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# Smarthub for supervising system for resource exploration and pollution control in deep-water and coastal areas based on ICT technologies



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## Abstract

**Purpose** – This study aims to explore the need for highly technological complexes for control and monitoring, as well as, new concepts and methodologies for maritime resource exploration and exploitation, which are in great demand nowadays.

**Design/methodology/approach** – This paper provides an analysis of demand, means of creation and development of the methodology and infrastructure for global monitoring, pollution control and supervision of smart systems for activities in exploration, future resource exploitation in deep-water and coastal areas based on Smarthub architecture, Unmanned Aircraft System (UAS), Continuous Acquisition and Life-Cycle Support (CALS) and Blockchain technologies.

**Findings** – Observational, experimental, simulation, derivational, hybrid descriptive and analytical models, as well as, surrogate models were created, analyzed and implemented for assigned tasks realization. Concept of distributed system for marine environmental monitoring, control and supervising as pilot technology in the context of Technology Readiness Levels (TRL) 3–5 was designed and evaluated.

**Originality/value** – The activities described in this article should be realized in the design and development of a complex, reliable, robust and sustainable monitoring and inspection system for the control and evaluation of the impact and risk assessment of the exploration and future exploitation of maritime resources.

**Keywords** Smarthub, Marine resources, Mining, UAS, CALS, Blockchain

**Paper type** Research paper

## 1. Introduction

The mining industry is increasingly venturing toward new frontiers. Currently, it is targeted at one of the most biodiverse, fragile and life-sustaining ecosystems on Earth: the deep sea and coastal areas, the least explored area on Earth, covering more than half of the planet and reach in minerals. Europe is responsible for a substantial share of the growing global demand for raw materials and rare minerals, using up to 20% of global mineral production for less than 10% of the world's population, Pim *et al.* (2021).

The EU and European countries can have a strong influence on the global future of the sector, since all are members of the International Seabed Authority (ISA), all of which underscore the need for a much more transformative European Green Deal, one that is able to downscale economic consumption, shifting its priority from destructive growth to meeting people's needs without overshooting the Earth's ecological ceiling. Environmental impact assessment (EIA) is a key tool for planning and evaluating the effects of human activity impact on the environment. The obligation to conduct an EIA is determined by several international legislative treaties and customs that specify the structure and scale of the assessment, Kaikkonen *et al.* (2018).

Traditionally, ecological impact assessments have been based on the knowledge of how ecosystems respond to human-induced disturbances. The risks of adverse effects on ecosystems caused by human activities were assessed based on the prevailing conditions of the environment against which the presumed impacts were compared. However, in the case of seabed mineral extraction, little previous experience in mining projects has been documented. Moreover, the scarcity of biological and geological baseline data on the deep and shallow seabed is another major issue in evaluating the impacts of physical disturbances, and the justification of statements on the severity of the impacts is not always detailed. The research status of the sustainable development of deep-sea mining from an overall scope of view is not defined, Ma *et al.* (2022).

In September 2015, the United Nations General Assembly accepted the 2030 Development Agenda, which defined 17 sustainable development goals (SDGs). Goals 6- (Clean water and sanitation) and 7 are in focus of article statement. The objective of mentioned paper is to discover the correlations among SDGs and information and communications technologies (ICTs). The paper discusses the roles and opportunities that ICTs play in pursuing the SDGs, Wu *et al.* (2018).

Environmental issues are acquiring more attention and this has triggered various initiatives, focused on environmentally-friendly communication topics. The topics include energy efficiency, energy harvesting and solutions to pollution issues all in the context of the internet of Things (IoT), Estevez and Wu (2015), which may be used also in the scope of deep sea and coastal areas exploration and expected to have a great impact on the green agenda.

Big data in information and communications technology (ICT) are widely recognized as being one of the most powerful drivers to promote innovation. To answer the interesting question whether there are inherent correlations between the two tendencies of big data and green challenges this paper discovers the relations between the trend of big data era and that of the new generation green revolution, Wu *et al.* (2016).

