ROBOMINERS

ROBOMINERS DELIVERABLE 10.9

DRAFT PLAN FOR SUSTAINABILITY

Summary:
This document identifies the key outputs of the ROBOMINERS project, and possible measures to sustain them on the long run. This is a first draft, that categorises sustainability factors, networks that will benefit from/support the project, and proposes a business canvas to be detailed before the project is completed and uptaken by all partners in their future exploitation of project results.

Authors:

Vitor Correia, European Federation of Geologists
Anita Stein, European Federation of Geologists

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Project Coordinator	Claudio Rossi	Project Coordinator	30.05.2022	[signature]

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1 EXECUTIVE SUMMARY

This document is the first version of the ROBOMINERS Sustainability Plan, and it defines the background framework for the uptake of findings and technological developments/innovations from the project. The detailed, action-oriented (final) Sustainability Plan will be presented by the end of the ROBOMINERS project. The final Sustainability Plan (D10.10) will build on the contextual analysis of market and competition made at this stage, detailing possible pathways to create alliances with the actors from the networks identified and advancing a business model embodied around the strategic management template set out in this document.

At this stage, the project's exploitable assets are of three types:

1) the ROBOMINERS mining robot prototype, capable of operating, navigating, and performing selective mining in an underground environment;
2) a mix of sensors, boring/tunnelling tools, communication and navigation technologies, energy management and control modules tailored to the harsh underground operational environment, but that could be easily adapted/put to use in other operating environments; and
3) a completely new mining ecosystem, encompassing future mine designs and methods alongside unconventional upstream/downstream raw materials processing approaches.

The spread use of mining robots will create a paradigm shift in the mining industry, because robots will have the ability to work in drifts with a (small) size matching the diameter of the robot, without the need for ventilation shafts or drainage tunnels. This would enable mining at bigger depths, of both small and big mineral deposits, and the combined extraction and pre-process of high-grade ores would make mines virtually invisible, overcoming many of the public objections the industry faces today.

This change would probably be gradual, starting with increasing levels of automation (already being adopted by big miners) and moving on to human-robots' collaborative environments. Mining companies working in remote locations, exploiting deep (and/or fragmented ore-bodies) or investing in deep-sea mining would probably be the first adopters of mining robots. In a more distant future, mining robots will also be used in space exploration for extracting raw materials and setting out the infrastructure for human colonisation.

ROBOMINERS sensors and other technological advances can also be easily transposed to robots working in different contexts, such as harmful settings (e.g., radioactive environments or military operations). At this stage, creating alliances and partnerships with research and academic communities interested in investigating potential complementary synergistic effects (from ROBOMINERS) in other research areas is the most effective way to widen the scope of possible funding sources/instruments/tools that could support the continuation of ROBOMINERS research after the current funding period.

There are two primary sources of funding to advance the TRL of the achievements/results of ROBOMINERS (after the end of the project):

- public funding (through calls/tenders made by public research funding organisations/instruments, such as ESA, EIT, EDF and Horizon Europe); and
- private funding (obtained through partnerships with business players/prospect clients).

Whatever the funding source considered, to maximise the chances of successfully getting funds to continue the ROBOMINERS research, the Consortium will use a business-oriented approach considering the contextual (market and competition) analysis, creating a competitive strategy built on project assets and consortium capabilities and knowledge.

2 INTRODUCTION

2.1 Objectives of the ROBOMINERS project

The H2020 Resilient Bio-inspired Modular Robotic Miners (ROBOMINERS) project started in June 2019 and will finish in November 2023. ROBOMINERS is creating a prototype of a bio-inspired, modular, and reconfigurable robot-miner capable of exploiting small and difficult-to-access mineral deposits that are not economical for exploitation by traditional mining methods.

The ROBOMINERS prototype would be capable of operating, navigating, and performing selective mining in an underground environment. The prototype will be placed underground, in or close to the deposits to be mined, via a large diameter borehole. The ROBOMINERS mining ecosystem, containing expected/future mining methods and upstream/downstream raw materials processes is also being created via simulations, modelling, and virtual prototyping. ROBOMINERS will test the prototype's mining ability and resilience under a range of scenarios and demonstrate the new technology's capability to exploit mineral raw materials. The key functions of the robot-miner will be validated to a level of TRL-4.

The technology being developed seeks to become a compelling part of the mining industry of tomorrow, and the overall strategic objective of the ROBOMINERS project is to enable EU access to strategic mineral raw materials from domestic mineral deposits.

2.2 ROBOMINERS follow-up

The ROBOMINERS project set into motion research works that don't stop with the end of the funding period. The creation of the prototype enables additional robotic research works on scalability, resilience, reconfigurability, self-repair, and operation in harsh environments, alongside developments in sensors and artificial intelligence dealing with collective behaviour or selective mining processes, and all the necessary converging and supporting technologies that enable a consistent mining ecosystem (e.g., mine design, ore processing, mill pumping).

The project consortium wants to ensure that achievements and successes are maintained as far as possible, and the ROBOMINERS sustainability plan will be put into action to ensure that crucial work is able to continue, and important achievements are promoted. At this point of the project development (building of the actual prototype being started), foreseen activities that would be significant to continue after the project closure include:

- User evaluation of the ROBOMINERS prototype;
- Refinement of the prototype (adjusting functional requirements, enhancement of sensory input and control output, enhancing power supply);
- Demonstration of the prototype in (close to) real-life situations;
- Enhancement of sensing/communication/environment mapping capabilities;
- Reinforcement of security and reliability;
- Facilitation of human-robot collaboration;
- Cost and design optimisations (materials and assembly optimisation –processors, memory, sensors, motors, tools, etc.).

Naturally, all these tasks are already being considered in the project development. However, the continuation of the work after the H2020 funding period would require additional funding and backing, and this document outlines supporting factors for advancing the ROBOMINERS prototype and concept, prospect partners and networks that will benefit from/support the project, and the business approach that would be used to seek funding from institutional funds or venture capital.

3 ROBOMINERS' SUPPORTING FACTORS

The interest in mobile robotics has increased continuously since the creation of Shakey, the world's first mobile robot, at the Stanford Center for Artificial Intelligence in 1966. In the 70s, robotics began to expand beyond industrial manufacture and science fiction oddity with the level of intelligence and ability we take for granted today, and reached a milestone in 1993, with an 8-legged robot named Dante. Dante was created at Carnegie University, and it could explore volcanic environments, firmly establishing the use of robots in the exploration of potentially harmful environments (Reach Robotics, 2018).

Mining is a dangerous industry, with a high number of fatalities and injuries, where people use heavy equipment in confined spaces, often with poor ventilation, high temperatures, water inrushes and sometimes explosive atmospheres. For this reason, the mining industry has a very high potential for the adoption of robots. Today, the industry is already using driverless haul trucks and automated drill rigs in opencast mines, and robots capable of working underground and underwater are being developed for inspection and testing.

Furthermore, as technology advances, mining robots have the potential to extract minerals from bigger depths in the Earth's crust, in harmful environments for humans (because of high temperatures and rock stress), which makes mining works highly expensive (because of safety and engineering requirements). By using robots, engineers and geologists can also create a paradigm shift in underground mining since the dimension of galleries can be reduced to the diameter of the robot, and there's no need to create ventilation shafts or drainage tunnels. This is a shift being initiated by ROBOMINERS, which will affect mine design and, more crucially, mining costs.

In this future vision, mines would become virtually invisible, since robots will work at big depths, excavating galleries with a size that fits precisely the mineralised areas of a ore-body, minimising the excavation of waste rock, and sending to the surface a high-grade, pre-processed, ore. As a result, the mining robots will save lives, boost productivity, and help the mining industry explore new frontiers for new mineral extraction opportunities.

3.1 Harmful environments

The definition of hazardous is involving or exposing one to risk (as of loss or harm)[1]. Examples of hazardous environments include nuclear reactors, outside the Earth's atmosphere and behind enemy lines in war. ROBOMINERS' capacity to excavate tunnels and work in harsh environments, using sensors and artificial intelligence to find, select and process minerals brings forward advances that could be uptaken and used in hazardous contexts.

