IEAI Technical University of Munich
School of Social Science and Technology
Institute for Ethics in Artificial Intelligence

TUM

Research Brief – December 2022

The Use of AI in the Mining Industry – Insights and Ethical Considerations

By Caitlin Corrigan and Paloma Laye

In the effort to rapidly transform the way we use energy, valuable metals are coming increasingly into high demand. Various minerals and metals, such as copper and cobalt, are required to advance new technologies and accelerate the lowering of carbon emissions. However, their extraction also comes with high societal and environmental costs. Therefore, developing ways to extract valuable minerals in a way that benefits global sustainability goals and mitigates the negative impacts of extraction, while rectifying imbalances between developing and developed countries, is a worthwhile endeavor. Artificial intelligence (AI) enabled applications provide one avenue to potentially speed up this process. The question remains, how do we ensure AI is used in a way that benefits communities, societal development, and environmental sustainability when it comes to the mining industry?

In the effort to rapidly transform the way we use energy, valuable metals are coming increasingly into high demand. Various minerals and metals, such as copper and cobalt, are required to advance new technologies and accelerate the lowering of carbon emissions (IEA, 2021: Mackenzie, 2022). However, mining these critical resources poses environmental, social, and economic challenges, especially in politically unstable and economically poor regions such as many countries in Africa and the 'Global South' (Lèbre, 2020; UNSDSN, 2016; UNEP, 2019; Sengupta, 2021). Indeed, the often cited 'resource curse' (Collier, 2007; Sachs and Warner, 2001,1995; Sala-i-Martin & Subramanian, 2003) includes observations of exploitation, environmental degradation, and counterintuitively poor economic development in countries rich in valuable oil and minerals.

Yet, despite these often observed negative impacts of mineral extraction, this energy transition needs to happen quickly and efficiently. Moreover, the economic potential of this transition is widespread as the mining or extractive industry is a strong actor in the economic sustainability of 81 countries (United Nations, 2021), and 63% of low- and middle-income countries have increased their dependence on extractives in recent decades (Roe, 2016). The Democratic Republic of Congo, for example, will control 80% of the global supply of cobalt by mid-decade (Mackenzie, 2022). However, many countries rich in these resource deposits also have a long history of exploitation, environmental degradation, and the resource curse.[1] Therefore, developing ways to extract valuable minerals in a way that benefits global sustainability goals and mitigates the negative impacts of extraction, while rectifying imbalances between developing and developed countries, is a worthwhile endeavor (United Nations, 2021).

Artificial intelligence (AI) enabled applications provide one avenue to potentially speed up this process. AI is already enhancing mining sector economics (Jung & Choi, 2021) by boosting productivity, optimizing operational costs, and maximizing profitability. The potential uses go far beyond this to support worker safety, environmental management and government monitoring. However, the ethical consideration of the use of AI-enabled tools in this context has, as of yet, been largely overlooked. The question remains, how do we ensure AI is used in a way that benefits communities, societal development, and environmental sustainability when it comes to the mining industry? This Research Brief explores this question, outlining ethical issues and providing a starting point to further research on the topic.[2]

Current and Potential Roles of AI in Mining

There are several already established applications of AI within the mining industry and its operations. The first is prospecting and exploration, which is the initial stage of locating an economic mineral, measuring its economic and market conditions in order to evaluate whether it is worth investing in. This process requires the 'reconnaissance of the area of interest, collection of geophysical, geological and economic data. Exploration involves sampling, laboratory work, borehole logging, and further investigation of prospects' (Böhmer & Kucera, 2013). AI-enabled applications for these tasks have been seen and used in Goldspot Discoveries Incorporated and IBM Watson to achieve high accuracy in locating mineable prospects (Goldspot Discoveries; Murphy, 2021).

Machine Learning (ML) models such as support vector machines (SVMs) and deep learning models are currently the most common systems used to produce, collect and share data collected from drilling, sensors, or measurements in real time (Jung & Choi, 2021). This includes drilling and blasting, equipment management, ensemble in geotechnical management and mine safety, as well as land cover monitoring and mine hazard assessment.

Workplace safety is another area where AI-enabled tools are being employed. Mining operations are a high-risk environment due to small workspace, inadequate lighting, contact with

[1] The Democratic Republic of the Congo, for example, has had a long history with natural resource exploitation and human rights and governance issues that may be exacerbated by the increased demand for high capacity batteries (Conca, 2018; UNEP, 2022).