The world is witnessing an unprecedented growth of cyber-physical systems (CPS), which are foreseen to revolutionize our world via creating new services and applications in a variety of sectors, such as environmental monitoring, mobile-health systems, intelligent transportation systems. It is expected to outstandingly increase the growth rate of raw sensed data and it transmission. CPS taxonomy via providing a broad overview of data collection, storage, access, processing and analysis is presented in the panoramic survey on big data for CPS. Cybersecurity solutions for protecting data against malicious attacks and unauthorized intrusion are provided as well as discussion concerned with big data meeting green challenges in the contexts of CPS, Atat *et al.* (2018)

So the need for highly technological ICT complexes for control and monitoring, as well as new concepts and methodologies for maritime resource exploration and exploitation, are in great demand. The role of emerging remote sensing and information technologies in supporting of this demand and in supporting the implementation of environmental directives policies is provided in, El Mahrad *et al.* (2022).

## 2. Methods

In the framework of this article, we discuss the appropriate technological and systemic solutions for assigned objectives in the form of a project. The results of implementing project objectives must be measurable and realistically achievable. The project is innovative in its essence and extends beyond the modern approach of solving this type of problem.

Exceptional groundbreaking research and development, as well as new concepts and approaches such as Smarthub architecture, Unmanned Aircraft System (UAS), Continuous Acquisition and Life-Cycle Support (CALS) and Blockchain technologies form the core of the proposed project. For example, the project "Blue Nodules (Breakthrough Solutions for the Sustainable Harvesting and Processing of Deep Sea Polymetallic Nodules) – H2020" http://www.blue-nodules.eu reflects the problems of research in this R&D direction, but with a comparatively narrow focus. Declared objectives: developing of a new highly-automated and technologically sustainable deep-sea mining system for the harvesting of polymetallic nodules from the sea floor. As a result of R&D activities presented mining system is locally oriented without complicated data exchange between distributed parts of infrastructure; lack of modeling methodology and novelty in modern spheres of ICT. UAS, CALS, IoT and Blockchain technologies are outside of mentioned project scope.

In the next article, there are illustrated and discussed some of the challenges for sustained coastal observations and provides details on how to address present gaps. The role of collaborative robotics between unmanned platforms in coastal areas and the methods to benefit from IoT technologies are discussed. The mentioned perspective methods with aim to move toward a distributed system for coastal ocean observations composed of a network of fixed and mobile heterogeneous nodes, which can coordinate data acquisition tasks and data management are presented. Work lays down the good basis in scope of system configuration and necessary infrastructure. Methodological aspects, cybersecurity problems and Blockchain technology implementation are not sufficiently discussed. But essential elements toward the implementation of a distributed and autonomous architecture for ocean monitoring and observation are described to achieve the ability to measure physical, chemical and biological variables across a range of spatial and temporal scales in coastal areas, Mariani *et al.* (2021).

Offered project allow adequate allocation of research and management efforts, and it is essential to point out the knowledge gaps in our current understanding of the impact of marine mineral extraction. The project should build environmentally friendly technologies for the monitoring and control of exploration and exploitation of the deep sea and lays down the basis for further technological development. The project should cooperate closely with the ISA, notably with its Legal and Technical Commission and consider the legal framework for the seabed and ocean floor and subsoil thereof beyond the limits of national jurisdiction. The project should take into account the developments of the international legally binding instrument under the United Nations Convention on the Law of Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction, United Nations (2023) and the Regulation of Mine Waters in the European Union discussed in, Kroll *et al.* (2002).

The described activities have general and specific objectives. The overall objective of the project is to ensure the protection and sustainability of marine ecosystems, to assess pollution, to establish risk areas due to contamination and encourage the production, management and to share the marine and coastal environmental knowledge.

The specific objectives are:

(1) Ecosystem approach-promotes further research providing new knowledge to mitigate the impacts of global climate change and the impact of multiple environmental and anthropogenic stressors, for example on the Baltic Sea, the Black Sea and Mediterranean; tools for ecosystem forecasting; the best practices for the management of the protected areas among the mentioned seabed areas; and encouraging and promoting joint monitoring.

(2) Assessment of pollution, especially in the scope of mining and other industrial activities-raise awareness, education on marine ecosystems, knowledge on the

prevention and response to pollution caused by ships and port areas and support research on the challenges related to marine bio resources of ecosystems and emerging pollutants.

