundreds people per year.

The high level of risk, combined with the remote in-situ operations and the tough physical effort required leads many workers to exclude the mining industry from their career plans, causing problems for mining companies in *talent attraction*. Furthermore, even non site-related departments such as marketing, finance and innovation are facing a shortage of talent acquisition due to poor mining companies' *employer brands*. For these reasons, according to EY (2019), the "future of workforce" in terms of safety and productivity is the second major risk for mining companies' management. Therefore, in order to solve it, investments in digital and technological innovation are definitely required. The employment of *Internet of Things* (IoT), *Augmented/Virtual Reality* (AR/VR) and *Artificial Intelligence* (AI) technologies is likely to lead an increase in mining workers' safety and employer brand attractiveness, and also to higher environmental tutelage and social acceptance.
According to EY (2019), a serious investment in the technologies listed above and others related to *digitization*, *big data* and *innovation* will help to foster some critical management activities (i.e. improvement of margins, business performance management, long-term scenario modelling, inventory optimization), boost operational productivity, and help mining companies to deal with new issues such as increasing operational complexity, remote mining, and the need for exploration effectiveness enhancement.

*Figure 5 – Mining Innovation Matrix*

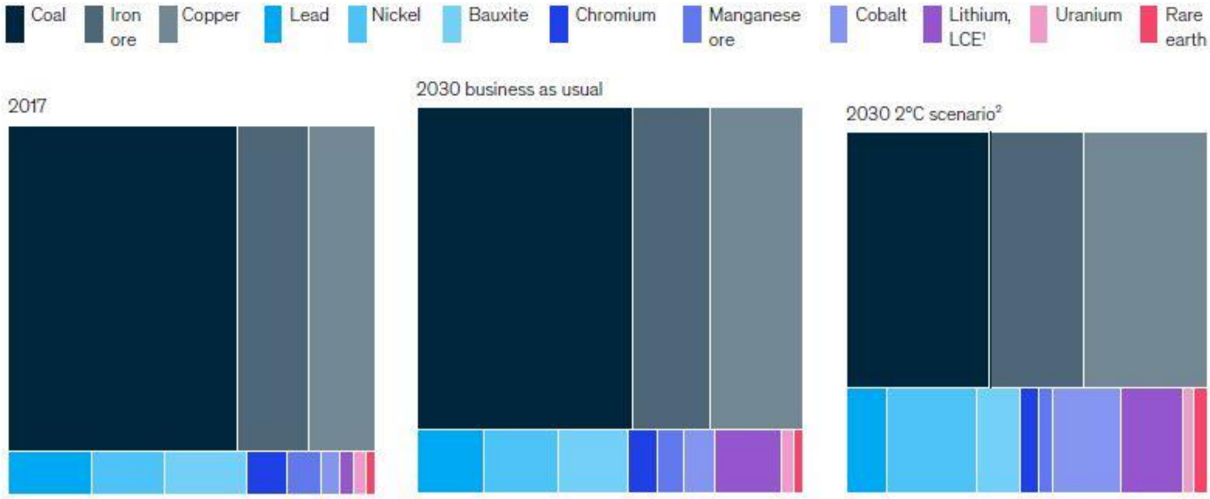



*Source: EY (2019). "Top 10 business risks and opportunities-2020"*

In relation to the latter, it is important to highlight that, according to McKinsey & Co. (2020), in the International Energy Agency's 2°C scenario, the demand for coal[8] will drop by 50% in 2030 but the total global mining market size will decrease only slightly thanks to the increase in the bauxite, nickel, cobalt, lithium, rare earths, copper and uranium demand. Therefore, a deep investment in *exploration* technologies able to find new and valuable resources is required, otherwise, according to EY (2019), the threat of supply crunch is more likely to happen.

[8] The coal market is about 50% of total mining one.

Figure 6 – Mining Market Size per Scenario




*Source: McKinsey & Co. (2020). "Climate risk and decarbonization: What every mining CEO needs to know".*

*Note:*

1. *Lithium-carbonate equivalent;*
2. *Based on IEA 2°C scenario.*

# 3. The Space Industry – A focus on Satellite Technologies

The previous chapter provided an overview of the mining industry's *environmental*, *social* and *business* challenges, and outlined that heavy investment in *digitization* and *innovation* are required for overcoming them. On this basis, the use of *space technologies* in the mining industry will provide valuable direct benefits (i.e. in exploration and monitoring) and will also play a pivotal role as enabler of other technologies (i.e. unmanned vehicles and disaster response).

In order to understand the space-related potentialities for the mining industry, the following chapter will provide a brief space industry overview with a particular focus on *satellite* technologies and applications.

## 3.1. Overview

Excluding the military segment, the commercial space industry can be classified into two streams: *Infrastructure and Support* (also known as *Upstream*) and *Space Products and Services* (also known as *Downstream*). Furthermore, according to Space Foundation (2014-2017), both business streams can be divided in specific sub-categories, in particular:

- The *Infrastructure and Support* stream is principally focused on infra-industry services able to empower and constantly improve *downstream* product and services. Therefore, the Upstream sub-categories are as follows: launch industry, satellite manufacturing, space stations, ground stations and equipment, commercial human spaceflight, independent R&D, and infrastructure support activities.

- *Downstream* products and services are delivered exploiting the satellite technologies, therefore the following sub-categories are classified on the basis on the principal groups of those technologies: *Satellite Communications*, *Earth Observation*, and *Global Navigation Satellite System (GNSS)*.

Since the ultimate goal of this report is to understand the benefits of space technologies, the following section will exclusively focus on the *Space Products and Services* stream, addressing the principal satellite technologies and applications.