[2] This research is part of a larger IEAI project *The Potential for AI in the Extractive Industries to Promote Multi-objective Optimization*.

toxic waste and gasses and inhalation of particles. For this reason, AI tools have been created to limit workers' exposure to these conditions through machines that 'autonomously monitor the atmosphere, send signals and warnings, locate problematic areas and work continuously even in dangerous situations' (Hyder et al., 2019).

AI is also being used in operational processes. Autonomous mining haulage trucks, such as from the company Caterpillar, have created a 15% reduction in operating costs due to the fact that these trucks can function continuously without breaks or changes in shifts (Dyson, 2017). This would also likely add to worker/driver safety.

Other AI-enabled tools are in development. To further improve worker conditions, robots or sensors that investigate the areas of concern and collect data on the levels of dangerous gasses, toxic dust and radiation in the mine can be used before human interaction with the area (Zhao et al., 2017). These systems would additionally trigger alarms or signals and/or redirect ventilation networks whenever unsafe conditions occur. This would not only improve working conditions, but could also aid in reducing breaks, increasing productivity, and lower risks of accidents and related costs (Hyder et al., 2019).

Within production, autonomous machines may soon be able to calculate things such as rock strength and hardness or monitor gas and methane, all while surveilling roof conditions (He et al., 2019; Isleyen et al., 2021; Wang et al., 2008). The data from these operations are collected and then used to analyze working conditions so that informed decisions can be made and corrective actions can be taken in the case of error or malfunction (Ge et al., 2022).

Another sector with potential applications for AI-enabled tools is in mineral processing, in which systems use color-sorting, X-ray transmission, or near-infrared sensors to eliminate waste. This would be useful in identifying various physical, mineralogical and chemical properties. These processes would, in turn, 'greatly increase the efficiency of the communication process and reduce energy cost as crushing and grinding are the most energy consuming and least energy efficient parts of the mineral processing cycle' (Hyder et al., 2019). Thus, improving efficiency and sustainability.

Moreover, data investigation and visualization methods have the opportunity to predict and consequently prevent potentially dangerous situations or eliminate the need for human work within hazardous environments, such as transporting, loading and triggering explosives, installing roof supports or removing toxic gasses and dust (Narkhede et al., 2021). Moreover, AI can help improve operational efficiency throughout the supply chain, predicting maintenance, reducing waste or lower transportation costs, among others (Kaack et al., 2020)

AI-enabled tools have the potential to help improve the comprehensiveness or sustainability of decision-making in mining operations.

Moving beyond economic and efficiency gains, AI-enabled tools have the potential to help improve the comprehensiveness or sustainability of decision-making in mining operations. By incorporating not only large amounts of economic data, but also significant amounts of data on environmental, land use, communities, and governance factors, multi-objective optimization of operations through machine learning processes is potentially useful.[3] By being able to better explore the interconnectedness of different types of ecosystems and quickly identify things such as the type of ground cover through AI-enabled image detection for earth observation, AI could contribute to more sustainable mining (Vinuesa et al., 2020).

Finally, AI has a potential role in monitoring mining sites and environmental or worker safety violations by companies or the government. For instance, some of the same technologies being already used to monitor biodiversity (Arteta et al., 2016; Kesari, 2019; Microsoft, 2020) or detect air or water

[3] For more information and emerging research on this idea, see the IEAI project *The Potential for AI in the Extractive Industries to Promote Multi-objective Optimization*.

pollution violations (Clean Water AI, n.d.; Carbon Tracker Initiative, 2020), could help governments in mining communities also monitor violations. Earth observation techniques that employ machine learning can also potentially aid in identifying illegal mining, speeding up verifications or administration for land management or identifying and planning for effective reclamation of land.[4] On the company side, facial recognition and image detection systems are already being used in public spaces (Tucker, 2020) and could potentially aid in monitoring and responding to trespassers or other perimeter/entry aspects of mining site operations.

There is a significant potential for the use of these tools to expand beyond narrowly defined uses and instead be used to monitor workers and surrounding communities in ways that may defy ethical principles or community expectations.

Challenges in the Implementation of AI in the Mining Industry and Ethical Considerations

Although the introduction of AI-enabled tools within the mining industry has the potential to optimize practices at different points of production and operations, the economic, environmental and societal impacts of using these tools come with tradeoffs and potentially significant ethical challenges.