(3) Support innovative marine research infrastructure in the European coastal areas for data collection and continuous monitoring and observation of marine bio resources (state-of-the-art research infrastructure is becoming more complex and costly);

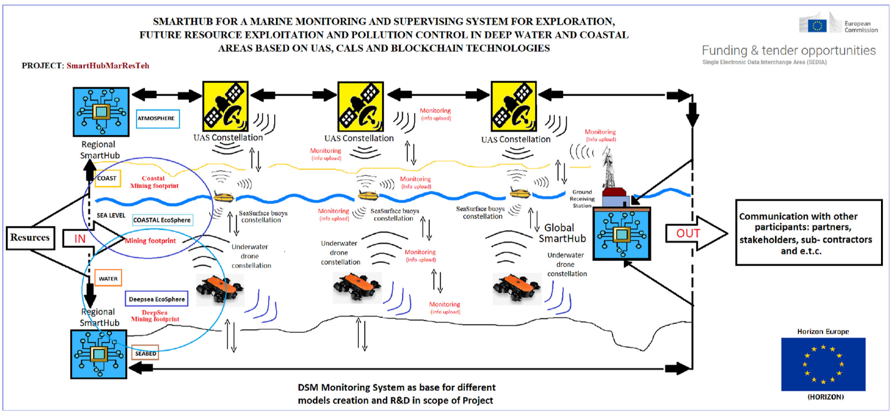
(4) Techniques and methodologies to encourage the production, management and sharing of marine and coastal environmental knowledge for effective environmental monitoring and observation; encourage science-based policy-making process; encourage marine data collection and sharing through existing databases; call for collection, maintenance and storage of environmental data through cooperation between governmental agencies; call for the development of a harmonized set of working methodologies, standards, and procedures on coastal and marine data collection; promote better understanding of coastal hazards; and increase ecosystem resilience knowledge.

The concept of pilot technology in the context of Technology Readiness Levels (TRL) 3–5 from experimental proof of concept to technology validated in a relevant environment (an industrially relevant environment in the case of key enabling technologies) will be realized. The foundations will be laid for a pilot technology to validate measurements "*in situ*" with those in the smart laboratory. The diagram illustrated the main elements of distributed system for marine monitoring, control and supervising is demonstrated in Figure 1.

## 3. Results

The chosen approach for conducting research activities is both quantitative and qualitative. Types of research data: observational, experimental, simulation and derivation; hybrid descriptive and analytical models as well as surrogate models will be created, analyzed and implemented for project task realization.

The principles of computer modeling are widely used in this project. During the implementation of the project, various types of computer models will be used, such as the Maritime ecosystem model (Coastal and Deep-water models); Model of underwater




**Source(s):** Authors' own work

**Figure 1.**
The main elements of distributed system

information acquisition, processing and representation; Model of aerial information acquisition, processing and representation; Model of communication and data transfer; Model of Smarthub performance; Risk impact model (Risk impact model coastal and Risk impact model deep water) and Model of result's obtaining – reaction.

Computer simulation has been provided as a method for implementing a model over time. The developing system needs to be fully transparent and capable of monitoring all relevant environmental parameters and at the same time protect business confidentiality. Owing to the complexity of such a system, the project has to be developed by a multidisciplinary team, looking at environmental, legal and technological solutions. Any bathymetry, geology, seabed habitats, chemistry, biology and physics marine data collected, particularly during the testing phase, should be The Infrastructure for Spatial Information in the European Community (INSPIRE) compliant and made available through the European Marine Observation and Data Network (EMODnet).

For each of the three main mineral deposits (polymetallic nodules, manganese crusts and sulfide deposits) found at different depths in the ocean, the project allow to:

(1) Identify all the biochemical and physical parameters to be monitored at the bottom of the sea, along the water column and at the surface.

(2) Create and develop the necessary theoretical bases for methodology, realize the process of modeling and computer simulation, prototype technology research and development in the scope of project objectives.

(3) Identify all technical requirements needed for real-time monitoring of all parameters at the bottom, along the water column and surface, including the use of satellite data (Global Navigation Satellite System and Copernicus satellite constellation), (Unmanned Aircraft Systems) and to make it continuously available for remote access.