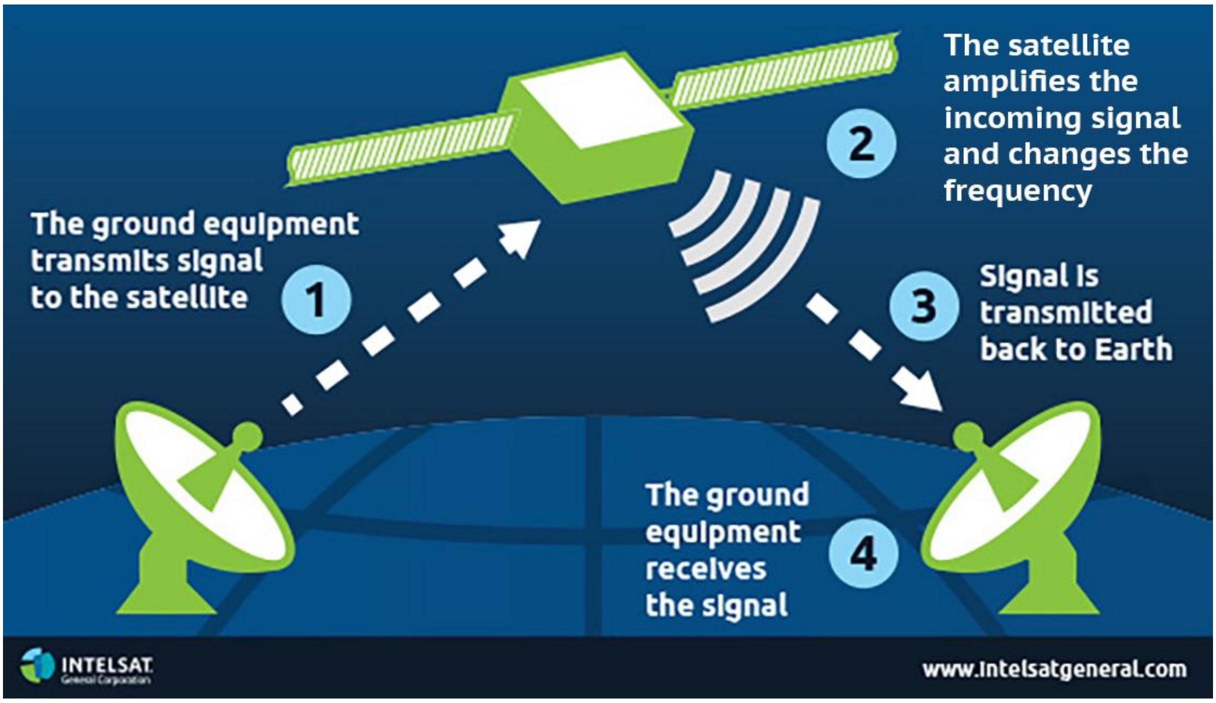
## 3.2. Satellite Technologies

Retrieving the space industry classification shown above, the principal characteristics, technologies and applications of the *Space Products and Services* subcategiories are as follows.

### 3.2.1. Satellite Communication

*Satellite communication* allows the communication between a *transmitter* and one or more *receiver* placed in different locations on Earth through the relay and amplification of radio telecommunication signals.

*Figure 7 - Basic architecture of satellite communications network*




*Source: INTELSAT General Corporation*

Obviously, the connection between two or more parties on the Earth can be enabled also by terrestrial means of communication. The main *Satellite communication* pros and cons from a technical point-of-view are listed below (Sisac, 2018).

- Advantages:
  - *Unlimited coverage* – satellites technologies enable communication in every part of the planet, including entities located in oceans, in remote areas and in the sky can have access to the whole telecommunication service.
  - *Flexibility* – this characteristic refers to the capability of change in the covered areas and in the content transmitted, and to the possibility of modulating the capacity allocated to different applications.
  - *Unlimited number of receivers* – the quality of downlink content broadcast is not impacted by the number of end-users involved.
  - *Network independence* – the satellite infrastructure can work as back-up system in case of failure of terrestrial services.

- Disadvantages:
  - *Latency* – in a two-way communication the propagation delay from geostationary orbit is approximately equal to 478 - 556 millisecond.
  - *Limited speed* – satellite communication is limited to a speed in the order of 100 mb/s, while terrestrial infrastructure reach much more higher speeds.

### 3.2.2. Earth Observation

According to Sasic (2018, p. 39), "*Earth Observation* can be defined as the acquisition, collection, analysis and presentation of data on Earth's physical, chemical and biological systems from aerial or satellite-based observations". Therefore, *Earth Observation* is principally based on active (i.e. to illuminate the target to detect reflections) and passive (i.e. to detect incident radiation which originates from the target*) remote sensing*[9] technologies able to capture the electromagnetic radiation of any body in the lithosphere, biosphere, hydrosphere and atmosphere. For example, *Earth Observation* may be employed in order to

[9] Remote sensing is the acquisition of information about an object or phenomenon without actually being in contact with it.

collect earth images, measure the height, temperature and moisture content of a body, provide weather information and assess land composition.

As for *Satellite communication*, the main advantages and disadvantages are (Sasic, 2018):

- Advantages:
  - *Wide spatial coverage* – In a given time span, satellites are able to cover larger areas than aerial means.
  - *High frequency* – On the one hand it is possible to reach a revisit time equal to zero employing geostationary satellites that constantly observe the same area. On the other hand, this solution cannot be pursued for missions that require high resolutions due to the high altitude of these satellites. However, in these cases, satellite constellations are able to provide better resolution images with daily observations.
  - *Customer centricity* – Images are prepared to satisfy specific client needs without time-consuming settings.
  - *Access to remote areas*.
  - *No-interaction with the object of study* – As already mentioned in the remote sensing definition, *Earth Observation* does not need to interact with the object of interest, thus eliminating any disturbance effects.
- Disadvantages:
  - *High cost* – on average the cost related to the acquisition of satellite services is higher than other technology options. However, the marginal cost is almost equal to zero, therefore an increase of satellite clients should result in a significant cost reduction.
  - *Capabilities niche* – In order to gather and interpret satellite information, the development of target expertise is required.

