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# Converging technologies to monitor pollution, and its legal

## approach for sustainable development

Tecnologías convergentes para monitorear la contaminación ambiental y su enfoque legal para el desarrollo sostenible

Tecnologias convergentes para o monitoramento da poluição ambiental e sua abordagem legal para el desenvolvimento sustentável

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**Abstract**

The objective of this review was to make visible cases in which Converent Technologies -CT- (such as technological platforms, real-time sensor images, Mahine Learning / Deep learning, Internet of Things (IoT)), are used to monitor and characterize pollution in air, soil, and water; as well as illustrating how from legal schemes, the development of technologies can be promoted with a fundamentally sustainable approach. The method used consisted of review of practical cases, scientific articles, related to the use of TC to monitor pollution in the environment (both in water, air and soil) in various countries; and legal documents (such as laws, judgments... at the international level, as well as in Colombia) that allow to understand the need to develop technologies for sustainable development. Among the main conclusions, the importance of TC to control pollutants in air, water and soil stands out, as well as to make visible legal tools that promote technological development to support sustainable development.
KEYWORDS: technologies; pollution; law; sustainability.

**Resumen**

El objetivo de esta revisión fue visibilizar casos en los que se utilizan Tecnologías Convergentes -TC- (como plataformas tecnológicas, imágenes de sensores en tiempo real, Aprendizaje Automático / Aprendizaje Profundo, Internet de las Cosas (IoT)) para monitorear y caracterizar la contaminación en el aire, suelo y agua; así como ilustrar cómo desde los esquemas legales se puede promover el desarrollo de tecnologías con un enfoque fundamentalmente sostenible. El método utilizado consistió en revisar casos prácticos, artículos científicos relacionados con el uso de TC para monitorear la contaminación en el medio ambiente (tanto en agua, aire como suelo) en varios países; y documentos legales (como leyes, fallos... a nivel internacional, así como en Colombia) que permiten comprender la necesidad de desarrollar tecnologías para el desarrollo sostenible. Entre las principales conclusiones, destaca la importancia de las TC para controlar los contaminantes en el aire, agua y suelo, así como para visibilizar herramientas legales que promuevan el desarrollo tecnológico en apoyo al desarrollo sostenible.
PALABRAS CLAVE: tecnologías; contaminación; derecho; sostenibilidad.

**Resumo**

O objetivo desta revisão foi destacar casos em que Tecnologias Convergentes (CTs) (como plataformas tecnológicas, imagens de sensores em tempo real, Aprendizado de Máquina/Aprendizado Profundo, Internet das Coisas (IoT)) são usadas para monitorar e caracterizar a poluição no ar, no solo e na água; e ilustrar como os esquemas legais podem promover o desenvolvimento de tecnologias com uma abordagem fundamentalmente sustentável. O método utilizado consistiu na revisão de estudos de caso, artigos científicos relacionados ao uso de CTs para monitorar a poluição no meio ambiente (tanto na água quanto no ar e no solo) em vários países; e documentos legais (como leis, decisões... em nível internacional, bem como na Colômbia) que permitem compreender a necessidade de desenvolver tecnologias para o desenvolvimento sustentável. Entre as principais conclusões, destaca-se a importância das TCs para o controle de poluentes no ar, na água e no solo, bem como para a visualização de ferramentas jurídicas que promovam o desenvolvimento tecnológico em prol do desenvolvimento sustentável.
PALAVRAS-CHAVE: tecnologias; poluição; direito; sustentabilidade.

## 1. Introduction

Convergent technologies (CT) such as Machine Learning, Internet of Things (IoT), Virtual Reality and Augmented Reality (VR/AR), Big Data, among others (Rozo-García, 2020), are tools of vital importance that must be promoted by governments, industries and civil society to increase their use, acquire skills for their use (World Economic Forum, 2021). That is why it is required to develop processes of training and qualification of personnel in companies and diverse types of organizations (Silva & Rocha, 2020) to maximize the benefits of its use.