3.1.1 Space exploration

In space, robots have been used as rovers that travel to distant planets and take data from their surroundings. NASA's Mars 2020, designed to seek signs of ancient life and collect rock and regolith samples for a possible return to Earth, is the ongoing most sophisticated space mission. The mission uses the rover Perseverance, a car-sized rover designed to explore the Jezero crater. In September 2021, NASA's Perseverance Mars rover successfully collected its first pair of rock samples (Figure 1). After collecting its first sample, named "Montdenier," on 6 September, the rover collected a second sample, called "Montagnac," two days later[2]. These core samples are ~6 cm long with volumes of ~8.5 cm^3 and

[1] https://www.merriam-webster.com/dictionary/hazardous
[2] https://mars.nasa.gov/news/9036/nasas-perseverance-rover-collects-puzzle-pieces-of-mars-history/

were imaged with CacheCam, a photographic camera using a 20-megapixel CMOS detector mounted inside the rover underbelly. The composition, mineralogy, and texture of the sampled rock outcrop, named "Rochette", were determined by a combination of instrument data, including SuperCam/LIBS, PIXL, SHERLOC, and the close-up cameras WATSON/ACI (Autofocus Context Imager) and PIXL/MCC (Micro Context Camera) on the abraded surfaces. According to Simon *et al*. (2022), "Rochette is holocrystalline with no intergranular porosity or evidence of cement. From elemental PIXL and SuperCAM/LIBS data, the 0.2-0.5 mm, intergrown light and dark minerals are pyroxene and plagioclase consistent in composition and texture with a basalt (or microgabbro). Secondary features include brown iron-rich patches, especially evident around white patches that may reflect cavities filled by secondary minerals such as Ca-sulphate (occasionally hydrated) and phosphate". SHERLOC also identified carbonate and amorphous silicates along with several types of aromatic organic signals.

Figure 1: Rock nicknamed *Rochette* after Perseverance sampling: The image, taken by NASA's Perseverance rover, shows two holes where the rover's drill obtained chalk-size samples. Credits: NASA/JPL-Caltech via < https://www.jpl.nasa.gov/images/pia24840-rochette-after-perseverance-sampling>.

ROBOMINERS uses a more comprehensive set of analytical mineralogical tools, included in a segment designed as an on-board lab that can communicate with other body parts of the robot, and that can be attached/detached as a part of the body of the robot as needed for real-time in-stream slurry characterisation as a kind of "digestive mineralogy". This segment uses state-of-the-art analytic techniques (encompassing high sensitivity solid-state XRF spectrometer / LIBS spectrometer, Gamma-Ray spectrometer, and combinations of optical UV-VIR-NIR techniques, such as Resonance UV Raman spectroscopy, time-resolved VIS Raman spectroscopy, NIR absorption spectroscopy and LINF spectroscopy).

This might be uptaken by space missions, enabling an initial screening of the rock's chemical/mineralogical composition, that could be relevant for sample selection or enhanced geological exploration. It must be highlighted that there are several space missions collecting rock samples: e.g., NASA's OSIRIS-REx mission — due to return to Earth in 2023 — collected a small amount of material from the asteroid Bennu (Gilbert, 2021); in December 2020, Japan returned a sample of the asteroid

Ryugu with the Hayabusa2 spacecraft[3]; on the same month China's Chang'e 5 mission[4] returned the first lunar samples since the 1970s.

3.1.2 Radioactive environments

In 1986, the Chornobyl nuclear disaster boosted robotics technology development in the USSR and abroad. Several robots were designed to advance cleaning (decontamination) works in the Chornobyl Nuclear Power Plant buildings, in conditions where the levels of radiation excluded the presence of people. But the high radiation levels affected radio communications, battery performance and control modules. Most robots tested/used turned out to be unsuitable for work in an environment with strong radiation fields.

The robots that stood to the test for some days were: the Soviet STR-1, which was operated at gamma-background levels of up to 3000 Roentgens per hour, and in some places, up to 10,000 roentgen per hour (Figure 2); the remotely operated Japanese amphibious bulldozer Komatsu D155W; and the German MF-2 robot (Bogatchev *et al*., 2001). Unfortunately, all these robots quickly lost their ability to work because of the high radiation levels, and the Soviet Union ultimately turned to "biorobots" (humans), as officials referred to them (Chernobyl X, 2021).

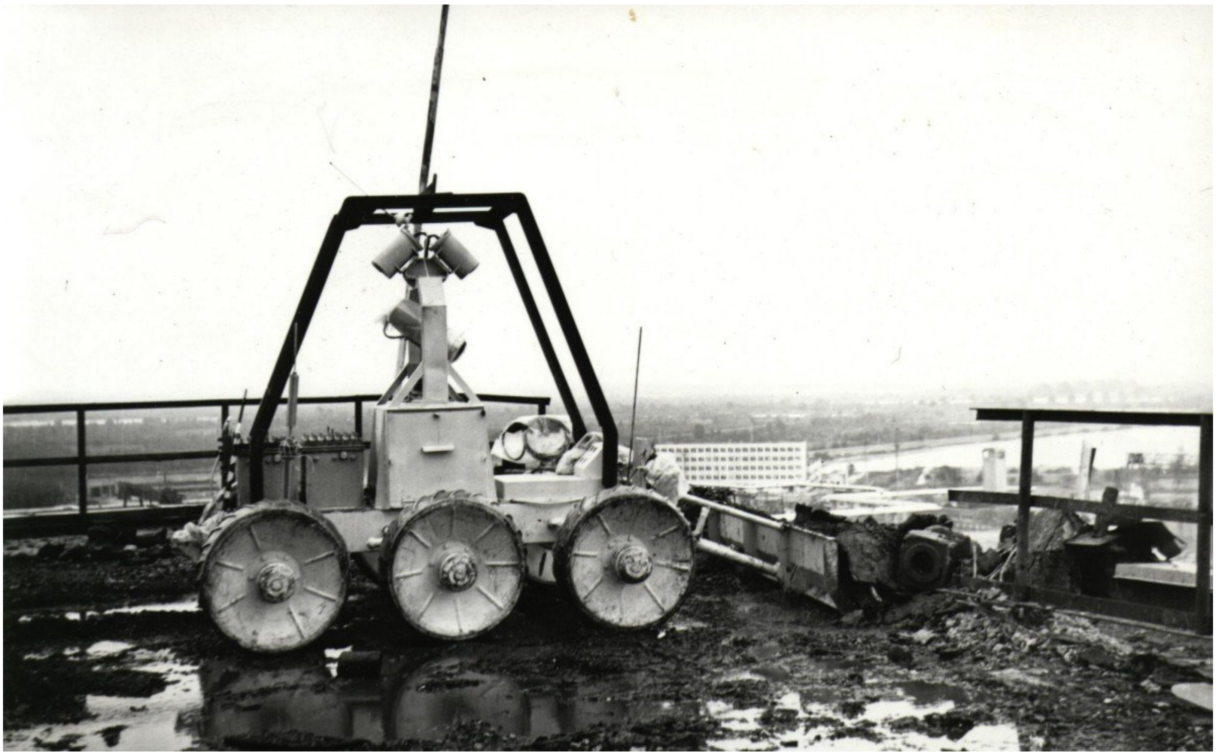

Figure 2: Soviet robot STR-1, photographed on the on the roof of the Chernobyl power plant, circa August 1986. Credits: VNII Transmash, via <http://www.rovercompany.ru/News/image/Str_1.jpg>.