### 3.2.3. Global Navigation Satellite System

According to the European GNSS Agency (2017, p.9), a *Global Navigation Satellite System* is defined as “the infrastructure that allows users with a compatible device to determine their position, velocity and time by processing signals from satellites”. This satellite technology is widely employed at military, business and civilian level, thanks to the high value added combined with ease of usage and affordable cost. For example, it has become indispensable for maritime, aerial and road navigation, or for insurance (i.e. distance travelled monitoring) and in car sharing businesses (i.e. car position identification). The only downside is in relation to the possible errors caused by ionosphere and troposphere effects, orbital error, multipath distortion, or other sources that could cause distortions or errors in the order of metres, but, in the last few years, technological progress has led to techniques able to reach accuracy levels in the order of 1 cm (i.e. Real Time Kinematic).

# 4. Space technology applications and the mining industry

The technologies described in the chapter above can be used alone or in combination with others in order to provide a multitude of services. Indeed, in order to develop digital and innovative technologies, strong partnerships among different industries are required. For example, according to ESA (2019), space technologies are fundamental for the development of AR/VR applications but other industries focused on digitization or gaming will have a pivotal role too.

**Box 2. Satellite technologies enable AR/VR applications.**

According to ESA (2019), the satellite technologies described in paragraph 3.2 are fundamental for the enablement of AR/VR applications. In particular:

- Earth Observation allows the collection of images and data employed in the AR/VR environment (i.e. production of maps);
- GNSS is fundamental for the determination of the precise location and movements of users and objects;
- Satellite Communication is employed for providing connectivity in situations in which terrestrial structures are not reliable or absent.

Source: ESA (2019). https://business.esa.int/funding/invitation-to-tender/virtual-and-augmented-reality-kick-start

The aim of this chapter is to describe *satellite-enabled activities* useful for the mining industry and to illustrate these benefits with insightful case studies.

## 4.1. Methodology

Combining the above discussion related to the possible implementation of satellite technologies, and the analysis of current mining industry requirements, the following table lists the main *satellite-enabled activities* currently used or developed by the mining sector in collaboration with the space industry and other innovative sectors.

*Figure 8 - List of the Satellite-enabled activities in Mining industry*

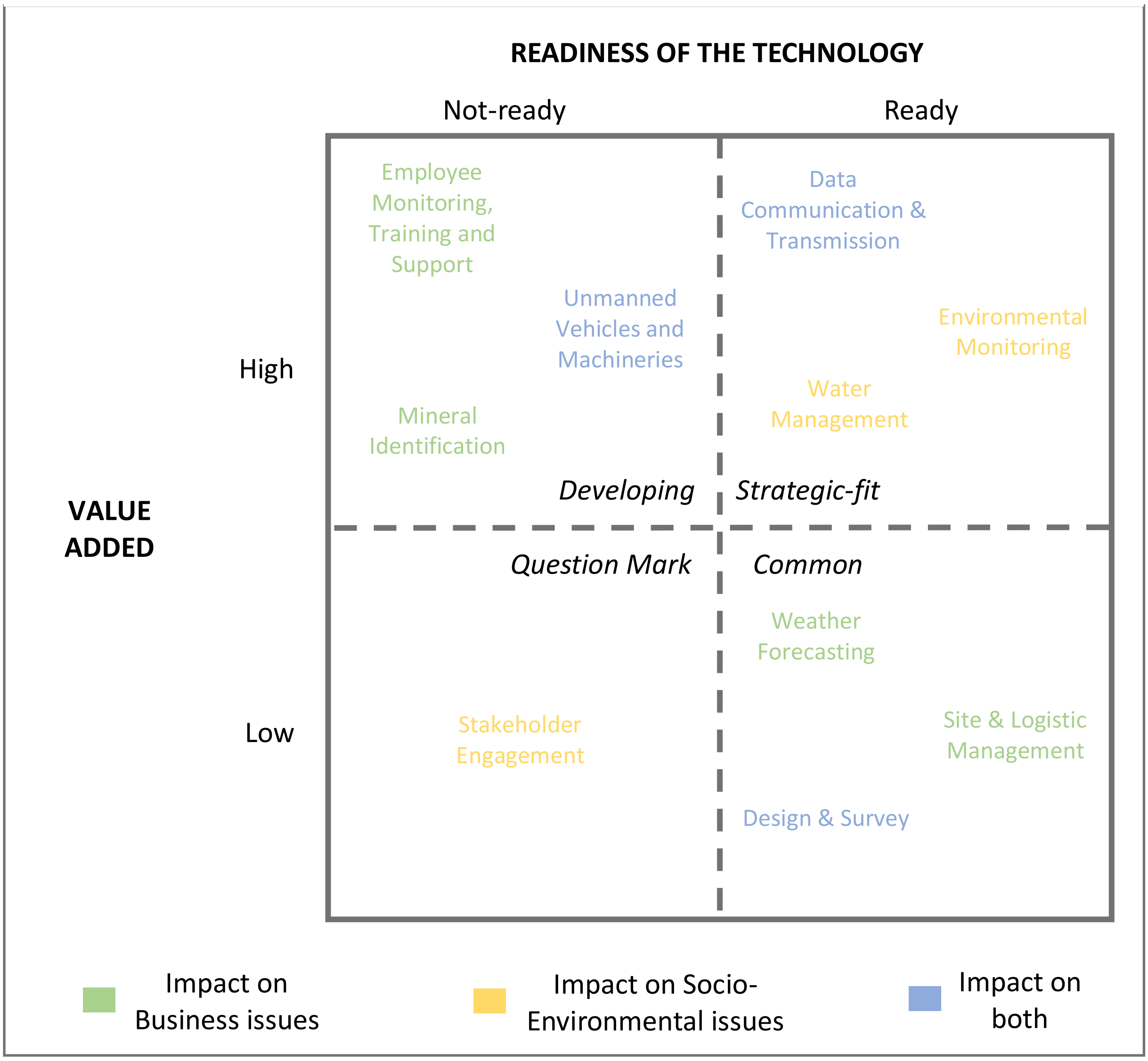
| Satellite-enabled activities in Mining industry | |
|---|---|
| Weather Forecasting | Water Management |
| Data Communication & Transmission | Site & Logistica Management |
| Mineral Identification | Employee Monitoring, Training & Support |
| Design & Survey | Stakeholder Engagement |
| Environmental Monitoring | Unmanned Vehicles & Machineries |

It is suggested that mining industry should conduct a strategic assessment regarding which of the possible activities fit their requirements the most and focus their effort on them. For this reason, the "Satellite-enabled activities" framework has been created combining the following variables:

- the level of *Value Added* - high or low. It has been addressed taking into consideration the improvement that could be brought by the implementation of new/better *satellite-enabled activities* on the issues highlighted in section 2.3.
- the *Readiness of the Technology* - ready or not-ready. It has been measured in terms of the further effort required for being fully operational.