Proper implementation of CT could improve human rights conditions in value chains (World Economic Forum, 2021) the use, for example, of Blockchain, could favor the optimization of value chains (Heidrich *et al*., 2020); highlights the importance of CT when facing various restrictions on life and social processes that Covid-19 represented (World Economic Forum, 2018). The benefits of the correct application of TC would be potentiated with the establishment of metrics that allow obtaining data in real time, as well as generating the due analysis and making decisions that favor sustainability, such as the characterization, monitoring, and control of pollutants (Atik & Ünlü, 2019; Carrillo *et al*., 2020).

The objective of this review is to make visible cases in which Convergent Technologies -CT- (such as technological platforms, real-time sensor images, Machine Learning / Deep learning, Internet of Things (IoT)), are used to monitor and characterize pollution in air, soil, and water; as well as illustrating how from legal schemes, the development of technologies can be promoted with a fundamentally sustainable approach.

## 2. Diversity of pollution on water, air and soil

In this segment, there will be shown some cases in which the use of CT supported the monitoring and characterization of pollution in water, air, and soil (TABLE 1).

TABLE 1. Relation of CT used to monitor pollution on air, soil and water

| Environment/Component | CT & technique used | Polluter | Region/Location of the study | Conclusion of the et study | Reference |
|---|---|---|---|---|---|
| Water | Microscopic Image Readers, Real-Time Image Systems | Microplastics in invertebrate bodies (particulate matter) | Rockall Trough, North Atlantic, deep sea (>2.200 mts) | We found 78 potential microplastics (17 synthetic, 28 cellulose, 33 unclear spectrum) observed in three forms: Original, ingested by benthic invertebrates, and in deep waters | Courtene-Jones *et al*., 2017 |
| Water | Geoaccumulation Index (Igeo) with technological equipment for contaminant analysis | (Cd) Cadmium and (Pd) Palladium | Abandoned mine in Yaoposhan (Guangdong Province, China) | There is clear contamination in water and soil in the areas studied, causing damage to crops, soils, etc. Mainly by substances such as (Cd) Cadmium and (Pd) Palladium | Sun *et al*., 2020 |
| Soil and Water | Geoacumulation Index (Igeo) with technological equipment for the analysis of pollutants | Microplastics (particulate matter) | Níger River, delta | Approximately 9000 oil production wells in the Niger River Delta generate serious negative consequences on the environment, soil properties, plants and agricultural processes, as well as soil compilations, terrestrial fauna; germination, growth and development of plants | Chukwuka *et al*., 2018 |
| Soil | Geoacumulation Index (Igeo) with technological equipment for the | Mercury (Hg) | San Martín de Loba, Bolívar, Colombia | 93% of the sample points yielded results higher than those registered in countries such as the United States, | Rocha-Román *et al*., 2018 |

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|---|---|---|---|---|---|
| | analysis of pollutants | | | China, Slovenia, Germany, Canada. 87% of the samples used are classified as heavily contaminated | |
| Air | USEtox® Environmental Impact Assessment | Ecotoxic pollutants in water emissions | New Scotland-Canada | It is relevant to differentiate amounts of emissions of toxic substances, with the degree of toxicity of them; for example, copper has greater ecotoxic potential in water emissions, but only obtained <1% of emissions (amount) in the study data | Taylor *et al.*, 2020 |
| Air | Real-time air measurement stations | PM10 (Particulate Matter) | Cuenca (Ecuador) | There are higher PM10 (Particulate Matter) values higher than suggested by the WHO guideline, which is 20 ug/m3 | Palacios-Espinoza & Espinoza-Molina, 2014 |

The previous TABLE allows to detect how using diverse techniques and CT(such as Image Readers, Real-Time Image Systems, Geoaccumulation Index -Igeo-), regions, companies and communities can detect pollution in water, soil and air; the related studies (Chukwuka *et al*., 2018b; Courtene-Jones *et al*., 2017; Sun *et al*., 2020) shows pollution in water bodies related to microplastic in the water itself and also in some (micro)organism that live in water, in the same way, studies analyzed concluded that there was detection of Cd and Pd in water, which polluted soil, crops, flora, fauna, and so on; all this situation of degradation and pollution of water was caused by human-action, due to processes of mining, extraction of oil, and other sources.