Ethical considerations in the development and use of AI are coming increasingly to the forefront of corporate and political discussions. Floridi et al. (2018), for instance, outlined five core principles of ethical AI: beneficence, non-maleficence, autonomy, justice, and explicability.[5] Taking these principles as a starting point, we focus on four main ethical considerations for the use of AI in the mining industry: (1) autonomy and observation, (2) balance of rewards, (3) bias and prioritization and (4) explainability and acceptance.

Autonomy and Observation:

As with the introduction of AI within various other fields, there remains pushback from stakeholders, such as workers, supervisors, surrounding communities and researchers, on how these tools could negatively impact job availability, social systems and relations between workers (Cazes, 2021). These fears lie in anxieties about automation tasks taking over the role of humans within the workforce, as well as increased surveillance leading to a loss of data privacy or ability to independently make decisions. Automated vehicles or monitoring systems have the potential to replace human drivers or operators. Nevertheless, the increased safety benefits of these same tools have to be considered alongside the potential for job costs. Thinking about systems that enhance rather than replace human workers, or use human-in-the-loop methods, would help alleviate the negative impacts of these innovations.

Moreover, if surveillance or facial monitoring tools are employed as mentioned above, for environmental impact monitoring, worker safety or the securing of mining site perimeters, there is a significant potential for the use of these tools to expand beyond narrowly defined uses and instead be used to monitor workers and surrounding communities in ways that may defy ethical principles or community expectations. Therefore, these surveillance systems need to be designed and implemented with privacy and human right preserving parameters in mind (Fontes et al., 2022).

Overall, the tradeoff between (1) improved efficiency and safety and (2) loss of worker/community autonomy and privacy needs to be considered as AI-enabled tools are increasingly being used at mining sites.

[4] The IEAI affiliated project, *Artificial Intelligence for Earth Observation: Reasoning, Uncertainties, Ethics and Beyond (AI4EO)* is working on some of these applications, as well as the ethical considerations related to them.

[5] Beneficence puts forth the promotion of well-being, perseveration, and dignity. Non-maleficence ensures privacy, security, and "capability caution" (upper limit of future AI capabilities). Autonomy involves finding a balance between the decision-making power that lies in the hands of humans and the one which is attributed to AI. Justice entails creating benefits that are (or could be) shared in order to preserve solidarity. Explicability, a concept particularly applicable to AI ethics, involves enabling the principles through intelligibility and accountability.

Balance of Rewards:

Issues related to the ethical principle of justice come into play when we think about the ‘winners’ and ‘losers’ that result when new technologies are employed. Potential discrepancies in this balance of rewards come into question when we think about the balance of benefits between companies or between countries. Due to the lack of local capital or relevant skills to maintain relative pace in terms of the progress of an AI-enabled mining industry, smaller firms may benefit less from these technological developments than the already advantaged international and large-scale firms.

Moreover, when we talk about mechanisms for monitoring environmental violations, smaller or underdeveloped governments may not have the capital to develop or employ these tools on the same level as big mining countries in the Global North, such as Canada, Austria or the US. This could potentially exacerbate, rather than correct, the often geographically determined effects of the resource curse, distorting the balance of potential rewards from the use of AI.

Furthermore, we can also think of the balance of rewards as it relates to beneficence. AI has the potential to lower some environmental costs of mining through more efficient mineral processing, transport or machine uses or more accurate environmental violation monitoring. However, AI tools come with their own environmental footprint that needs to be considered (Coeckelbergh, 2021).

Even more significantly, making mining more efficient and profitable could lead to the over-extraction of minerals or unnecessary growth in the mining of dirty resources as well, such as coal. Making the extraction of minerals easier may help speed up our transition away from fossil fuels in some ways, but the same tools may make fossil fuels cheaper to extract, delaying that transition as well (Victor, 2019). Therefore, we have to think about how and where these tools are being employed in order to make sure they contribute to broader sustainability goals rather than slowing them down.

Finally, AI may increase economic efficiency for companies or may even reduce energy costs, promoting environmental goals, but the large amounts of data it may require to do this may come at the expense of the privacy of those providing the data (such as workers). This once again affects the balance of the rewards. In this case, those designing and employing AI in the mining sector need to think about the tradeoffs between the effectiveness of the tool and the data-gathering implications of those who are proving the data.