[3] https://solarsystem.nasa.gov/missions/hayabusa-2/in-depth/#:~:text=Hayabusa2%20is%20a%20Japanese%20spacecraft%20that%20explored%20asteroid%20Ryugu%20(162173,to%20collect%20samples%20from%20Ryugu

[4] https://www.planetary.org/space-missions/change-5

The Fukushima nuclear accident in 2011 created both a market and a testbed for ever-advancing robot technologies designed to operate in hazardous conditions in the months and years that followed. After the accident, remote-controlled front-end loaders, backhoes, and other heavy equipment were put to work to break up radioactive debris and load it onto remote-controlled dump trucks. A four-legged walking robot investigated the reactor buildings. Robots with 3-D scanners were sent in to gather imagery and map radiation levels. Swimming robots inspected pools where spent fuel rods were stored, taking pictures. But none of these robots could penetrate the innermost areas of the reactors because debris tripped them up, yard-thick concrete walls blocked wireless signals, and radiation fouled up their microprocessors and camera components (Betser, 2018). Hence, in August 2013, the Japanese government assembled a consortium of public utilities and private companies, including Mitsubishi, Hitachi, and Toshiba, to create robots specifically for the most challenging environments. Finally, in 2017, the consortium successfully tested Mini-Manbo (Figure 3) a robot made of radiation-hardened materials with a sensor to help it avoid dangerous hot spots in Fukushima's flooded reactor buildings. After three days of carefully navigating through a shattered reactor building, Mini-Manbo reached the heavily damaged Unit 3 reactor and beamed back video of a gaping hole at the bottom of the reactor and, on the floor beneath it, clumps of what looked like solidified lava: the first images ever taken of the plant's melted uranium fuel (Fackler, 2017).

Figure 3: Mini-Manbo (meaning "little sunfish") at a demonstration in Yokosuka, Japan. It succeeded where previous robots had failed, manoeuvring around debris and avoiding excess radiation to locate the uranium fuel spilled at Fukushima plant. Credits: Ko Sasaki for The New York Times via <https://www.nytimes.com/2017/11/19/science/japan-fukushima-nuclear-meltdown-fuel.html>.

ROBOMINERS' ability to excavate rocks/take samples and navigation capacity might be helpful in dry and wet (underwater) radioactive environments, where a robot has to deploy sensors, sampling payloads, map the environment in 3D, and cut and retrieve samples of structural materials.

3.1.3 Military operations

Robots provide diverse capabilities across the range of military operations: environmental sensing and battle-space awareness; chemical, biological, radiological, and nuclear (CBRN) detection; counter-improvised explosive device capabilities; port security; precision targeting; and precision strike (Pradhan, 2012).

Unmanned aircraft systems (UAS) or Unmanned Aerial Vehicles (UAVs) have experienced explosive growth and have proved to be an invaluable force multiplier. UAS can provide both a persistent and highly capable intelligence, surveillance, and reconnaissance (ISR) platform to troops requiring a look "beyond the next hill" in the field or "around the next block" in congested urban environments and, if necessary, also assist troops in contact or perform strike missions against high value opportunity targets (Pradhan, 2012). The term "drone" became mainstream when General Atomics' hulking MQ-1 Predator and MQ-9 Reaper drones caught on in US wars in Afghanistan and Iraq. By 2011, the US military had an estimated 11 000 of these drones (Shankland, 2022). Rarely, however, have drones played the role they're taking on in the asymmetric war between Ukraine's low-budget forces and Russia's colossal military power. Miniaturisation has improved the cost, flight time and range of commercial drones and military, and Ukrainians have used both types successfully against Russian armoured vehicles that can cost millions of dollars.

The drones that have changed the complexion of war from the sky are being replicated at sea, as the United States, United Kingdom, China and Russia develop and deploy unmanned underwater vessels (UUV) to gain a strategic edge in the Pacific and beyond (Honrada, 2022; Figure 4). Underwater drones are being used for bathymetric mapping, alongside recording the thermal, magnetic, and acoustic properties of specific underwater passages to find blind spots where submarines can travel undetected safely. They can also potentially be used for mine-hunting and minelaying operations. They may reduce, but not eliminate, the need for specialized diver teams to investigate, identify, and demine potential landing beaches for amphibious warfare operations, and, more significantly, underwater drones can become strategic weapons when loaded with nuclear weapons (Honrada, 2022). Such nuclear-armed underwater drones can bypass enemy missile defences by travelling underwater, slipping near or into major coastal cities, ports and naval bases for attack purposes.

Figure 4: China's HSU-001 unmanned underwater vehicle can recognise, follow and attack an enemy submarine without human instruction. Credits: Getty for AFP, via <https://asiatimes.com/2022/01/underwater-drones-herald-sea-change-in-pacific-warfare/>.

Sales of military drones are expected to increase about 7% per year, to $18 billion in 2026, up from $13 billion in 2021, according to the Business Research Company (2022), and ROBOMINERS' navigation capacity (in slurries, using probabilistic navigation algorithms and sensor fusion) and ability to move underwater, over surfaces and in flooded environments might be relevant for military purposes.

3.2 Increasing work productivity

Driving the increase in public interest in robotics and automation is both a fascination with the potential of these technologies to change the way we live and work and a fear of their impact on jobs. This fear is tied into broader geo-political and social shifts driven by trade policy and immigration issues that contribute to a sense of insecurity about the employment prospects of current and future generations.

Robots improve productivity when applied to tasks that they perform more efficiently and to a higher and more consistent level of quality than humans (IFR, 2018). A study from the McKinsey Global Institute (2017) found that investment in robots contributed 10% of growth in GDP per capita in OECD countries from 1993 to 2016. The same study found that a one-unit increase in robotics density (which McKinsey defines as the number of robots per million hours worked) is associated with a 0.04% increase in labour productivity. Looking ahead, the McKinsey Global Institute (2017) predicts that up to half of the total productivity growth needed to ensure a 2.8% growth in GDP over the next 50 years will be driven by automation.

3.2.1 Automation

As figures from the International Federation of Robotics show (IFR, 2021), demand for industrial robots has risen considerably since 2010 due to the ongoing trend towards automation and continued technological innovation in industrial robotics. Between 2005 and 2008, the average annual number of robots sold was about 115,000 units, before the global economic and financial crisis caused robot installations to fall to just 60,000 units in 2009, with lots of investments being postponed. In 2010, investments increased and drove robot installations up to 120,000 units. By 2015, annual installations had more than doubled to almost 254,000 units. In 2016, the 300,000 installations per year mark was exceeded, and in 2017, installations surged to almost 400,000 units. The 400,000 units per year mark was crossed for the first time in 2018, but the trade conflict between China and the United States caused a drop of 10% in installations in 2019, reflecting the difficult times the two main customer industries, automotive and electrical/electronics, experienced. In 2020, robot installations grew again to 383,545 units, making 2020 the third most successful year for the robotics industry, despite the Covid-19 pandemic (Figure 5).

According to Ralf Völlinger (2021), Covid-19 put tried-and-tested production methods and supply chains to the test, where fluctuations in demand made it necessary to adjust production volumes quickly. Moreover, the need to protect employees from infection required new shift models, while the adoption of minimum working distances in factories created numerous challenges for the manufacturing environment. To cope with these demands, many manufacturers decided to implement industrial robots. The industry has seen not only large companies continue to automate, but lots of small and medium-sized enterprises, many of which were looking to implement robots for the first time. For example, companies from the pharmaceutical sector have been deploying robotic automation to help produce Covid-19 tests and aid the fight against the pandemic, while the food industry has seen an upturn in demand for home cooking ingredients and associated products. Robots have helped many food plants to combat extremely high supply chain demand in what is a very labour-intensive sector. With production becoming ever-more interconnected, new efficiency gains in the manufacturing industry are looming, made possible through process monitoring and preventive maintenance, for example. However, reliability and service availability, including the use of remote service tools, will become progressively more important. In an increasingly competitive environment, the industry will see a big upturn in the take up of robotic automation due to its inherent flexibility and ease of use (Völlinger, 2021).