(4) Ensure effective data acquisition, processing and information storage and exchange in the global system for monitoring, pollution control and supervision of a distributed system for exploration and future resource exploitation in deep-water and coastal areas.

(5) Identify existing technological solutions and develop new ones to fulfill the technical requirements;

(6) Design and develop the architecture of the system in view of incorporating monitoring parameters, technical requirements and legal constraints.

(7) Develop a trial version of the system and test it.

As an example of one of the methodology concepts that will be realized in the framework of the project, we offer a more detailed exposition of the methodology, which is based on Blockchain technology through which we can create a database that considers the decentralized model vs centralized model and smart (computerized and secure) infrastructures for transmitting data related to quality of environmental factors using smart Blockchain technology.

The methodology behind the creation of the Smarthub infrastructure consists of distributed computing methods, which can be viewed as a network of computers working together as a single system. IoT, Blockchain technologies are the core of discussed methodology.

The Internet of Things (IoT) is basically like a system for connecting computer devices, mechanical and digital machines, objects, or individuals provided with the unique system

(UIDs) and without transfer to transmit data over an ability human-to-human or computer-to-human relation. The utilization of IoT in the cloud, fog, IoT technologies with applications and security, specifically, provision of IoT architecture for design and development with sensors in 6G will be useful technologies for above mentioned system, Laghari *et al.* (2021).

The vast enhancement in the development of the Internet of Vehicles (IoV) as development of (Inter of Things (IoT)) methodology has created a new paradigm, such as the security-related resource constraints of Industry 5.0. A new revolution and dimension in the IoV popup raise various critical challenges in the existing information preservation, especially in node transactions and communication, transmission, trust and privacy and security-protection-related problems. A Blockchain saw tooth-enabled modular architecture for protected, secure and trusted execution, service delivery and acknowledgment with immutable ledger storage and security and peer-to-peer (P2P) network on-chain and off-chain inter-communication for vehicular activities is provided in Laghari *et al.* (2021). As well as Lightweight-BIoV: Blockchain Distributed Ledger Technology (BDLT) for Internet of Vehicles (IoVs) is discussed in Laghari *et al.* (2023).

In addition, the intersection of Blockchain and industrial IoT has gained more consideration and research interest. However, there is an emerging limitation between the inadequate performance of industrial IoT and connected nodes and the high resource requirement of permissioned private Blockchain ledger. Due to the introduction of NuCypher Re-Encryption infrastructure, hashing tree and allocation, deployment of Blockchain proof-of-work it is required more computational power as well. There are discussed possible solutions of mentioned problems in, Khan *et al.* (2022a, b, c).

In healthcare sphere. BIoMT: a state-of-the-art consortium server-less network architecture for healthcare system using Blockchain smart contracts is introduced, which provides security, integrity, transparency and provenance to health-related transactions and exchanges sensitive clinical information in a server-less peer-to-peer (P2P) secure network environment, Khan *et al.* (2022a, b, c).

(HI), human interface is an important part of architecture of system for monitoring and control. A brain–computer interface (BCI) as next step of development affords real-time communication, significantly improving the quality of lifecycle, brain-to-internet (B2I) connectivity and communication between the brain and external digital devices. The system converts brain information to understandable signals for multimedia devices without physical interference and replaces human-based languages with the external environment control protocols as discussed in Khan *et al.* (2022a, b, c).

Above mentioned research works illustrate and consolidate necessary elements and methodologies in scope of distributed computing structure for supervising system for resource exploration and pollution control in deep-water and coastal areas based on ICT technologies.

Computing systems can be placed side-by-side and connected to a single local area network. Other networks such as Blockchains widely use geographically dispersed computer networks. A Blockchain is a peer-to-peer (P2P) network, in which distributed systems are groups of independent nodes connected to each other in a certain way to produce a common result and are structured such that these groups look like a single system well defined for the end user. Through these networks, every system can communicate with others through messages and responses. The main advantage is that communication between systems provides synchronization as well as an error-free environment.