***Making the extraction of minerals easier may help speed up our transition away from fossil fuels in some ways, but the same tools may make fossil fuels cheaper to extract, delaying that transition as well*.**

Bias and Prioritization:

The use of large amounts and varieties of data to employ AI applications within the mining sector is necessary to generate the accuracy and efficiency of related tools. However, issues related to the principle of justice come into play here. Particularly for employing AI-enabled applications in mining regions in the Global South, the data available to train AI systems may be inappropriate for the context in which the tool will ultimately be used. This could lead to a bias in decisions or outputs due to a lack of local or representative data *(*Australian Resources & Investment, 2021*)*.

For instance, if facial recognition systems are not designed with the local population in mind (i.e. in Sub-Saharan Africa, where a large number of workers and community members would be people of color), they might be less accurate (Raji et al. 2020). If we want to factor environmental, cultural (i.e. language), governance or community-level data into machine learning applications used in the mining industry, this may be less available or accurate in certain regions of the world.

Moreover, the concepts commonly identified in AI ethics discourses come with their own geographical bias that may distort what issue should be salient or relevant for a given context (ÓhÉigeartaigh et al., 2020; Roche et al., 2022), particularly when we are talking about AI being used in regions outside of the Global North. For this reason, the involvement of local or regional stakeholders at all levels: company directors, workers, international and local policymakers and the surrounding community is vital to reducing these potential data bias issues.

Lastly, we also have to think about the issue of prioritization of data indicators and whom this ends up benefiting. For example, with the concept of multi-objective optimization of mining activities, the idea is to use data from multiple facets of the operational environment (i.e. not only profit-related data but also data on environmental, cultural, social and governance-related impacts) to arrive at decisions. However, someone designing that system still has to make decisions about the value or weight given to each facet. Do we prioritize optimization of the environment or of cultural land use over community development? Who is accountable for that prioritization, and how do we manage or justify the tradeoffs between different types of prioritizations? These are the questions designers and employers of these tools need to think about.

*Explainability and Understanding***:**

A final category of ethical consideration is explicitly related to the principle of explainability and concept of transparency in AI systems (Angelovet al., 2021; Larsson & Heintz, 2020). The worries of mine workers that they will be put out of work by AI or the concerns of local governments or community members about the use of surveillance systems around mines can be managed and alleviated to some extent through knowledge sharing, explainable and transparent systems and stakeholder engagement. As mining is inexplicably tied to the land and, therefore, the physically surrounding communities, it is paramount to build local community understanding and acceptance through transparency and education on the creation of these technologies, their methods and the extent to which they are or will be employed.

Companies considering using more invasive AI-enabled tools should work with employees and communities to gain acceptance of how these tools will be used. Stakeholder engagement to explain what AI does and does not do and to obtain real consent for use is key here. Not only does this link clearly to the responsible or ethical use of AI-enabled tools, but it also can help with accuracy. If communities and workers understand the tradeoffs of new technologies and systems built with human-in-the-loop designs in mind, they will be more willing to engage with the systems, improving the accuracy of data and use.

Final Thoughts

The use of AI-enabled tools in the mining industry is already underway. Given the key role of this sector in the energy transition and the speed with which that transition needs to occur, AI has the potential, if used correctly, to increase the efficiency of this process. If AI is employed while factoring in sustainability and community development needs, the potentially negative ethical implication of AI use could be significantly reduced. However, if considerations for the ethical use of these tools, and the tradeoffs that accompany their use, are not taken into account, we risk losing the opportunity to transition away from fossil fuels in a sustainable and planet/ human-centric way. Thus, it is a pressing and worthwhile endeavor for both industry players and policymakers to take an ethical and holistic perspective on the use of AI in the mining sector.

References

Angelov, P.P., Soares, E.A., Jiang, R., Arnold, N.I., & Atkinson, P.M. (2021). Explainable artificial intelligence: an analytical review. Wiley Interdisciplinary Reviews: Data Mining andKnowledge Discovery, 11(5), e1424.https://doi.org/10.1002/widm.1424.

Australian Resources & Investment. (2021, June 24). Ethical considerations of artificial intelligence in mining. https://www.australianresourcesandinvestment.com.au/2021/06/07/ethical-considerations-of-artificial-intelligence-in-mining/

Böhmer, M., & Kucera, M. (2013). Prospecting and Exploration of Mineral Deposits (ISSN) (2nd ed.). Elsevier Science.