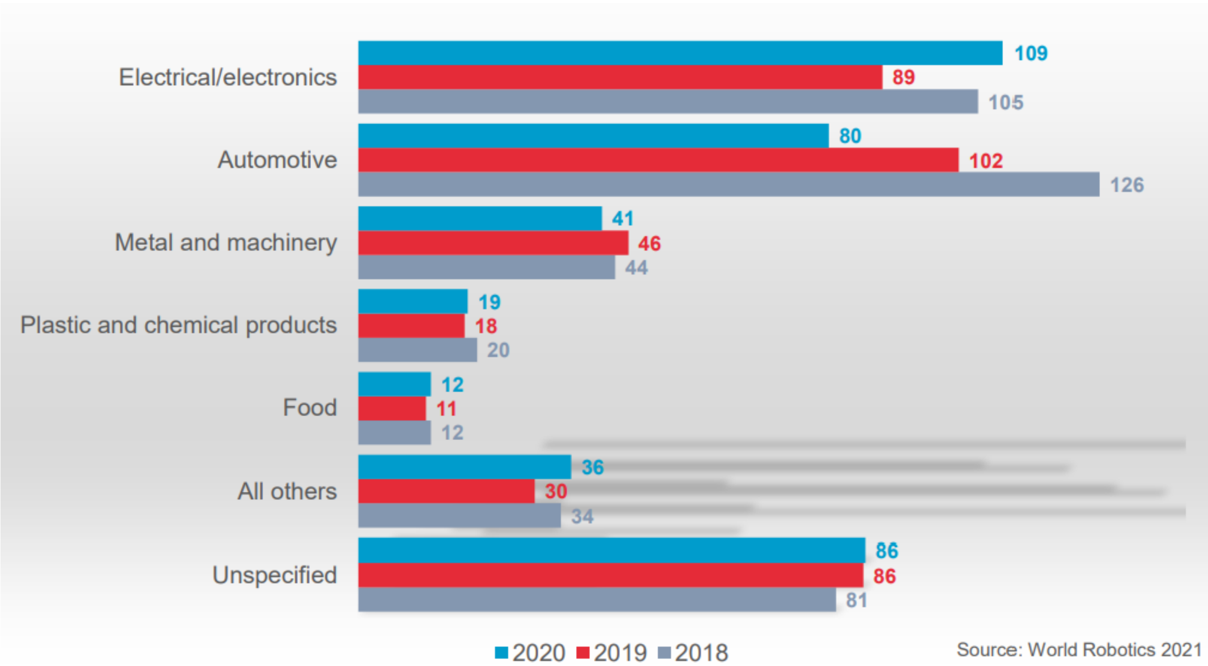

Figure 5: Annual installations (world) of industrial robots by customer industry (x 1,000 units) in the period 2018-2020. Credits: International Federation of Robotics, via < https://ifr.org/ifr-press-releases/news/robot-sales-rise-again>.

It should be pointed out that, in the mining industry, Australia's largest miners started the journey towards automation more ten years ago, and that one of the main challenges they face is developing the necessary skills within their workforces by reskilling or upskilling (Correia *et al*., 2021).

ROBOMINERS' mining ecosystem and the robot autonomy, modularity, configurability, selective mining ability, resilience and strength under a range of operating scenarios, including simulated malfunctions, are laying down the foundations for the automation of underground mining.

3.2.2 Complementing human labour

Robots substitute labour activities but cannot replace most jobs since less than 10% of jobs are fully automatable (Walker, 2019). Increasingly, robots are used to complement and augment labour activities.

The International Federation of Robotics recognises two main groups of robots (IFR, 2021): industrial robots used in automation in an industrial environment and service robots for domestic and professional use. Service robots are considered collaborative robots, also known as cobots, as they are intended to work alongside humans. Industrial robots have traditionally worked separately from humans behind fences or other protective barriers, but cobots remove that separation.

Cobots are now opening up new fields of application working alongside humans in a safe environment. Demand is also increasing because cobots can be installed directly in the current production system, with less space than conventional robots (Völlinger, 2021). Equipped with intelligent features such as vision and force sensors, the flexibility of cobots means they can perform tasks like palletising, parts handling, assembly, bin picking and arc welding. Manufacturers adopting cobots, particularly those featuring vision and inspection systems, are not only seeing an increase in quality and efficiency but a reduction in the requirement for personnel to work in close proximity to one another.

According to Ralf Völlinger (2021), FANUC's latest collaborative lightweight robot, CRX, in 2020 helped numerous companies to start automating their production in areas never seen before (Figure 6). With CRX, a standard tablet PC hosts icon-based programming that gives a familiar feel to the programmer, making the cobot particularly suitable for first-time robot users. At the same time, the reliability and durability of a cobot are just as important as a standard industrial robot, which is why CRX provides an assurance of maintenance-free operation for a minimum of eight years. Manufacturers require high versatility from their automation due to unforeseen market demands, so the capability to use the CRX in highspeed, non-collaborative mode is also proving very popular (Völlinger, 2021).

There is a clear trend toward flexibility in user interfaces; interfaces that allow simple icon-driven programming and the manual guidance of robots, while not limiting the robot to more complicated applications by programming in a proprietary language, have more demand (Völlinger, 2021). This versatility is helping manufacturers to understand the full power of robot programming and the required levels of integration.

Although simple robot programming helps manufacturers to compensate for skills shortages, it remains necessary to train workers in robot programming and thus help maximise the return on automation investments. Some robot manufacturers are already actively contributing to education and training in the field of robot programming (Robotics 24/7, 2021).

The ROBOMINERS mining ecosystem does not consider coexistence with humans working alongside the robot miner, nor sequential collaboration between the robot and humans. But cooperation and responsive collaboration between the robot and human workers will be embedded in the system, especially for validation of exploration data and geologic models.

Figure 6: FANUC CRX cobot ("FANUC timeline programming" is shown on the screen of TP). Credits: International Federation of Robotics, via <https://ifr.org/img/worldrobotics/Editorial_WR_Industrial_Robots_2021.pdf>.

3.3 Exploring new frontiers for mining

In a world of deeper mines, more complex ore bodies, rising energy costs, increasing social and geopolitical risks, skill shortages and resource nationalism, mining companies remain under exceptional pressure to control costs and improve efficiency. To turn this context of poor productivity and hostile sentiment, the mining industry started to actively explore innovations (Deloitte, 2014).

The technologies already being uptaken by the industry include autonomous vehicles, automated drilling and tunnel-boring systems, drones and smart sensors. These technologies enable higher levels of productivity and lower personnel costs, but the fundamental relationships underpinning the social license of mining companies to operate are becoming increasingly strained due to the downward labour pressures associated with automation.

This combined effect is pushing away the mining industry to remote operating environments, smaller and deeper deposits, deep sea, and space mining.

3.3.1 Remote locations

By definition, remote mining locations are far from the nearest road or port and power grid, often in sparsely populated or inhabited regions. Examples of such areas include the Amazon forests, the Northern arctic areas, the Australian bush and the Siberian plains.

Mining in remote areas usually has strong and negative impacts on local natural ecosystems and on the existing communities and people who live nearby or use local resources. For the industry, the typical challenges include setting up the necessary infrastructure, managing the workforce employed at remote mine sites, dealing with logistical and transport problems and preventing adverse environmental impacts (Figure 7).

Figure 7: The Diavik diamond mine, shown here in February 2015, is located on a small island in Lac de Gras, approximately 300 km northeast of Yellowknife and 220 km south of the Arctic Circle, in a remote region of Canada’s Northwest Territories. Fuel, equipment, and supplies are brought by large trucks to the mine through the 400km long arctic ice road (which opens briefly every year, typically in

February and March). Credits: Diavik Diamond Mine via https://www.gia.edu/gems-gemology/summer-2016-diamonds-canadian-arctic-diavik-mine>.

There are five benefits of ROBOMINERS that makes its technology particularly attractive for mining in remote locations (in comparison with conventional underground mining):

1. No personnel in the mine,
2. Reduction of necessary groundworks and access routes both on the surface and underground,
3. No dewatering costs and associated environmental impacts,
4. Less waste, so that the cost of removing and managing waste rocks is minimal,
5. Cheaper capital cost than an underground mine, quicker set up and closure.