The resulting framework is as follows:

*Figure 9 – "Satellite-enabled activities" framework*




*Note: According to G.P. Pisano's paper (2015), the innovation strategy of every company should depend on the fit between innovation and business strategy, and on the resources to be allocated. In accordance with this approach, the "Satellite-enabled activities" framework as used in this report involves a consideration of the former, based on the value added that the innovation is likely to bring about, and the latter, in which the readiness of the technology and the effort that is still required to achieve benefits are evaluated.*

## 4.2. Activities groups

### 4.2.1. Group 1: Question mark activities

The *Question mark activities* group applies exclusively to *Stakeholder Engagement* activity. Only a few mining companies employ the latter, because the technologies are not mature yet and the obtainable value added is not clear. Therefore, investment in this activity might not be strategically important.

- Stakeholder Engagement

As reported in paragraph 2.3.2, the risk of losing a *Licence to operate* is ranked as one of the most critical by mining management, leading to the necessity to identify new tools for engaging strategic stakeholders. In particular, employing AR technologies, it would be possible to show in an effective and clear manner the mine project, its development and its impact on the physical location, with the aim of increasing stakeholder alignment and breaking down communication barriers.

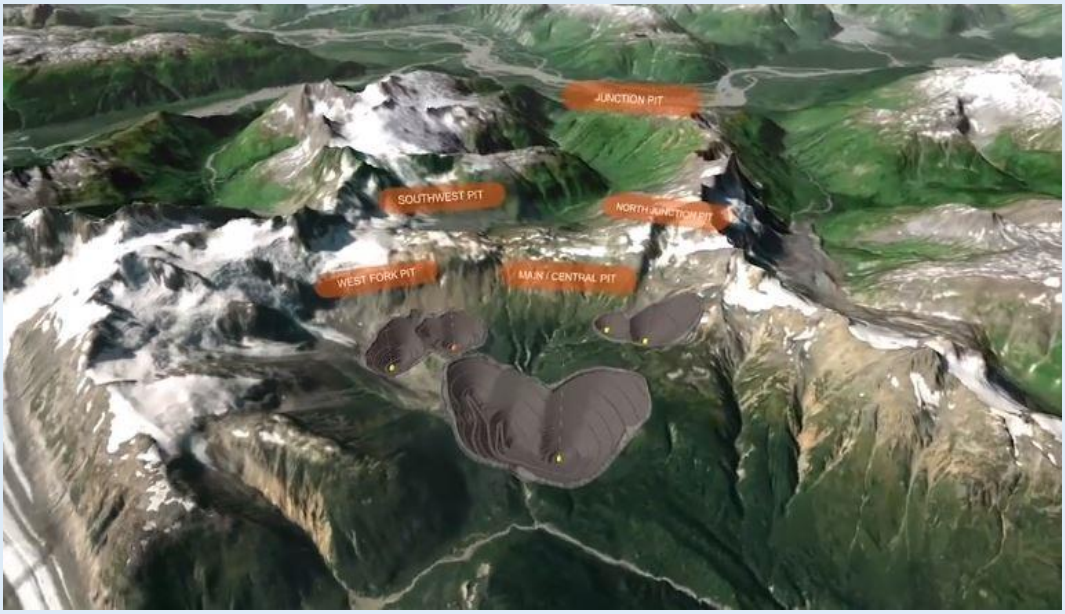
**Case Study 1.**

**MineLife VR in the Galore Creek project**

The Galore Creek project hosts one of the largest undeveloped copper-gold-silver deposits in the world and is managed by the Galore Creek Mining Corporation - GCMC (a 50/50 partnership between Teck Resources Limited and Newmont Goldcorp Corporation). Due to the remoteness of the site, GCMC was unable to engage the strategical stakeholders and a project stagnation issue suddenly came up. In order to solve it, GCMC partnered with LlamaZOO, an award-winning 3D visualization solutions company, with the aim to create a digital representation of the mine.

After 8 weeks LlamaZoo completed the job providing a reliable 3D visualization of Galore Creek project integrating mine planning, drill holes, equipment, facilities, local biosphere, and any other kind of data related to the project. As results GCMC was able to engage the stakeholders and unlock the project, reducing the time and cost of the visits, and enhancing the digital perception of the company.

*Figure 10 - LlamaZoo digital visualization*




*Source: Llamazoo*

*Source: Llamazoo. https://www.llamazoo.com/*

### 4.2.2. Group 2: Common activities

The *Common activities* group comprises *Weather Forecasting*, *Site & Logistic Management* and *Design & Survey* activities. These activities are based on technologies well developed, therefore they are widely known and employed in the mining industry whenever considered viable or more effective than other solutions.

- <u>Weather Forecasting</u>

*Weather Forecasting* employs *Earth Observation* technologies and other technologies in order to provide weather forecasts through complex algorithms[10]. Since mining activities are typically outdoor, this is precious information for mining companies' management during the whole mining process to help plan day-to-day tasks wisely. Furthermore, historical

[10] "Around 75% of the data used in numerical weather prediction models comes from satellites". (Sasic, 2018, p. 53)

observations would provide strong insights from a long-term point of view, assisting the design of mines in an effective way to mitigate disasters (e.g. mine collapse due to torrential rains), and to calculate the risk of mining closure and loss of productivity caused by the harsher climate conditions mentioned in paragraph 2.3. For example, according to the National Climate Change Adaptation Research Facility – NCCARF (2013), "the 2010/2011 Queensland floods closed or restricted production of about forty out of Queensland's fifty coal mines costing more than $2 billion in lost production".