Cazes, S. (2021, December). The impact of artificial intelligence on the labour market: What do we know so far?: OECD. https://www.oecd.org/publications/the-impact-of-artificial-intelligence-on-the-labour-market-7c895724-en.htm

Collier, P., (2007). The Bottom Billion: Why the Poorest Countries are Failing and What Can Be Done About It. Oxford University Press, Oxford.

Conca, J. (2018, September 26). Blood Batteries - Cobalt And The Congo. Forbes. https://www.forbes.com/sites/jamesconca/2018/09/26/blood-batteries-cobalt-and-the-congo/

Dyson, N. (2019, September 5). BHP to double autonomous trucks at Jimblebar. Mining Magazine. https://www.miningmagazine.com/innovation/news/1331400/bhp-to-double-autonomous-trucks-at-jimblebar

Floridi, L., & Cowls, J. (2019). A Unified Framework of Five Principles for AI in Society. Harvard Data Science Review, 1(1). https://doi.org/10.1162/99608f92.8cd550d1

Fontes, C., Hohma, E., Corrigan, C.C. & Lütge, C. (2022). AI-powered public surveillance systems: why we (might) need them and how we want them. Technology and Society, 71. https://doi.org/10.1016/j.techsoc.2022.102137

Ge, S., Wang, F.-Y., Yang, J., Ding, Z., Wang, X., Li, Y., Teng, S., Liu, Z., Ai, Y., & Chen, L. (2022). Making standards for smart mining operations: Intelligent Vehicles for Autonomous Mining Transportation. *IEEE Transactions on Intelligent Vehicles*, *7*(3), 413–416. https://doi.org/10.1109/tiv.2022.3197820

Goldspot Discoveries. (n.d.). Goldspot discoveries helps monarch mining find new gold-rich zones at the BEAUFOR Gold deposit using artificial intelligence. GoldSpot Discoveries Corp. https://goldspot.ca/news/goldspot-discoveries-helps-monarch-mining-find-new-gold-rich-zones-at-the-beaufor-gold-deposit-using-artificial-intelligence/

He, M., Zhang, Z., Ren, J., Huan, J., Li, G., Chen, Y., & Li, N. (2019). Deep convolutional neural network for fast determination of the rock strength parameters using drilling data. *International Journal of Rock Mechanics and Mining Sciences*, *123*, 104084. https://doi.org/10.1016/j.ijrmms.2019.104084

Hyder, Z., Siau, K., & Nah, F. (2019). Artificial Intelligence, Machine Learning, and Autonomous Technologies in the Mining Industry. Journal of Database Management, 30(2), 67–79. https://doi.org/10.4018/jdm.2019040104

IEA. (2021). The Role of Critical Minerals in Clean Energy Transitions, International Energy Agency, Paris. https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions

Isleyen, E., Duzgun, S., & McKell Carter, R. (2021). Interpretable deep learning for roof fall hazard detection in underground mines. Journal of Rock Mechanics and Geotechnical Engineering, *13*(6), 1246–1255. https://doi.org/10.1016/j.jrmge.2021.09.005

Jeswiet, J., & Szekeres, A. (2016). Energy Consumption in Mining Comminution. Procedia CIRP, 48, 140–145. https://doi.org/10.1016/j.procir.2016.03.250

Jung, D., & Choi, Y. (2021). Systematic review of machine learning applications in mining: Exploration, exploitation, and reclamation. Minerals, 11(2), 148. https://doi.org/10.3390/min11020148

Kaack, L., Donti, P.L., Strubell, E., Rolnick, D. (2020). Artificial Intelligence and Climate Change: Opportunities, considerations, and policy levers to align AI with climate change goals. E-Paper. Heinrich-Böll Stiftung.

Kappal, S. (2017, October 13). The Biggest Challenges in Implementing AI. dzone.com. https://dzone.com/articles/the-biggest-challenges-in-implementing-ai

Larsson, S. & Heintz, F. (2020). Transparency in Artificial Intelligence. Internet Policy Review, 9 (2). https://doi.org/10.14763/2020.2.1469.