3.3.2 Deeper, fragmented deposits

Typically, modern underground mines have drifts with a minimum of 3m high and 4m wide, since they're made according to human scale, and this is the minimum size required to have loaders and trucks operating underground. Although suitable for some types of ore deposits, such as volcanogenic massive sulphides, this is a significant shortcoming when the ore is in veins or layers, with thicknesses of just 20 or 30 centimetres, generating vast amounts of waste rock that needs to be extracted, processed, and stored/discarded, at huge costs. This is why cut-off grades affect the economics of mining and often prevent the extraction of deeper sections of mineral deposits (only feasible for high-value metals).

According to Mining Technology (2019), the world's deepest mine from ground level is Mponeng, in South Africa. This gold mine reaches a depth of about 4 km, and the mineralised gold reef consists of, on average, a 20cm thick, tabular auriferous quartz pebble conglomerate. Over 5400 metric tonnes of rock are excavated from Mponeng each day to extract the tabular reef, with gold grades at over 8g/t.

Work conditions of the 4,000 workers that descend into the mine each day are challenging (Figure 8); the trip from the surface to the bottom of the mine takes over an hour, and the temperature of the rock at the lowest levels reaches 66 °C. To cool down the air to below 30 °C, the mine pumps 5,000 tons of ice slurry underground each day, causing humidity levels to reach 95%. Seismic events often cause rock bursts and collapses, interrupting mining operations (Hart, 2013). According to NS Energy (n.d.), in March 2020 production from the mine was halted due to a seismic event that killed three miners approximately 3.5km below the surface. Although the mine resumed operations running at 50% capacity in April 2020, the production was again halted after several positive COVID-19 cases were reported in May 2020.

Advancing the ROBOMINERS vision encompasses the creation of a completely new mining ecosystem, where the mine design is in line with the deposit characteristics and the robot requirements, including power supply, drilling methods and paths for slurry transport to the surface. This would change the economics of mining, making the extraction of small and difficult to reach (deep) mineral deposits economically feasible. Mponeng perfectly illustrates how challenging deep mining is, and the many advantages of using robotic miners in such environments.

Figure 8: Drilling works at Mponeng mine. Credits: Graeme Williams/The New York Times/Redux, via <https://www.wsj.com/articles/SB10001424052702304854804579236640793042718>.

3.3.3 Deep sea mining

The world's first deep-sea mining robots were built by Soil Machine Dynamics—a UK firm known for providing construction equipment for laying undersea cables, servicing offshore oil platforms, and other heavy-duty, deep-sea jobs. The robots were delivered to Nautilus Minerals, a Toronto based mining company, in 2012. Still, its deployment to mine the rich deposits of gold, copper, and silver that are found 1,600m into the Bismarck Sea (in the vicinity of Papua New Guinea) was put on hold due to a dispute between the Papua New Guinean government and Nautilus (Javelosa, 2016).

According to David Hambling (2018) the main robots were a pair of tractor-trailer-size excavators. One used 4-meter-wide counterrotating heads studded with tungsten carbide picks to chew through the metal-rich chimneys that form around super-hot water spewing from sulphurous vents on the seafloor. The other added strength using a studded drum that was 2.5m in diameter and 4m wide to pulverize rock walls. A third robot would feed a slurry of crushed rock and water up a pipe dangling from the production vessel. There the water would be wrung out from the ore, which will be loaded on another ship and carried to China for processing.

Nautilus project was plagued with community opposition and financial setbacks, and in 2019 the company filed for protection from its debts in a Canadian Court. The company tried to restructure, but it failed to find any buyers for its assets. In August 2019, court approval was obtained for creditors to liquidate the company (Stutt, 2019).

Seabed mining has many critics, including environmentalist David Attenborough, who claim that seabed mining is untested and has a largely unknown environmental impact. Google, BMW, AB Volvo, Renault and Samsung SDI have backed a call for a moratorium on deep-sea mining (WWF, 2021).

Figure 9: the three Nautilus Minerals robots, built by SMD. Credits: Nautilus Minerals, via <https://www.theguardian.com/world/2019/sep/16/collapse-of-png-deep-sea-mining-venture-sparks-calls-for-moratorium>.

On 8 September 2021, the Congress of the International Union for Conservation of Nature (IUCN) voted overwhelmingly in favour of a moratorium on deep-sea mining. In total, 81 governments and government agencies voted in favour of the IUCN moratorium motion, and 18 voted against it. Of the European participants, government agencies or ministries of Italy, Sweden, Spain, Germany, Austria, Italy, Portugal and Romania all voted yes. Norway and Belgium were in the minority in rejecting the motion. According to the Seas at Risk NGO (2021), the negative votes from Norway and Belgium were unsurprising. Norway is seeking to safeguard its plans for deep-sea mining on its continental shelf, while the Belgian vote reflects Belgium's sponsorship of an exploration contract in the Pacific held by Global Sea Mineral Resources (GSR, a Belgian company) and the assertion that deep-sea mining can be sustainable.

Also on 8 September 2021, the European Commission published its 2021 Strategic Foresight Report, announcing plans to step-up deep-sea mining exploration. The Commission's perspective was backed by the EU Parliament, which adopted on 24 November a resolution addressing the topic of deep seabed mining that states that commercial deep seabed mining activity should be allowed to commence when there is proof that the technologies and operational practices 'do no serious harm to the environment'.

GSR owns a 25-tonne seabed mining robot named Patania II, developed by the Dutch company Seatools to collect potato-sized nodules rich in cobalt and other battery metals that pepper the seabed in the Clarion Clipperton Zone (Deme Group, 2021), an expanse of ocean between Hawaii and Mexico that’s as big as the continental US.

Figure 10: Patania II was tested at depths of around 4,500m in the Clarion-Clipperton Zone. Credits: Global Sea Mineral Resources, via https://www.seatools.com/projects/subsea-mining-vehicle-patania-ii/.

In February 2022 GSR got a mineral exploration license within the Cook Islands exclusive economic zone (SBMA, 2022). The company claims that seabed mining can be a trustworthy source of the primary metals needed for the clean energy transition, and if exploration works are successful will apply for a mining lease.

The oil and gas sector must also be mentioned. Offshore operations have been under greater scrutiny (particularly after the Deepwater Horizon oil rig explosion and oil spill in the Gulf of Mexico in 2010), and the industry is constantly looking for new technological innovations to increase productivity and minimise costs and risks. For this reason, the oil and gas sector demand for robots capable of performing monitoring and inspections of physical underwater infrastructures has been rising. A report from Grand View Research (2018) predicts the growth of the oil and gas market segment for Autonomous Underwater Vehicles at a compound annual growth rate of 13.5% from 2018 to 2025, reaching USD 6.74 billion by 2025.

Summing up, selective real-time mining ability, locomotion, communication, navigation, power density and reliability, coupling systems and adaptative behaviour are some of the ROBOMINERS robot features that could be transposable for seabed mining and oil and gas operations.

4 RELEVANT INSTITUTIONS AND NETWORKS FOR THE UPTAKE OF ROBOMINERS

The uptake of ROBOMINERS results and its sustainable development depends on more than project results. It is also fundamentally linked to the earliest development of connections and solid partnerships with relevant stakeholders or networks that could build upon project outputs after the H2020 funding period. This includes the research/academic circles and networks, alongside business communities and decision-makers managing public research funding.

4.1 Research and academic communities

Europe is a main player in robotics: it has nurtured a large community of researchers, educated many thousand students, created large and small companies, and established advanced facilities for conducting scientific research and contributing to technological innovation. For this reason, since the start of ROBOMINERS, clustering activities have been regularly performed to identify ongoing research projects that are similar or complementary to ROBOMINERS (i.e. developing similar technologies or facing similar challenges), aiming to foster the exchange of experiences, work towards shared solutions and the creation of synergetic effects and reduction of unnecessary duplication in research and development[5].