Traditionally, weather forecast data are freely shared by global meteorological satellite communities, but in-depth analysis conducted by experts can lead to a better understanding of in-situ data providing better criteria to assess when to demobilise and remobilise operations and when to re-allocate resources away from more dangerous and weather-affected site areas. Furthermore, the deployment of renewable sources of energy can only be optimized through weather predictions able to provide reliable insights on the capacity and energy-mix required.

**Case Study 2.**

**Karara Mining partners with Ubimet for "Precise Hyper-local Weather Data".**

Located 200 km south-east of Geraldton in the Shire of Perenjori, Western Australia, Karara is the largest mining operation and the first major magnetite mine in the Midwest of Australia. It has an expected life higher than 30 years and produces a premium, high-grade concentrate product for export to steelmakers.

The severe weather events that Karara mining experiences need to be tracked in order to ensure the maximization of workers safety and business productivity. Furthermore, the need to have timely and accurate forecasts is critical for safeguarding the huge investments in infrastructure (i.e. elevated steel processing structures, crane operations and rail operations, and aerodrome). Through the customized weather cockpit provided by Ubimet, the Karara's management was able to reduce downtime, protect their employees and preserve their investments, tracking and monitoring storm and lightning activities.

*Source: Ubimet. https://www.ubimet.com/en/*

- Site & Logistic Management

The *Site & Logistic Management* activity addresses the implementation of GNSS-based technologies in order to enhance workflow and improve security during the whole mining process. Through GNSS technology, mining companies should be able to improve mining operativity by tracking equipment and materials. GNSS tracking would also be helpful as anti-theft technology in mines and in logistic transportation (in India, for example, GNSS systems have been installed in 700 trains in order to prevent coal and oil theft). Another important implementation of GNSS technology is related to fleet management. *Logistic Management* is an important activity in the mining industry because mines require a constant flow of materials, equipment and workers in and out of the site. For this reason, it is important for mining companies to employ GNSS tracking of their fleets in order to improve driver security, manage traffic and accidents, and reduce fuel costs.

**Case Study 3.**

**Mining company uses satellite tracking to improve road safety**

Ivanhoe Mines employed Inmarsat's machine-to-machine service IsatData Pro to track vehicles travelling from and to the Kamoa-Kakula project during the exploration stage. The Kamoa-Kukula mine is located 25km west of Kolwezi (Republic Democratic of Congo – RDC), in a location in which journey that would normally take a few hours, could take several days due to the unsafety conditions of the road caused by the presence of unpaved road with big potholes and frequent dust clouds. Furthermore, the absence of telecommunication services impeded fast response actions in case of accidents, leading to several concerns about the security of the over 30 tracks employed by Ivanhoe Mines. Due to these factors, Ivanhoe Mines decided to install the IsatData Pro to its fleet in order to reduce the risks of accidents, vehicles damages, and to improve their response timing. In particular, the Inmarsat's service allows to immediately contact the driver in case of accident or broke down and to track the speed of every vehicle. The driver and the HQ would be informed whether the speed limit set by the company has been exceeded, and the vehicle is prompted to slow down.

Furthermore, the collaboration with Inmarsat allowed Ivanhoe Mines to improve the relations with local communities by reducing disruption and traffic jam in their villages.

*Source: Inmarsat. https://www.inmarsat.com/news/mining-company-uses-satellite-tracking-to-improve-road-safety/*

- <u>Design & Survey</u>

The *Design & Survey* activity employs *Earth Observation* and *GNSS* technologies and refers to all of those tasks aimed at analysing and measuring the lithological, geophysical, geological, topographical and biological characteristics of the mine area and surround in order to plan the deployment of mining, logistics, power, waste and administration infrastructures and facilities during the *feasibility & planning* and *development* stages. Focusing on the *Earth Observation* and according to Geoimage[11] website, the list below provides some examples of *Design & Survey* outcomes and benefits.

- *Elevation models* are useful for the creation of relief maps, water flow and mass movement modelling, terrain analysis, flood mitigation analysis, environmental overview, and risk assessment;
- *Site visualisation* is able to reduce construction time and costs through 3D visualization, and optimise site location planning through multi criteria analysis;
- *Site access overview* aims to reduce plant and equipment relocation costs, improve construction time, and enhance control over risk management;
- *Biosphere overview* allows the reduction of environmental impact during the *development* and *operative* stages and optimize the *closure & reclamation* one.

Therefore, through *Earth Observation* technology, mining companies are able to gather precious and thorough information without physically inspect the site. However, the principal drawback related to this technology is the lower level of accuracy compared to other methods, i.e. the *elevation models* obtained by *Earth Observation* technology (DEM – *Digital Elevation Model*) has an accuracy in the order of meters, while *GNSS*' *Land survey* methodology has an accuracy equal to +/- 10mm in position and 25mm in height (source:

**Case Study 4.**

**GNSS surveying in the BHP Billiton's Jimbelbar mine.**

BHP Billiton partnered with Sinclair Knight Merz, a former leading engineering company, in the development of the Jimbelbar mine located 40km east of Newman (Australia). In particular, the development work was related to the construction of a new ore processing plant, which required important survey services able to support the design and construction of the facility through GNSS base stations and RTK technologies.

Trigon survey[12]). For this reason, the latter technology has been extensively employed by mining companies leading to a reduction in surveying labour cost equal to 30%-40% (Acil Allen, 2013).

### 4.2.3. Group 3: Developing activities

*Unmanned Vehicles & Machineries*, *Mineral Identification*, and *Employee Training, Support and Monitoring activities* are included into the *Developing activities* group. Just a few mining companies are currently developing these activities because the required technologies and the capabilities related to them are not ready for massive implementation. Notwithstanding, the value added obtainable by applying IoT, AI, AR/VR and digital innovation technologies should lead to a significant enhancement in revenues, margins, workers morale, social approval and employer branding.