In the same way, it was clear how CT (Geoacumulation Index -Igeo-) supported research to detect pollution in soil (Rocha-Roman *et al*., 2018), for instance, the presence of Hg in soil in Montes de María's region in Colombia, in a rate clear higher that the index of Hg found in compared countries. Technologies (USEtox® Environmental Impact Assessment) also allow to find that there are hazardous toxic substances in the air, polluting the quality of it, and in special, the related studied about air pollution, invites to differentiate the toxicity level of some substances (copper), focusing much more on toxicity that in the amount of (percentage) of substances found in air (Taylor *et al*., 2020); CT (Real-time air measurement stations) is an important allied to detect PM 10 in air (Palacios-Espinoza & Espinoza-Molina, 204), and define the level of pollution.

## 3. Cases of application of CT to monitor and characterize pollution

This fragment of the document, will be focused on the diversity of CT to monitor and characterize pollution, summarize in the following TABLE:

TABLE 2. Cases of use of CT to monitor and characterize pollution

| CT | Specific Technique - Technology | Polluter – Phenomenon | Conclusion of the study | Reference |
|---|---|---|---|---|
| Applied-Technological platforms | Real-time data analysis of 292 groundwater sites per continent (146 hours of reported work) | Nitrate ($NO_3^-$) | The presence of nitrates in groundwater is constantly growing, there are areas that have values higher than WHO standards (50 ppm), there are inadequate wastewater practices, wrong treatment of septic tanks, abusive use of fertilizers and pesticides in crops | Abascal *et al.*, 2022 |

| | | | | |
|---|---|---|---|---|
| Applied-Technological platforms | Low-cost technological platform 'Arduino' - which allowed to compare three data acquisition technologies, four wireless communication systems that complement a node and was interpreted by a network of wireless sensors | Several polluters | There are reliable inputs for environmental monitoring, it provides light on how affordable, low-cost and easily replicable technologies can help communities, regions, governments and companies to control, monitor and characterize pollutants in the environment | Tang *et al*., 2022 |
| Applied-Technological platforms | Analysis of real-time data analysis platforms on pollution, between 2014 and 2018 | Air pollutants such as PM, SO2, NOX and CO2 | There are some decreases in polluting emissions, but this does not happen in the same sense for the case of CO2 emissions | Espitia, 2014 |
| Machine Learning & Deep Learning | Analysis of air pollution forecasts, using the genetic algorithm (GA) method, as well as in the short-term memory Deep Learning Algorithm (LSTM) | Air polluters | Air pollution predictions based on the metaheuristic principle give a better prediction of outcomes than those that work to determine parameters manually | Drewil & Al-Bahadili, 2022 |
| Machine Learning & Deep Learning | In vitro and in vivo method PM2.5 exposure models (concentrated in hsa_circ_0005045) | PM2.5 (concentrated in hsa_circ_0005045) | There is reduced environmental emissions of PM2.5 provides a specific approach to protect non-smoking COPD patients against exacerbation of air pollution-related diseases | Meng *et al*., 2022 |
| Internet of Things (IoT) | DS18B20 sensor, as well as the NodeMCU device, and the subsequent storage of data in the cloud, and so it could be consulted from any device and web application. | Variation in temperature | The averages obtained manually (0.00776) are lower compared to what was obtained with the use of the proposed framework (0.01948), which means that with the use of the proposed framework it was possible to do a greater number of crop monitoring tasks compared to the manual way | Arteaga Quico & Wong Portllo, 2021 |
| Internet of Things (IoT) | Sensors to collect contaminants on land, data that was pooled on a website fed from the network of sensors that received information from monitoring toxins in the soil | Toxins in the soil. | It allowed to improve the management and control of pollutants by pate of the Centralized Committee for Pollution Control (CPCC) | Rayabharapu *et al*., 2022 |
| Real-time images and sensors | Google Street View and computer vision methods in high spatial resolution and was called Green View Index (GVI) | Urban green spaces at street level and air pollution | Higher levels of urban green space were associated with decreases in air pollution by (PM) | O'Regan *et al*., 2022 |
| Real-time images and sensors | Synthetic aperture radar -SAR- (specifically satellites such as Sentinerl-1A) | Oil spill areas | The total area of oil slick contamination of the water surface in the disaster area was 800 square kilometers | (Pashayev *et al*., 2018) |