The identification of related research projects is based on desk research, later screened and validated by consortium partners, and commonly the clustering actions are materialised in joint workshops, where different projects/research organisations share results, existing challenges and experiences. So far, the Consortium has identified more than 100 ongoing European research projects dealing with robotics or with by-processes (e.g. new mining tools) relevant to ROBOMINERS (of the more than 500 ongoing robotics projects listed in the EU portal of the Community Research and Development Information Service - CORDIS).

Most of the identified research projects are funded by the European Space Agency (ESA), the European Institute of Innovation and Technology (EIT) and the EU research programme H2020. The list of the linked institutions (to the projects identified within work package 8) comprises 53 universities and more than 80 industrial partners – active as consortium partners and/or as suppliers of equipment for these projects.

Despite the innovation competition between organisations seeking research grants, most participants attending the workshops organised by ROBOMINERS highlighted potential synergies and interest in cooperating with the project in the fields of:

1. Mining automation,
2. Communication and cooperative behaviour of robots,
3. Energy supply and robot autonomy,
4. Real-time condition monitoring,
5. Work in harmful environments,
6. Real-time collection of geological data.

[5] Clustering activities are being developed under work package 8. For more information see https://robominers.eu/media-corner/.

Alongside the 53 universities/research centres identified for clustering within ROBOMINERS, it is important to point out three European research networking initiatives in the field of robotics, created with EU funds, that might be relevant for the uptake of results from ROBOMINERS (text box below): the European Robotics Research Network (EURON), the European Coordination Hub for Open Robotics Development (ECHORD), and the Robotics Digital Innovation Hub of Europe (ROBOTUNION).

Another relevant European association in the field of robotics is euRobotics[6]. euRobotics grew out of the European Robotics Technology Platform (EUROP) and the academic network EURON, with the support of the euRobotics coordination action funded by the European Commission. euRobotics was founded in September 2012 to strengthen Europe's competitiveness and ensure the industrial leadership of manufacturers, providers, and end-users of robotics technology-based systems and services. With more than 250 member organisations, euRobotics also provides to the European robotics community a route to engaging in SPARC, a public/private partnership with the European Commission (see section 4.2).

There are two academic associations relevant to the uptake of ROBOMINERS results in the geosciences field: the International Union of Geological Sciences (IUGS) and the European Geosciences Union (EGU).

The IUGS was founded in 1961. It has 121 national members, representing over a million geoscientists, and is one of the World's largest scientific organisations. It encourages international co-operation and participation in the Earth sciences in relation to human welfare. IUGS works through topic specific Commissions, Task Groups, and Initiatives as well as Joint Programmes with other organisations, that are concerned with a wide range of geologic research of direct interest to governments, industry, and academic groups within the Earth sciences. It must be pointed out that the IUGS Secretariat is located in Beijing (China) and is financially supported by the Government of China.

EURON was founded in 2000, with support from the Fifth Framework Programme of the European Commission. The goal of the network was to stimulate and promote research, education and technology transfer of robotics in Europe. EURON had 230 members in 27 countries as of August 2011. These members were all basic and applied research centres in robotics from universities, technology transfer institutes (such as the German Fraunhofer Gesellschaft), national research networks (such as the French National Centre for Scientific Research), and companies (such as ABB or KUKA). EURON also served as a central contact point to the European Commission, mainly to prepare roadmaps and facilitate the access to funding proposals for its members in the area of robotics research.

ECHORD was created in 2009 and installed as an incubator to drive innovation by facilitating the cooperation between academia and industry. The Seventh Framework Programme of the European Commission provided additional funds to this endeavour (renamed ECHORD++), with the aim of promoting the interaction between robot manufacturers, researchers and users.

ROBOTUNION was an acceleration programme funded by H2020, bringing together a team of accelerators, investors, business platforms, research & technological centres and corporations in the robotics startup ecosystem. The programme launched two open calls, and the top 20 startups joined a 16-months acceleration programme to help them progress from TRL4 to TRL7 onwards. ROBOTUNION provided funds alongside technical and non-technical support services.

[6] See https://www.eu-robotics.net/.

The European Geosciences Union (EGU) is a non-profit international union in the fields of Earth, planetary, and space sciences whose vision is to "realise a sustainable and just future for humanity and for the planet." The organisation has headquarters in Munich (Germany). Membership is open to individuals who are professionally engaged in or associated with these fields and related studies, including students and retired seniors. EGU most prominent event is its General Assembly, an annual conference in Vienna that brings together over 15,000 scientists from all over the world.

4.2 Business communities

The most relevant European industry association in the field of robotics is the International Federation of Robotics (IFR)[7]. The IFR was established in Germany as a non-profit organization in 1987. Its 75 members from more than 20 countries come from the robotics industry, national or international industry associations and research & development institutes. The IFR sponsors the International Symposium on Robotics, a conference on industrial and service robotics that brings together researchers and engineers from around the globe to present their pioneering works. Each symposium is organized by a national industry robot association either in America, Europe, or Asia and takes place in conjunction with an international robot exhibition.

Another relevant industry association in Europe is EUnited, the European Engineering Industries Association. EUnited connects machinery and equipment companies in one association to improve awareness and understanding among decision-makers and policy actors in the European Union. EUnited Robotics is a sector of the EUnited association, serving the robotics industry in Europe. Its members are robot manufacturers, component suppliers, and system integrators, creating a network of industry leaders. EUnited Robotics aims to develop, advocate, and communicate topics of industrial relevance to support its members, expand Europe's competitive edge and boost its global economic standing. EUnited Robotics communicates industry's perspective on relevant EU policies and funding issues. And it also serves as a liaison between key industry players and the European Commission.

Since 2013, the above mentioned euRobotics association (see section 4.1) provides to the European robotics community a route to engaging in SPARC, a public/private partnership with the European Commission. SPARC is the largest research and innovation programme in civilian robotics in the world, with 700 million euros in funding from the European Commission between 2014 to 2020, which is tripled by European industry to yield a total investment of 2.1 billion euros. SPARC was designed to stimulate the robotics community and foster research/industry collaboration to develop technical transfer and commercial exploitation successfully.

More recently, on May 2021, the AI, Data and Robotics Association (ADRA)[8], a non-profit organisation aiming to deliver the greatest benefit to Europe from AI, Data and Robotics, was founded by euRobotics, the Big Data Value Association (BDVA), the Confederation of Laboratories for Artificial Intelligence Research in Europe (CLAIRE), the European Laboratory for Learning and Intelligent System (ELLIS), and the European Association for Artificial Intelligence (EurAI).

A relevant EU industry organisation in the metals mining domain is the European Association of Mining Industries, Metal Ores & Industrial Minerals (Euromines). The 35 members of Euromines are engaged in securing a sustainable and verifiable supply of raw materials and champion the EU principles for sustainable raw materials supply. Furthermore, Euromines cooperates with the EU authorities and national governmental institutions to ensure early consultation in all those areas of EU policy and legislation affecting the mining industry.

[7] See https://ifr.org/.
[8] See https://adr-association.eu/.

Another pertinent European industry association is Eurometaux, an umbrella association representing the interests of non-ferrous metals producers and recyclers towards EU policymakers. Eurometaux has 61 members, encompassing European commodity associations, companies and national associations.

A third industry association that should be mentioned is the International Council on Mining and Metals (ICMM). ICMM is the mining industry's most influential organisation, bringing together 28 of the world's largest mining and metals companies and over 35 regional and commodities associations. Industry members include companies such as Rio Tinto, Anglo American, BHP, Sumitomo and Boliden, who are known adopters of new automation technologies.

4.3 Public research funding

Public research funding is the primary mean for exercising research, technological development and innovation (RTDI) policies, and therefore it is the principal set of instruments for government intervention in the innovation process.

In the EU, RTDI instruments leveraging robotics and mineral raw materials research include the European Space Agency (ESA) 16 programmes and initiatives, the European Institute of Innovation and Technology (EIT) communities, the European Defence Fund (EDF) managed by the European Defence Agency and Horizon Europe, the world's biggest funding programme for research and innovation.