Lèbre, É., Stringer, M., Svobodova, K. et al. (2020). The social and environmental complexities of extracting energy transition metals. Nature Communications 11, 4823. https://doi.org/10.1038/s41467-020-18661-9

Mackenzie, Wood. (2020, October 29). The Energy Transition Will Be Built With Metals. Forbes. https://www.forbes.com/sites/woodmackenzie/2020/10/29/the-energy-transition-will-be-built-with-metals

Murphy, P. (2019, April 2). How AI technology can make mining more productive. IBM. https://www.ibm.com/blogs/client-voices/ai-technology-mining-productive/

Narkhede, P., Walambe, R., Mandaokar, S., Chandel, P., Kotecha, K., & Ghinea, G. (2021). Gas detection and identification using multimodal artificial intelligence based sensor fusion. Applied System Innovation, 4(1), 3. https://doi.org/10.3390/asi4010003

ÓhÉigeartaigh, S.S., Whittlestone, J., Liu, Y., Zeng, Y. & Liu, Z. (2020) Overcoming Barriers to Cross-cultural Cooperation in AI Ethics and Governance. Philos. Technol. 33, 571–593. https://doi.org/10.1007/s13347-020-00402-x

Raji, I.D., Gebru, T., Mitchell, M., Buolamwini, J., Lee, J., & Denton, E. (2020). Saving Face: Investigating the Ethical Concerns of Facial Recognition Auditing .Proceedings of the 3rd AAAI/ACM Conference on Artificial Intelligence, Ethics, and Society (AIES), ACM (2020).

Roche, C., Wall, P.J. & Lewis, D. (2022). Ethics and diversity in artificial intelligence policies, strategies and initiatives. AI Ethics. https://doi.org/10.1007/s43681-022-00218-9

Roe, A.R. (2016, November 17). Like it or not, poor countries are increasingly dependent on mining and oil & gas. UNU-WIDER. https://www.wider.unu.edu/publication/it-or-not-poor-countries-are-increasingly-dependent-mining-and-oil-gas

Sachs, J.D., Warner, A.M., (1995). Natural resource abundance and economic growth. Natl. Bur. Econ. Res. Work. Pap. Ser. Working Paper 5398.

Sachs, J.D., Warner, A.M., (2001). The curse of natural resources. Eur. Econ. Rev. 45, 827–838.

Sala-i-Martin, X., Subramanian, A., (2003). Addressing the Natural Resource Curse: An Illustration from Nigeria. NBER Work. Pap. 9804.

Sengupta, M., (2021). Environmental impacts of mining: Monitoring, restoration and control. CRC Press. https://doi.org/10.1201/9781003164012

Tucker, A. (2020). The Citizen Question: Making Identities Visible Via Facial Recognition Software at the Border. IEEE Technology and Society Magazine, 39 (4), 52-59. https://doi.org/10.1109/MTS.2020.3031847

United Nations Environmental Program (UNEP). (2019). Mineral Resource Governance in the 21st Century: Gearing Extractive Industries Towards Sustainable Development - Summary for Policymakers and Business Leaders. United Nations Environment Programme. https://www.unep.org/resources/report/mineral-resource-governance-21st-century

United Nations Environmental Program (UNEP). (2022, September 20). Can the Democratic Republic of the Congo's mineral resources provide a pathway to peace? https://www.unep.org/news-and-stories/story/can-democratic-republic-congos-mineral-resources-provide-pathway-peace

United Nations. (2021, May). Transforming Extractive Industries for Sustainable Development. https://www.un.org/sites/un2.un.org/files/sg_policy_brief_extractives.pdf

UNSDSN. (2016). Mapping Mining to the Sustainable Development Goals: An Atlas. Columbia Center on Sustainable Investment, United Nations Development Programme, UN Sustainable Development Solutions Network, World Economic Forum.

https://www.undp.org/publications/mapping-mining-sdgs-atlas.

Victor, D.G. (2019). How Artificial Intelligence will affect the Future of Energy and Climate. A BluePrint for the Future of AI. Brookings Institute, 10 January 2019.

Vinuesa, R., Azizpour, H., Leite, I., Balaam, M., Dignum, V., Domisch, S., Felländer, A., Langhans, S.D., Tegmark, M. & Nerini, F. F. (2020). The role of artificial intelligence in achieving the Sustainable Development Goals. Nature Communications, 11(1), 1-10.

Wang, X. R., Lizier, J. T., Obst, O., Prokopenko, M., & Wang, P. (2008). Spatiotemporal Anomaly Detection in Gas Monitoring Sensor Networks. Lecture Notes in Computer Science, 90–105. https://doi.org/10.1007/978-3-540-77690-1_6

Zhao, J., Gao, J., Zhao, F., & Liu, Y. (2017). A Search-and-Rescue Robot System for Remotely Sensing the Underground Coal Mine Environment. Sensors, 17(10), 2426. https://doi.org/10.3390/s17102426