- <u>Unmanned Vehicles & Machineries</u>

The deployment of *Unmanned Vehicles & Machineries* (either autonomous or remote controlled) will revolutionize mining operations in the next few years. An important role in achieving this will be played by satellite technologies. However, an increase in detail specification and capability is still required. Notwithstanding, some mining companies have decided to start pilot projects in the past few years, the main ones having been deployed by Rio Tinto. This company launched the "Mine of the Future" programme in 2008 and one of the main objectives was the autonomation of mining sites. In 2016, they rolled out the world's first fully driverless mine logistic in Yandicoogina and Nammuldi mines (Australia). Since then, other Rio Tinto mines have been automated and other mining companies have invested as well, with the aim of automatizing or remotely controlling haul trucks, dozers, excavators and many other vehicles and machines. The removal of on-site human labour, has the potential to bring about numerous operational benefits. In particular, the direct advantages are likely to be in the following areas:

[12] Trigon has over 30 years' experience working on the front line of a wide range of civil engineering and private sector development projects.

- *Work environment*. The use of *Unmanned Vehicles & Machineries* will reduce the exposure of workers to high-risks tasks. Furthermore, the need for in-situ workers will be drastically reduced, improving employee morale and reducing the impacts on communities.
- *Operations*. The improvements in operations are two-fold. On the one hand, the productivity of mining is enhanced by longer working hours per days, and more precise and coordinated tasks. On the other hand, there is a significant reduction in costs driven by higher efficiency (thanks to better fuel and maintenance management) and overhead cost contraction (e.g. less worker facilities).

Furthermore, other indirect advantages can be identified such as the enhancement of talent attractiveness and the reduction of pollution.

- <u>Mineral Identification</u>

*Mineral Identification* activity is widely performed during the *prospecting* and *exploration* stages but, as already stated in paragraph 2.3.3, in the near future major investments in exploration will be needed, many of which will be channelled towards *Earth Observation* technologies because of the increase in the remoteness of sites and difficulty of access. According to ESA (2019), *Mineral Identification* activity allows users to “map and identify large-scale geological structures related to […] mineral deposits that ground-based surveys may find more difficult to see:

- Satellite radar interferometry can precisely identify surface faults or slight ground motion […];
- Multi-spectral optical sensors can directly identify different minerals, either valuable in their own right or chemically altered by contacts with oil and gas deposits”.

The techniques mentioned above are already employed in many exploration activities, but in the last few years important innovations have extended *Mineral Identification* capabilities. For example, University of Alabama Birmingham (UAB) researcher Reda El-Arafy has been developing “The Mix” technology aimed at identifying uranium and other metal ores through the study of electromagnetic spectra. So far, this technique allows users to discover ores located hundreds of meters below the Earth's surface with an accuracy of 90%. Another example of *Mineral Identification* innovation is the employment of *Geobotanical Surveys* for "mapping geological formations and […] locating fresh water, saline aquifers, and mineral deposits" (Gandhi and Sarkar, 2016) in not arid or semi-arid areas through the identification of *indicator plants* able to signal the existence of a particular element in the soil in which they grow.

Further improvements in the *Mineral Identification* activity would definitely lead to significant benefits for mining companies in terms of exploration investment reduction, business-risk related to site value contraction (driven by more effective surveys that enable more reliable data), faster opportunity identification (satellites can collect data from many regions) and cash-flow generation (reducing the first two stages of mining process).

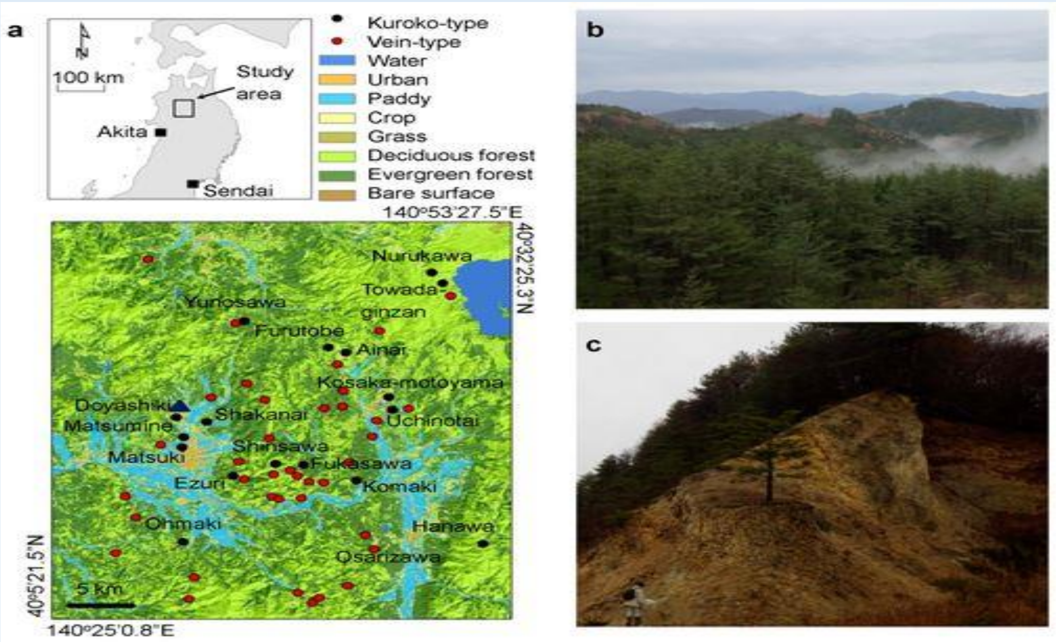
**Case Study 5.**

**How can satellite imagery be used for mineral exploration in thick vegetation areas?**

Hede et al. published in 2017 a paper that demonstrates the effectiveness of *Geobotanical remote sensing* in identifying mineral resources through *Vegetation Index* analysis. In particular, they based their study on the kuroko deposits in the Hokuroku district (northern Japan), which have been thoroughly explored under thick vegetation cover. Hede et al. (2017) demonstrated the correspondence between vegetation and geologic anomalies with a multivariate analysis of geological and geophysical data and ore deposit exploration. Furthermore, they found out that "the vegetation anomaly zones detected appear overlapped with the ring structures that controlled the distributions of ore deposits, and most major ore deposits in the forest areas were in agreement with the vegetation anomalies" (Hede et al., 2017, p. 594).