4.3.1 European Space Agency

ESA offers funding and support to businesses from any sector that intend to use space (satellite navigation, earth observation, satellite telecommunication, space weather, space technologies) to develop new commercial services through 16 research programmes[9]. Three ESA programmes seem particularly appropriate to expand the ROBOMINERS concepts: the Technology Development Element Programme (TDE), the General Support Technology Programme (GSTP) and Business Applications and Space Solutions (BASS).

TDE is responsible for early development stages across all ESA service and technology domains, taking cutting-edge ideas and testing their suitability for space applications. It focuses on TRL 1-4, and it is composed of a two-year work plan that covers classic technology development. Procurement plans are made annually, with 100% of the contracts offered to industry and universities on an open competitive basis. Invitations to Tender are issued continuously throughout the year via ESA's tendering services.

GSTP is an optional programme that takes previously proven innovations through to succeeding engineering stages. It ensures that the right technology is available at the right time. Through GSTP, ESA, participating states and industry work together to convert promising engineering concepts into a broad spectrum of useable products. The programme takes leading-edge technologies that are not ready to be sent into space and then develops them to be used in future missions. It covers all technology disciplines and applications except telecommunications. GSTP performs its activities under three distinct elements: Develop, Make and Fly.

BASS is designed to provide multiple entry points such as ESA Business Incubation Centres (ESA BICs), ESA Technology Transfer Broker Network, ESA Business Application Ambassadors and the ESA Business Applications programme. There are two main ways to apply for ESA Business Applications support & funding. In the Open Call for Proposals, companies can submit their ideas on any topic at any time of the year. With Competitive Tenders, entities can respond to one of the thematic calls for proposals.

[9] See https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Research.

4.3.2 European Institute of Innovation and Technology

The EIT innovation communities comprise eight topic-aligned groups[10]:

1. EIT Climate-KIC, working to accelerate the transition to a zero-carbon economy,
2. EIT Digital, driving Europe's digital transformation,
3. EIT Food, working to make food system more sustainable, healthy and trusted,
4. EIT Health, developing health solutions to enhance the health of citizens,
5. EIT InnoEnergy, accelerating sustainable energy innovations,
6. EIT Manufacturing, fostering the creation of globally competitive and sustainable manufacturing,
7. EIT RawMaterials, enabling the competitiveness of the European minerals, metals and materials sector,
8. EIT Urban Mobility, working to encourage positive changes in the way people move around cities.

EIT grants typically cover 75% of total eligible costs, and proposals have to be aligned with the topics selected by each community (naturally aligned with the circular economy, the digital transition and the contribution towards the EU Green Deal goals).

The results of ROBOMINERS might be relevant (i.e. directly transposable for development) in five of these communities: climate, digital, energy, manufacturing and raw materials. Joining one (or more) of these communities might be relevant to seeking funds to build on ROBOMINERS results, get business development support, and access to markets and customers.

4.3.3 European Defence Fund

Research and technology are at the heart of defence capability development, and given the importance of increasing EU defence capacity and the dimension of this challenge, the European Commission created the European Defence Fund (EDF) in 2017[11].

The EDF aims to coordinate and increase Member States' investment in defence research and improve interoperability between national armed forces. EDF supports competitive and collaborative projects throughout the entire research and development cycle for a more significant impact on the European defence capability and industrial landscape. The EDF 2022 33 calls are split across 16 categories, and participation of small and medium-sized enterprises is encouraged. At first glance, seven of these categories might be relevant for the uptake of ROBOMINERS results:

1. Sensors,
2. Digital transformation,
3. Materials and components,
4. Energy and environment,
5. Underwater warfare,
6. Disruptive technologies,
7. SME calls.

[10] See https://eit.europa.eu/our-communities.
[11] See https://ec.europa.eu/defence-industry-space/eu-defence-industry/european-defence-fund-edf_en.

4.3.4 Horizon Europe

Horizon Europe is the EU's primary funding programme for research and innovation, with a budget of €95.5 billion for 2021-2027 (the most ambitious EU research and innovation programme ever). The programme facilitates collaboration and strengthens the impact of research and innovation in developing, supporting and implementing EU policies while tackling global challenges. Furthermore, it supports creating and better dispersing of excellent knowledge and technologies[12].

The programme has an exclusive focus on civil applications, and the budget is divided into four pillars and 15 components to support all the areas of research and innovation. Pillar II (Global Challenges and European Industrial Competitiveness) is organised in six thematic clusters, and four of these clusters are relevant for the uptake of ROBOMINERS outcomes:

1. Civil security for society (responds to the challenges arising from persistent security threats, including cybercrime, as well as natural and man-made disasters),
2. Digital, Industry and Space (building a competitive, digital, low-carbon and circular industry, and ensuring the sustainable supply of raw materials),
3. Climate, Energy and Mobility (fight climate change by better understanding its causes, evolution, risks, impacts and opportunities, and making the energy and transport sectors more climate and environment-friendly, more efficient and competitive, smarter, safer and more resilient),
4. Food, Bioeconomy, Natural Resources, Agriculture and Environment (reducing environmental degradation, halting and reversing the decline of biodiversity on land, inland waters and sea and better managing natural resources).

The selection of projects to fund is made through open calls for proposals (usually with themes revisited every two years), selected according to excellence, impact, and implementation quality and efficiency.

[12] See https://ec.europa.eu/info/research-and-innovation/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en.

5 SETTING A COMPETITIVE BUSINESS STRATEGY

Defining a strategy to exploit ROBOMINERS results fully entails using a business-oriented approach built on project assets and consortium capabilities and knowledge. This strategy implies the existence of entrepreneurship behaviour and will set a course of action that relates business models and competition-based activities.

5.1 ROBOMINERS assets

In the Horizon 2020 programme, project results[13] are defined as:

'*Any tangible or intangible output of the action, such as data, knowledge and information whatever their form or nature, whether or not they can be protected, which are generated in the action as well as any attached rights, including intellectual property rights*.'

Specifying the ROBOMINERS results is the first step to defining a competitive strategy to take full advantage of their exploitation potential (encompassing the scientific and technological dimensions for commercial and non-commercial uses). Naturally, results are obtained during the project, but their potential exploitation is usually more relevant towards the end of a project when the bulk of expected outcomes typically surface. At this stage, the project results (assets) are of three kinds:

1) the ROBOMINERS prototype, capable of operating, navigating, and performing selective mining in an underground environment;
2) a mix of sensors, boring/tunnelling tools, communication and navigation technologies, energy management and control modules tailored to the harsh underground operational environment, but that could be easily adapted/put to use in other operating environments; and
3) a completely new mining ecosystem, encompassing future mine designs and methods alongside unconventional upstream/downstream raw materials processing approaches.

The detailed definition of ROBOMINERS' results will be made with the active contribution of all consortium partners, and it will consider IP management and rights.

5.2 Contextual analysis

The contextual analysis of ROBOMINERS assets and their potential use is the second step in defining an exploitation strategy. This analysis would consider ROBOMINERS strengths, weaknesses, opportunities and threats, following a structured analysis method known as SWOT (Humphrey, 2005). The SWOT analysis classifies the internal (i.e. ROBOMINERS-specific aspects) and external factors that are favourable and unfavourable to achieve a generic aim, and will be detailed in the final sustainability plan.

The external factors will be classified as opportunities or threats. An opportunity is a favourable external factor that the consortium can use to its advantage. A threat is a factor that can negatively impact the consortium or the project results. It is possible that a factor might be simultaneously considered an opportunity and a threat (e.g., resources nationalism). That will depend, basically, on specific framing factors. It is also relevant to stress that the analysis would be made from the perspective of the ROBOMINERS consortium, i.e., factors classified as opportunities to the consortium don't necessarily represent opportunities to robotics or the raw materials sector.

[13] From Article 26º of the H2020 Annotated Model Grant Agreement: https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/common/guidance/aga_en.pdf.

The internal factors will be classified as strengths or weaknesses. Strengths would be the results of the ROBOMINERS project that enable/create a competitive advantage. Weaknesses are aspects that are not performing at their optimum level. They have the potential to reduce progress or to give a competitive edge to the competition.