What constitutes a new concept as a model and research hypotheses in a smart network of Smarthub consists in the characteristics of the nodes of the infrastructure network, namely they are programmable, autonomous and error-free; each node has its own storage medium and computing processor; nodes have shared memory and can operate simultaneously; nodes are interconnected to provide services and to share or store data; all nodes communicate with each other through messages; each node in the distributed system is able to send and receive messages to and from the other nodes.

In the computer network of the Smarthub infrastructure, communication takes place between two types of entities: the client that issues a request, requesting certain information and the server that receives the request, processes it and then sends the requested information to the client. Depending on the hierarchy of the connected equipment in a network, there are two types of networks: peer-to-peer networks and client-server networks.

The project methodologies comply with the principle as per Article 17 of Regulation (EU) No 2020/852 on the establishment of a framework to facilitate sustainable investment. This means that the methodology is designed such that it does not significantly harm any of the six environmental objectives of the EU Taxonomy Regulation.

(1) Climate change mitigation

(2) Climate change adaptation

(3) The sustainable use and protection of water and marine resources

(4) The transition to a circular economy

(5) Pollution prevention and control

(6) The protection and restoration of biodiversity and ecosystems, Regulation (EU) No 2020/852 (2020).

The project serves as an effective trigger for every mentioned objective in some forms and with different achievable results, but it fully complies with the "do no significant harm" principle.

There are some topics where the work program of the project indicates the need for the integration of social sciences and humanities. In the scope of project activities the creation of a model of coastal and deep-sea marine ecosystem will be additionally realized by organizing an assessment of the state and will be designing a database by conducting systematic monitoring of the coast, surface and depth of the water column based on common methodology and indicators to confirm the importance of maintaining a good marine environment. The computerized technology of Smarthub monitoring takes over, analyzes, processes and tests the samples taken from various locations at local and regional level; the resulting information is distributed using high-performance technologies, methodologies and information systems.

The database of Smarthub offers for example:

(1) A real-time presentation of evolutionary data of the degree of bio resources in situations of contamination;

(2) The presentation of warning information in case of high degree of ecological risk

(3) Safety and Operational Risk assessment

(4) Social impact assessment

(5) New dimension analysis and new sites identification

(6) Scaling-up design

(7) Marine spatial planning maps for contamination areas

(8) Maps for identification the bio resources in situations of contamination

(9) Exploitation Strategy and risk's maps in the region.

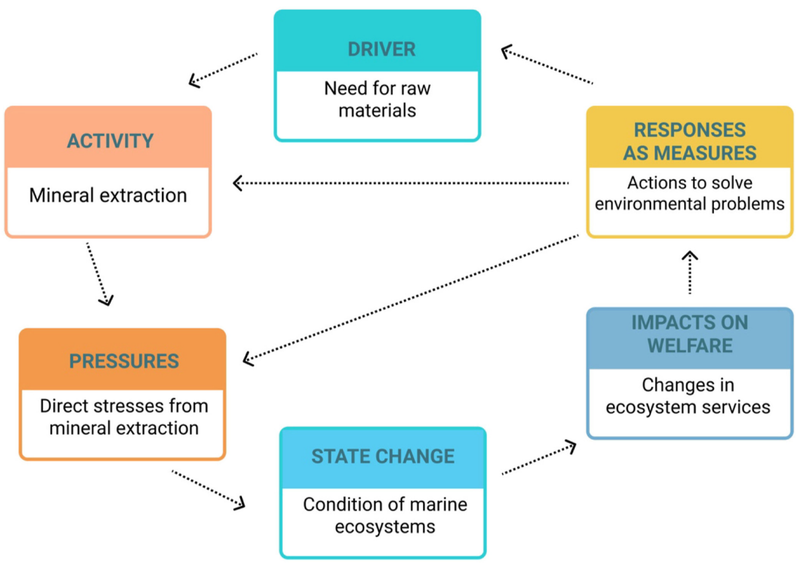
This activity is based on the principles of sustainable development, assessment of the impact of measures on the environment and their impact on social and economic development after a cost-benefit analysis, adopting the principles of the blue economy and providing a good marine environment, which is essential not only for the conservation of biological diversity but also for human well-being and economic development of the regions.