This methodology is therefore opening the possibility to employ *Earth Observation* technologies even in not-arid locations, extended the usability of this technology regardless the characteristics of the target area. However, it is important to take into consideration that, according Hede et al. (2017), anthropogenic or other natural factors may conceal the effect of metal-related effects, leading to unreliable results. Therefore, further improvements in this study are needed.

*Figure 11 - Location of the Hokuroku district, Akita Prefecture, northern Japan*




*Source: Hede et al. (2017)*

*Note:*

- *A - Map of the known ore deposits overlaid upon a land cover;*
- *B - sceneries of evergreen forest in which the predominant vegetation community is conifer;*
- *C - a strongly altered outcrop of the East Kannondo in the northern Doyashiki deposit.*

- <u>Employee Training, Support and Monitoring</u>

As mentioned in paragraph 2.3.3, the numerous injuries and fatalities that affect mining workers are still a relevant problem in the industry. The unpredictable nature of many accidents, together with the difficulty of replicating specific situations, limits the opportunity for mining companies to train their employees to take correct actions in dangerous environments. For this reason, the mining industry is currently partnering with AR/VR and satellite companies with the aim of overcoming these limitations (i.e. VR disaster response training).

Another important application of AR/VR technologies for mining companies is related to the enhancement of operational efficiency. In particular, according to J.Bassan et al. (2011) and J. Jacobs et al. (2016), AR applications could be employed for *digital maintenance & collaboration* and *operative* activities. Through the former, mining workers would obtain virtual information to perform tasks, or receive remote assistance from experts. Referring to the latter, J. Jacobs et al. (2016) provided an insightful example related to the application of AR technologies in drilling operations. In particular, a visual guidance of the drilling equipment would provide the exact location and direction of it, allowing fast reactions and adjustments by operators, and, consequently, the improvement of accuracy.

Furthermore, in the future satellite GNSS and communication technologies could be employed to provide location information in case of disaster, track movements, and monitor mining workers' health and efficiency by collecting data from sensors that monitor heart-beat, blood-pressure and other vital signs.

**Case Study 6.**

**Augmented Operator Advisors.**

Schneider Electric, a leading company in the digital transformation of energy management and automation, recently presented its EcoStruxure™ Augmented Operator Advisor. The product is able to provide industrial AR support enabling the users to experience a fusion of real-life environment with virtual objects. The main benefits of leveraging this product are the following:

- Reduced human errors – employees would be able to consult operators guide and to locate the right equipment.
- Speed up operations and maintenance – workers can quickly complete their tasks, with an immediate access to instructions, diagrams and other relevant information (i.e. machine history, variables of processes, and documents).
- Reduced or avoided downtime – operators would be able to virtually inspect machineries and facilities, i.e. they can virtually open the electrical cabinet doors and detect errors.

*Source: Schneider Electric. https://www.se.com/au/en/*

### 4.2.4. Group 4: Strategic-fit activities

The *Strategic-fit activities* group includes *Data Communication & Transmission*, *Environmental Monitoring* and *Water Management* activities. These activities are not yet extensively deployed by mining companies, despite the fact that the technologies required are widely known and the obtainable level of value added is strong, enhancing big data applications and environmental management.

- <u>Data Communication & Transmission</u>

*Data Communication & Transmission* activity is necessary during the whole mining process. Mining sites are usually located in remote areas not covered by terrestrial communications, therefore the mines would be completely isolated without *Satellite Communication* technology. As mentioned in paragraph 2.3, this technology has some disadvantages compared to the terrestrial network, therefore the mining companies usually build this infrastructure during the *development* stage. However, it is important to highlight that not all of them do, and, in any case, *Data communication & Transmission* activity remains fundamental for the first two mining stages (*prospecting* and *exploring*) when the companies explore the site, and for collecting information from isolated facilities or resources (such as water basin) during the *development*, *operative* and *closure & reclamation* stages. The automatic and instant collection of data would enable an enhancement of productivity driven by a reduction on time-consuming activities (such as manual data collection from remote and difficult-to-reach sites), faster communication with stakeholder (e.g. suppliers, consultants, and governments), and better and faster management-decision and problem-response processes. As regards as the latter, *Satellite Communication* technology would be useful also in disaster management situations as an instant means of communication and as backup system.

**Case Study 7.**

**Using satellites to connect a remote mining community.**

Newcrest Mining is the biggest gold mining company in Australia and one of the biggest in the world. It operates long life mines in Côte d'Ivoire, Indonesia, Papua New Guinea and Australia. In 2017, Telstra and Newcrest Mining worked together in the Lihir project, a remote gold mine located in Aniolam Island (Papua New Guinea), in order to connect the over 2000 people living and working on the Lihir mine to family and friends around the world, and to enhance productivity and cost savings through digitalization.

Before the partnership, the geostationary (GEO) satellite link that served the mine was unable to provide a reliable and constant connection (download between 6 and 10Mbps). Therefore, the only way to improve it was via a Medium Earth Orbit (MEO) satellite service provided by Telstra in collaboration with O3b Networks. The latter own a constellation of MEO satellites that orbit at 8,062 km above the Earth's equator, almost 30,000km lower than GEO satellite, enabling the reduction of interferences and latency, and the enhancement of connection bandwidth.

As stated by Newcrest's Chief Information Officer Gavin Wood, "Newcrest is very proud to be the first gold miner in the southern hemisphere to make use of this innovative new service to significantly improve the network experience at Lihir. Any mining company claiming it wants to be a leader in the application of digital technologies can't be serious about that, without first delivering quality network connections to their sites, regardless of how remote they are. As well as the ability to deliver better IT and digital solutions to Lihir, the new link will have a tangible effect on the quality of life for our people who live and work on the island".