Continued table 2

| | | | | |
|---|---|---|---|---|
| Real-time images and sensors | Synthetic aperture radar -SAR- (specifically satellites such as Sentinerl-1A) | Oil spill areas | The total area of oil slick contamination of the water surface in the disaster area was 800 square kilometers | (Pashayev *et al.*, 2018) |
| Real-time images and sensors | Satellite imagery of Landsat-4 (1987), Landsat-5 (1991, 1997, 2009), Landsat-7 (2000, 2003), Landsat-8 (2014, 2016, 2017), and Sentinel-2 (2019, 2021); PCI Geomatics software | Pollutants that affect snow-capped –glacier- mountains | It is estimated that the glacier of the Sierra Nevada del Cocuy will become extinct approximately by the year 2048, due to the rate of decrease in the glacial area of said mountain system, which has been reduced by 37.92% with reference to the first scene (year 1987) | Molano *et al.*, 2022 |
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Previous TABLE let to understand clearly how using diverse technologies, it can be detected punctually from different polluters (Tang *et al.*, 2022) the levels of pollution in various spheres and environments; for example, using Applied-Technological Platforms allows to define the level of NO3 in water, in a range of pollution higher than the WHO standards (Abascal *et al.*, 2022); as well as the level of increase or decrease of pollution from substances as PM, NOX, $CO_2$, SO2 (Piñeres-Espitia & Mejía-Neira, 2013).

Technologies like Machine Learning & Deep Learning, support the detection of pollution (decrease or increase) related to PM2.5 (Meng *et al.*, 2022); another technology used to monitor and control pollution is Internet of Things (IoT), technique that allows to conclude that using that methodology (technology) produce much more data related to crops temperature variation, and support better in order to monitor pollution than the manual technique (Arteaga-Quico & Wong-Portillo, 2021), as well as improves the management and control of toxins in soil (Rayabharapu *et al.*, 2022).

To complement the range of technologies, it was observed that the use of Real-Time Images and Sensors helped to determine the level of decrease of snow-capped-glacier in mountains due to variation in temperatures (Molano *et al.*, 2022), also to conclude that areas with more 'green spaces' reduce the concentrations of PM (O'Regan *et al.*, 2022), also, that the area of affectation-pollution in a particular case of oil spill, was around 800 square kilometers (Pashayev *et al.*, 2018). All these examples of usage of CT are evidence of how technologies are an important instrument for governments, companies, and society in order to measure, monitor, and control pollution.

## 4. Legal approach in favor of developing converging technologies focus on sustainability

All efforts related to the support for developing technologies in favor of sustainable development are valuable, even more, if they are conceived with a deep sustainable approach. In the international field, and in the framework of the seventy-sixth session of the General Assembly of the United

Nations that took place on July 26, 2022, the member states of said international organization ratified adopting measures to minimize environmental degradation, promoting a healthy environment, understanding as a healthy environment, including technologies with a sustainable approach (Resolución A/76/L.75, 2022).

Related to the promotion of technologies development to protect Human Rights, contemplated by the United Nations, they are applicable as *jus cogens* norms in the member countries, emphasizing that the use of technologies leads to the acceleration of the fulfillment of the Sustainable Development Goals (Pacto Mundial Red Española, 2019) established by said international entity, in the world community.