Successful control of the parameters of the quality of the environment is connected and depends on the monitoring mechanism, which is the core of this activity. During the implementation of this activity, a monitoring system must be organized. It includes the development of methodologies for monitoring the coastal zone and the water column, which include providing the necessary devices and methods for characterizing the qualities of the operating system (OS). Determination of focal points for monitoring, coordination of the activity, if necessary, with the relevant regulatory mechanisms of the region, organization of a database for maintaining opportunities for analysis and evaluation, accumulation of necessary data, synchronization of newly obtained data with existing bases for filling deficits, preparation of model of coastal ecosystem and model of deep-water ecosystem, which will include risk zones of the ecosystems need to be provided. Artificial intelligence (AI)-based dynamic risk assessment and prevention management, as well as data transfer and communications allow to ensure in real-time update of the risk assessment and necessary prevention.

The conceptual interrelations between different processes in the scope of the proposed methodology are presented in Figure 2, Kaikkonen *et al.* (2018).

Risk assessment has been provided as main part of research activities. The results are provided below in Table 1.

A risk matrix (5 × 5) is used during risk assessment to define the level of risk by considering the category of probability or likelihood against the category of consequence severity in Table 2.




**Source(s):** Figure courtesy of Kaikkonen *et al.* (2019)

**Figure 2.**
The conceptual interrelations between different processes

| Risk assessment | | | | | | |
|---|---|---|---|---|---|---|
| | | | Assessment (1-5points scale) | | | Risk prevention/ |
| No | Risk | Risk description | Probability | Losses | Impact | reduction measures |
| 1 | Financial risks | Financial risk is the possibility of losing money on an investment or business venture | 4 | 3 | 12 | Limiting – deliberate limitation of possible losses in accordance with a predetermined limit<br>Accounting – collection of additional information |
| 2 | Implementation on risks | Implementation risk is the potential for a development or deployment failure | 3 | 5 | 15 | Tracking triggers (signs of risk events)<br>Reservation – creation of reserves for resources |
| 3 | Risks of achieving results | Uncertainty that leads to the emergence of danger of not achieving the set goals | 4 | 3 | 12 | Diversification – spreading risk across multiple alternatives |
| 4 | Environmental risk | Environmental risk arises from environmental hazards or environmental issues. The chance of harmful effects to human health, ecological systems | 5 | 5 | 25 | Tracking triggers (signs of risk events) |
| 5 | Information technology risk | IT risk arises from the potential that a threat may pose | 3 | 2 | 6 | Reservation – creation of reserves for various types of resources |

**Source(s):** Authors' own work

**Table 1.**
Classification of risks

| N | Forms of risks | Impact | Color |
|---|---|---|---|
| 1 | Environmental risk | 25 | |
| 2 | Information technology risk | 6 | |
| 3 | Financial risks | 12 | |
| 4 | Implementation risks | 15 | |
| 5 | Risks of achieving results | 12 | |

**Source(s):** Authors own work

**Table 2.**
Risks rating

This is a simple mechanism to increase visibility of risks and assist management decision making. As the name suggests, your numbers will go up to 5 on each axis, giving a maximum score of 25 ($5 \times 5$) = 25) in Figure 3.

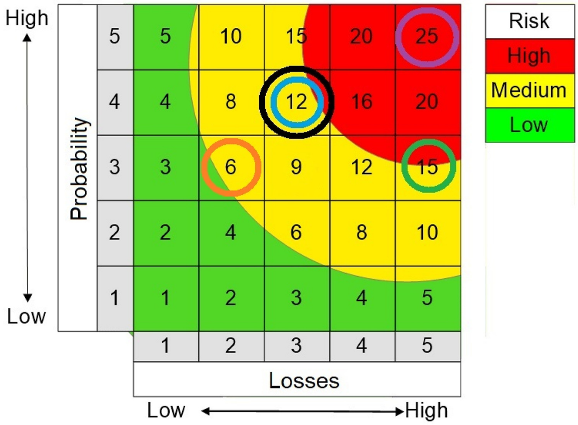



**Figure 3.**
Risk matrix

**Source(s):** Authors' own work

Conclusion of risk analysis: the environmental risk is the most significant (according to the matrix – 25), because of environmental hazards or environmental issues. The chance of harmful effects to human health, etc. the following preventive measures are proposed: tracking triggers (signs of risk events). The Information technology risk is the least insignificant (according to the matrix – 6), because of the information technology (IT) risk (or cyber risk) arises from the potential that a threat may exploit a vulnerability to breach security and cause harm. The following preventive measures are proposed: Blockchain technology usage, reservation – creation of reserves for various types of resources.