5.3 Defining a strategic position

The definition of a strategic position to exploit ROBOMINERS assets will depend on the following aspects (Drucker, 1954):

- What are the goals of the relevant consortium members?
- Who is the target customer for the uptake of a specific asset?
- What is considered "value" by the target customer?
- Which businesses, products and services should be included or excluded from the ROBOMINERS portfolio of assets?
- What differentiates ROBOMINERS outcomes from alternative solutions (competition) in the eyes of target customers and other stakeholders?
- What are the important opportunities and risks for the ROBOMINERS consortium?
- How can ROBOMINERS generate more value for the consortium?

These questions will be discussed inside the ROBOMINERS consortium after the definition of ROBOMINERS assets (at the beginning of the fourth quarter of the project development), and the answers obtained will affect the strategy to exploit ROBOMINERS results and the specific short-term and long-term exploitation goals. The organisation of the ideas will be made using the business canvas proposed by Alexander Osterwalder *et al*. (2005) in the following nine categories (Figure 11):

Key partners

Who are your key partners/suppliers?

What are the motivations for the partnerships?

Key activities

What key activities does your value proposition require?

What activities are important the most in distribution channels, customer relationships, revenue stream…?

Resources

What key resources does your value proposition require?

What resources are important the most in distribution channels, customer relationships, revenue stream…?

Value proposition

What core value do you deliver to the customer?

Which customer needs are you satisfying?

Customer relationships

What relationship that the target customer expects you to establish?

How can you integrate that into your business in terms of cost and format?

Customer segments

Which classes are you creating values for?

Who is your most important customer?

Channels

Through which channels that your customers want to be reached?

Which channels work best? How much do they cost? How can they be integrated into your and your customers' routines?

Cost structure

What are the most cost in your business?

Which key resources/ activities are most expensive?

Revenue streams

For what value are your customers willing to pay?

What and how do they recently pay? How would they prefer to pay?

How much does every revenue stream contribute to the overall revenues?

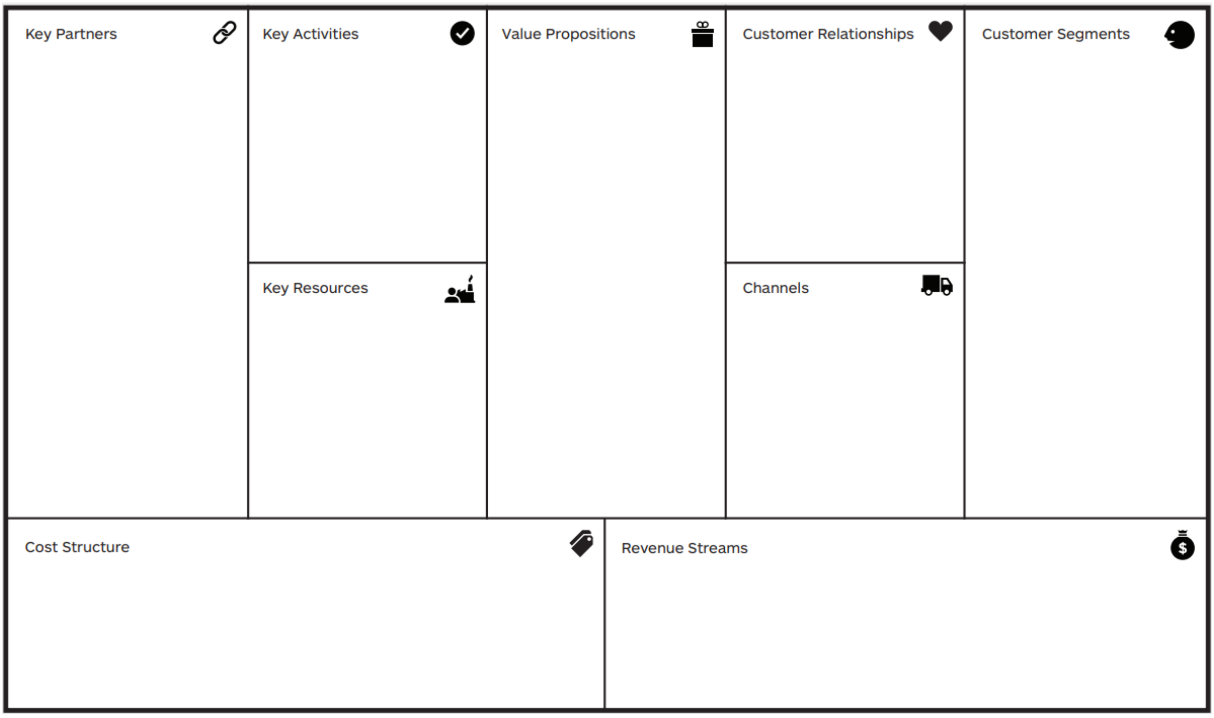

Figure 11: Business canvas that would be used to detail the strategic position to exploit ROBOMINERS assets. Credits: Strategyzer, via < https://platform.strategyzer.com/resources>.

5.4 Planning and monitoring exploitation actions

The planning of exploitation actions will consider:

- The goal of the action and the target stakeholders,
- The detailed description of the implementation of the action,
- The definition of resources committed (e.g., capital, human resources),
- The timing and sequence of the exploitation actions,
- The responsible for each action.

The key performance indicators (KPIs) that should be used for measuring the performance of ROBOMINERS exploitation efforts should cover three dimensions:

1) Finance,
2) Customer relationships,
3) Synergies created.

The exploitation actions, and the ratios, objectives, data sources and periodicity of analysis of the mentioned KPIs will be detailed in the final sustainability plan.

6 CONCLUSIONS

This first version of the ROBOMINERS Sustainability Plan aims to define the background framework for the uptake of findings and technological developments/innovations from the project. And since time and proactivity are critical success factors of any business strategy, and ROBOMINERS is now entering the last quarter of its 48 months duration, the Consortium partners, with the support of the External Advisory Board, will use this document to immediately start discussing exploitation routes that could be considered after the end of the EU funding period.

That discussion will establish a shared vision, to be transposed to a detailed action-oriented Sustainability Plan (final) that will be presented by the end of the ROBOMINERS project. The Sustainability Plan (final) will build on the contextual analysis of market and competition made at this stage, detailing possible pathways to create alliances with the actors from the networks identified, and advancing a business model embodied around the strategic management template set out in this document.

From the overall analysis of supporting factors and networks that could be used for exploiting the ROBOMINERS results, it is essential to highlight the following:

- The project exploitable results (assets) will include: 1) the ROBOMINERS prototype, capable of operating, navigating, and performing selective mining in an underground environment; 2) a mix of sensors, boring/tunnelling tools, communication and navigation technologies, energy management and control modules tailored to the harsh underground operational environment, but that could be easily adapted/put to use in other operational environments; and 3) a completely new mining ecosystem, encompassing future mine designs and mining methods, alongside unconventional upstream/downstream raw materials processing approaches.
- Advancing the TRL of the achievements/results of ROBOMINERS (after the end of the project) will require additional funding.
- Creating alliances and partnerships with research and academic communities interested in investigating potential complementary synergistic effects (from ROBOMINERS) in other research areas will widen the scope of possible funding sources/instruments/tools that could support the continuation of ROBOMINERS research after the current funding period.
- Two main funding approaches could be considered: 1) public funding (through calls/tenders made by public research funding organisations/instruments, such as ESA, EIT, EDF and Horizon Europe); and 2) private funding (obtained through partnerships with business players/prospect clients).

It is also relevant to point out that the exploitation of partial results (e.g., specific sensors or navigation solutions) is a route that the Consortium should also consider, not only for the potential revenue, but also because it enables and accelerates potential scientific and technological advances made by other players.

Whatever the ROBOMINERS Consortium's vision and aims to exploit project results, it is clear that using a business-oriented approach, built on project assets and consortium capabilities and knowledge, is the best way of maximising the chances of successfully achieving success in getting funds to continue the ROBOMINERS research.

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