In conclusion, the adoption of this cost-effective solution improved Newcrest operations through faster and more capable software applications and collaboration tools, and employee morale and quality of life thanks to better connectivity with their family.

- <u>Environmental Monitoring</u>

*Environmental Monitoring* activities are carried out during the last 3 stages of the mining process (*development*, *operation*, and *closure & reclamation*) and for several years after the closure of mines, with the ultimate goal of complying with government policies regarding the environment, reducing community environmental concerns and ensuring natural disaster prevention. In order to do so, both *Satellite Communication* and *Earth Observation* technologies would provide an enhancement of monitoring effectiveness for mining companies. Indeed, according to Inmarsat (2017), 57% of mining sector respondents cited

*Environmental Monitoring* as the most exciting IoT innovation, while the 47% of them identified it as their number one priority for their IoT deployments.

On the one hand mining companies employ *Satellite Communication* technology in combination with terrestrial sensors with the aim to gather information on tailing dam movements and GHGs emissions in a more effective and continuous way, avoiding the need of costly on-site audits. On the other hand, they are able to collect this information directly from satellites through *Earth Observation* technologies. In particular, the Interferometric Synthetic Aperture Radar (InSAR) technique is widely employed for ensuring the drainage and robustness of tailing dams and for monitoring changes. The same technology is utilized for detecting ground deformation that may occur due to resource extraction and may cause damage for communities or the biosphere. As regards the measurement of GHGs emissions, *Earth Observation* technologies have only become available in recent years. Indeed, Sentinel-5P, part of Copernicus constellation of satellites, operational since 2018, is able to detect sulphur dioxide ($SO_2$), ozone ($O_3$), carbon monoxide (CO), nitrogen dioxide ($NO_2$), formaldehyde (HCHO) and methane ($CH_4$), as well as aerosols in the Earth's atmosphere.

Furthermore, satellite imagery has been employed for several years in observing the closure of mines with the aim of ensuring correct rehabilitation.

**Case Study 8.**

**UK Space Agency project homes in on tailings dams**

In 2018 a project led by HR Wallingford and funded by the UK Space Agency's International Partnership Programme aimed at employing the Earth Observation technologies to allow a more effective monitoring of tailing dams in Peru. In particular, the object of the project was to provide to multinational mining companies operating in Peru and to local stakeholders the following benefits:

- Develop a robust monitoring system integrating satellite technologies with in-situ devices;
- Increase the number of continuously monitored dam by 20%;
- Detect 95% of abnormal behaviours of dam;
- Increase by 20% the number of mitigation actions taken for correcting failures;
- Reduce the proportion of toxic leakages by 20%;
- Provide recommendation to the governments for improving the dam regulation.

In order to do so, a consortium of companies and institutions with various capabilities was needed, in particular the project consortium included Telespazio VEGA, Siemens Corporate Technology, Satellite Application Catapult, Oxford Policy Management, the Smith School of Enterprise and the Environment at Oxford University, and the international partners Ciemam SAC, the National Foundation for Hydraulic Engineering (Peru), and the National University of Cajamarca: School of Hydraulic Engineering and Faculty of Engineering.

*Figure 12 – Tailing dam in Peru*

*Source: gov.UK (2018)*

*Source: gov.UK. https://www.gov.uk/government/case-studies/space-based-dam-monitoring*

- <u>Water Management</u>

Water resources are fundamental for the operation of mining sites. Therefore, the forecasted increase in water stress will cause various problems for mining companies. For this reason, mining companies could improve their *Water Management* capabilities employing space-related technologies. In particular, *Earth Observation* technology allows users to locate water resources and to manage them measuring the evaporation, precipitation, surface water level, groundwater, soil mosture and other relevant information in an effective way.

The implementation of *Water Management* activity is strategically important in almost all the mining stages:

- During the *feasibility & planning* and *development* phases, mining companies locate water resources, and plan the activities required to comply with governmental policies.
- In the *operative* stage they need to effectively manage water quantity, quality and timing for empowering the operations.
- In the *closure & reclamation* stage and in the subsequent period, they also need to restore water resources.

# 5. Conclusion

The constant increase of stakeholders' concerns regarding a more sustainable and safe mining business model is negatively affecting its long-term economic and socio-environmental viability. Innovative solutions and technologies can play a pivotal role in addressing these challenges. In particular, the *Satellite Communication*, *Earth Observation* and *GNSS* services supplied by the satellite industry will be increasingly important to the means by which mining companies will conduct business and meet stakeholder expectations. Ten *satellite-enabled activities* have been identified in this report but mining companies will need to take strategic decisions regarding technology development priorities. Starting with information gathered from an analysis of the main characteristics and benefits of each activity, this report proposes a "Satellite-enabled activities" framework aimed at assessing the *readiness of the technology* and the expected *value added*. In particular, the following four categories have been identified:

- *Question mark activities* - characterised by not-yet-mature technology and not-clear value added. *Stakeholder Engagement* activity has been included in this group.
- *Common activities* - based on well-developed and widely available technologies, with only minor value added obtainable by further development. This group includes *Weather Forecasting*, *Site & Logistic Management* and *Design & Survey* activities.
- *Developing activities* - require further technological development through close collaboration between mining, space and other industries. When the solutions will be ready, they will bring strong value added to the companies involved. The main activities in this group are *Unmanned Vehicles & Machineries*, *Mineral Identification*, and *Employee Training, Support and Monitoring.*
- *Strategic-fit activities* - are those in which mining industry needs to focus on to obtain significant value added with low effort. The technology solutions are already developed and the obtainable value added from productivity enhancement and socio-environmental risk reduction is strong. The activities included in this group are *Data Communication & Transmission*, *Environmental Monitoring* and *Water Management.*

Overall, considering the current and prospective factors weighing on the mining industry, it is possible to conclude that *"satellite technologies perfectly fit many of the mining industry's environmental, social and business needs, therefore close collaboration between the mining and space sectors in the development of technologies and services will lead to solid benefits for the players involved"*.

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