## 4. Conclusions

The obtained results would make a novel contribution to the outlined outcomes specified in this topic and to the wider impacts in the longer term. Offered project is in compliance with response to the 2016 communication on international ocean governance; the European Parliament adopted a resolution on January 16, 2018, on International ocean governance: an agenda for the future of our oceans with motto: the effects of deep-sea mining on the marine environment, biodiversity and human activities at sea must be studied and researched sufficiently and all possible risks are understood, European Parliament Resolution (2018).

The project will directly and significantly contribute to specific scientific advances, across and within disciplines (not only to deep-sea mining, but also in a broad sense, to Earth sea ecosystem monitoring and exploration), create new knowledge, reinforce scientific equipment and instruments and computing systems (i.e. research infrastructures). The project will also contribute to the economic and technological sphere, for example, bringing new technologies to deep-sea mining monitoring and negative impact mitigation, and it will increase efficiency, minimize costs of demand side management (DSM), increase profits, contribute to setting standards in the sphere of sea exploration and exploitation, green production, ecology, etc.

Offered project outcomes will be sufficient for global climate sustainability and societal impact in such a way that will be valuable. The results can make a difference, for example, in the framework of Blockchain technology R&D.

Blockchains have been used in various network-interaction systems. Generally, these applications are framed in the five categories.

The third category is record-keeping applications, which provide decentralized data storage. The fourth category is Blockchain network security services.

The computerized technology of Smarthub is taking over, analyzing, processing and testing the samples taken from various locations at local and regional levels, ensuring the resulting information distribution using high-performance technologies. Methodologies and information systems contribute to the development and sustainability of deep-sea mining and resolve problems related to future resource exploration. The focus of the project is to improve the entire supply chain of deep-sea mining and make it technologically ready to extract deep-water resources in a cost-efficient manner. The main issues to overcome for the future development of marine mineral exploitation include the location of the deposits, the determination of their type and abundance and the assessment of commercial viability, particularly in view of resource uncertainties and current technological barriers, Rademaekers *et al.* (2015).

## References

Atat, R., Liu, L., Wu, J., Li, G., Ye, C. and Yang, Y. (2018), "Big data meet cyber-physical systems: a panoramic survey", *IEEE Access*, Vol. 6, pp. 73603-73636, doi: 10.1109/ACCESS.2018.2878681.

El Mahrad, B., Newton, A., Icely, J.,D., Kacimi, I., Abalansa, S. and Snoussi, M. (2022), "Contribution of remote sensing technologies to a holistic coastal and marine environmental management framework: a review", *Remote Sens*, Vol. 12 No. 14, 2313, doi: 10.3390/rs12142313.

Estevez, C. and Wu, J. (2015), "Recent advances in green internet of Things", *Proceeding 7th IEEE Latin-American Conference on Communications (Latincom)*. doi: 10.1109/LATINCOM.2015.7430133.

European Parliament Resolution (2018), "On International ocean governance, texts adopted – international ocean governance: an agenda for the future of our oceans in the context of the 2030 Sustainable Development Goals – tuesday", available at: https://www.europarl.europa.eu/doceo/document/TA-8-2018-0004_EN.html (accessed 16 January 2018).

Kaikkonen, L., Venesjari, R., Nygard, H. and Kuikka, S. (2018), "Assessing the impacts of seabed mineral extraction in the deep sea and coastal marine environments: current methods and recommendations for environmental risk assessment", *Maritime Pollution Bulletin*, Vol. 135, pp. 1183-1197, doi: 10.1016/j.marpolbul.2018.08.055.