When developing a close up in the local (Colombia, home country of the authors of this paper) level, there was found that Colombian jurisprudence, in application of fundamental and universal rights, has been emphatic in establishing that children in rural schools require access to the Internet and new technologies to achieve their harmonious and structural development within the framework of the social environment (Corte Constitucional de Colombia, 2020b), this as an example about how technologies promotion can be developed with a sustainable scope.

In this same way, Colombia, within the framework of its constitutional principles, its essential purposes, and its fundamental rights, undertakes to prioritize access to and use of information and communications technologies in non-discriminatory conditions in connectivity, education to achieve sustainable participation in society. In addition, in the case of Colombia, the State undertakes to prioritize access to information and communications technologies in vulnerable areas of the nation, to comply with the essential purposes of the State (Congreso de la República de Colombia, 2019).

From a legal and judicial point of view, the highest constitutional organism in Colombia, has specified that there is a correlation between the new technologies implicit in electronic documents and legal certainty, reliability and above all, speed (Corte Constitucional de Colombia, 2020a), the latter being an indispensable legal value to carry out the principle "Prompt and Fulfilled justice" as a public service in charge of the state.

## 5. Conclusion

The review of cases, practical and legal sources consulted, allow us to glimpse the potential represented by CT on the two fronts analyzed: 1. monitoring and characterizing pollution in various scenarios such as air, soil and water; as well as 2. how the legal spectrum -both international, as in the specific case of Colombia- can support the promotion and dissemination of technological development in the country, with the purpose of promoting sustainable development.

The two scenarios in which the phenomenon of CT was analyzed, allow us to show that its development can be promoted with a focus directly related to sustainability; technologies can be understood beyond artifacts, or merely as a tool for economic purposes; rather, it can be developed for the protection of human rights and the environment.

## 6. References quoted

ABASCAL, E.; GÓMEZ-COMA, L.; ORTIZ, I. & A. ORTIZ. 2022. "Global diagnosis of nitrate pollution in groundwater and review of removal technologies". *Science of The Total Environment*, 810: 152233. Disponible en: https://doi.org/10.1016/j.scitotenv.2021.152233.

ARTEAGA QUICO, A. D. & L. R. WONG PORTLLO. 2021. "Framework for monitoring the temperature of aquaculture crops based on IOT". *DYNA*, 88(218): 239-246. Disponible en: https://doi.org/10.15446/dyna.v88n218.90626.

ATIK, H. & F. ÜNLÜ. 2019. "The Measurement of Industry 4.0 Performance through Industry 4.0 Index: An Empirical Investigation for Turkey and European Countries". *Procedia Computer Science*, 158: 852-860. Disponible en: https://doi.org/10.1016/j.procs.2019.09.123.

CARRILLO, J.; GOMIS, R.; DE LOS SANTOS, S.; COVARRUBIAS, L. & M. MATUS. 2020. "¿Podrán transitar los ingenieros a la Industria 4.0? Análisis industrial en Baja California". *Entreciencias: Diálogos en la Sociedad del Conocimiento*, 8(22). Disponible en: https://doi.org/10.22201/enesl.20078064e.2020.22.76089.

CHUKWUKA, K. S.; ALIMBA, C. G.; ATAGUBA, G. A. & W. A. JIMOH. 2018. "The Impacts of Petroleum Production on Terrestrial Fauna and Flora in the Oil-Producing Region of Nigeria". En: *The Political Ecology of Oil and Gas Activities in the Nigerian Aquatic Ecosystem*, pp. 125-142. Elsevier. Disponible en: https://doi.org/10.1016/B978-0-12-809399-3.00009-4.

CONGRESO DE LA REPÚBLICA DE COLOMBIA. 2019. *Ley 1978*. Disponible en: https://www.funcionpublica.gov.co/eva/gestornormativo/norma.php?i=98210.

CORTE CONSTITUCIONAL DE COLOMBIA. 2020a. *Sentencia C-662-00*. Disponible en: https://www.corteconstitucional.gov.co/relatoria/2000/C-662-00.htm.