Khan, A.A., Laghari, A.A., Shaikh, A.A., Dacko-Pikiewicz, Z. and Kot, S. (2022a), "Internet of Things (IoT) security with blockchain technology: a state-of-the-art review", *IEEE Access*, Vol. 10, pp. 122679-122695, doi: 10.1109/ACCESS.2022.3223370.

Khan, A.A., Laghari, A.A., Shaikh, A.A., Dootio, M.A., Estrela, V.V. and Lopes, R.T. (2022b), "A blockchain security module for brain-computer interface (BCI) with multimedia life cycle framework (MLCF)", *Neuroscience Informatics*, Vol. 2 No. 1, 100030, doi: 10.1016/j.neuri.2021.100030.

Khan, A.A., Wagan, A.A., Laghari, A.A., Gilal, A.R., Aziz, I.A. and Talpur, B.A. (2022c), "BIoMT: a state-of-the-art consortium serverless network architecture for healthcare system using blockchain smart contracts", *IEEE Access*, Vol. 10 No. 2022, pp. 78887-78898, doi: 10.1109/ACCESS.2022.3194195.

Kroll, A., Amézaga, J., Younger, P., *et al.* (2002), "Regulation of mine waters in the European union: the contribution of scientific research to policy development", *Mine Water and the Environment*, Vol. 21, pp. 193-200, doi: 10.1007/s102300200043.

Laghari, A.A., Khan, A.A., Alkanhel, R., Elmannai, H. and Bourouis, S. (2023), "Lightweight-BIoV: blockchain distributed ledger technology (BDLT) for internet of Vehicles (IoVs)", *Electronics*, Vol. 12 No. 3, 677, available at: https://www.mdpi.com/2079-9292/12/3/677#

Laghari, A., Wu, K., Laghari, R., Ali, M. and Ayub Khan, A. (2021), "A review and state of art of Internet of Things (IoT)", *Archives of Computational Methods in Engineering*, Vol. 29, doi: 10.1007/s11831-021-09622-6.

Ma, W., Zhang, K., Du, Y., Liu, X. and Shen, Y. (2022), "Status of sustainability development of deep-sea mining activities", *Journal Marine Science Engineering*, Vol. 10, 1508, doi: 10.3390/jmse10101508.

Mariani, P., Bachmayer, R., Kosta, S., Pietrosemoli, E., Ardelan, M.V., Connelly, D.P., Delory, E., Pearlman, J.S., Petihakis, G., Thompson, F. and Crise, A. (2021), "Collaborative automation and IoT technologies for coastal ocean observing systems", *Frontiers in Marine Science*, Vol. 8, 647368, doi: 10.3389/fmars.2021.647368.

Pim, J.E., Dom, A., Rijnhout, L. and Martnez, E. (2021), *Seas at Risk. At a crossroads:Europe's Role in Deep-Sea Mining*, Seas at Risk, Brussels, available at: https://seas-at-risk.org/publications/at-a-crossroads-europes-role-in-deep-sea-mining/

Rademaekers, K., Widerberg, O., Svatikova, K., van der Veen, R. and Panella, E. (2015), "Deep-seabed exploitation. Tackling economic, Environmental and societal challenges, Study", Commissioned by: European Parliament/STOA, available at: http://www.europarl.europa.eu/RegData/etudes/STUD/2015/547401/EPRS_STU%282015%29547401_EN.pdf

Regulation (EU) No 2020/852 (2020), available at: https://www.eurosif.org/policies/eutaxonomy/

United Nations (2023), "Convention on the Law of Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction (General Assembly resolution 72/249)", available at: https://www.un.org/bbnj/fifth_substantive_session

Wu, J., Guo, S., Li, J. and Zeng, D. (2016), "Big data meet green challenges: big data toward green applications", *IEEE Systems Journal*, Vol. 10 No. 3, pp. 888-900, doi: 10.1109/JSYST.2016.2550530.

Wu, J., Guo, S., Huang, H., Liu, W. and Xiang, Y. (2018), "Information and communications technologies for sustainable development goals: state-of-the-art, needs and perspectives", *IEEE Communications Surveys and Tutorials*, Vol. 20 No. 3, pp. 2389-2406, doi: 10.1109/COMST.2018.2812301.

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