CORTE CONSTITUCIONAL DE COLOMBIA. 2020b. *Sentencia T-030-20*. Disponible en: https://www.corteconstitucional.gov.co/Relatoria/2020/T-030-20.htm.

COURTENE-JONES, W.; QUINN, B.; GARY, S. F.; MOGG, A. O. M. & B. E. NARAYANASWAMY. 2017. "Microplastic pollution identified in deep-sea water and ingested by benthic invertebrates in the Rockall Trough, North Atlantic Ocean". *Environmental Pollution*, 231: 271-280. Disponible en: https://doi.org/10.1016/j.envpol.2017.08.026.

DREWIL, G. I. & R. J. AL-BAHADILI. 2022. "Air pollution prediction using LSTM deep learning and metaheuristics algorithms". *Measurement: Sensors*, 24: 100546. Disponible en: https://doi.org/10.1016/j.measen.2022.100546.

ESPITIA, G. P. 2014. "Plataformas tecnológicas aplicadas al monitoreo climático". *Prospectiva*, 11(2): 78. Disponible en: https://doi.org/10.15665/rp.v11i2.42.

HEIDRICH, F.; GONCALVES DE MORAIS, D. & J. BLUMETTI FACÓ. 2020. "La teoría de las opciones reales en la gestión de inversiones en la industria 4.0: Un estudio de caso". *Revista De Gestão, Finanças E Contabilidade*, 10(2): 60-85. Disponible en: https://www.revistas.uneb.br/index.php/financ/article/view/7304.

MENG, Q.; WANG, J.; CUI, J.; LI, B.; WU, S.; YUN, J.; ASCHNER, M.; WANG, C.; ZHANG, L.; LI, X. & R. CHEN. 2022. "Prediction of COPD acute exacerbation in response to air pollution using exosomal circRNA profile and Machine learning". *Environment International*, 168: 107469. Disponible en: https://doi.org/10.1016/j.envint.2022.107469.

MOLANO, S. M.; CARDENAS, D. P.; GÓMEZ, H. S.; ALVARADO, D. M.; GALINDO, A. F.; SANABRIA, J. F. & J. S. GÓMEZ-NEITA. 2022. "Evaluación del retroceso glaciar de la Sierra Nevada del Cocuy, Colombia a partir de la clasificación de imágenes multisensor". *Boletín de Geología*, 44(1). Disponible en: https://doi.org/10.18273/revbol.v44n1-2022002.

O'REGAN, A. C.; BYRNE, R.; HELLEBUST, S. & M. M. NYHAN. 2022. "Associations between Google Street View-Derived Urban Greenspace Metrics and Air Pollution Measured Using a Distributed Sensor Network". *SSRN Electronic Journal*, 87: 1-10. Disponible en: https://doi.org/10.2139/ssrn.4179128.

PACTO MUNDIAL RED ESPAÑOLA. 2019. *7 formas en las que la tecnología puede contribuir a los ODS*·

*Pacto Mundial*. Disponible en: https://www.pactomundial.org/noticia/7-formas-en-las-que-la-tecnologia-puede-contribuir-a-los-ods/.

PALACIOS-ESPINOZA, E., & C. ESPINOZA-MOLINA. 2014. "CONTAMINACIÓN DEL AIRE EXTERIOR. CUENCA - ECUADOR, 2009- 2013. POSIBLES EFECTOS EN LA SALUD." *Revista de La Facultad de Ciencias Médicas de La Universidad de Cuenca*, *32*(2), 6–17. file:///D:/DESCARGAS/Trabajo de titulación.pdf

PASHAYEV, N. M.; RAGIMOV, R. M.; SAMEDOV, F. R. & D. S. GAHRAMANOVA. 2018. "Aerospace monitoring of the oil pollution of the Caspian Sea on the base of GIS technology and radar space images". *IFAC-PapersOnLine*, 51(30): 558-560. Disponible en: https://doi.org/10.1016/j.ifacol.2018.11.266.

PIÑERES-ESPITIA, G., & MEJÍA-NEIRA, A. 2013. "Plataformas tecnológicas aplicadas al monitoreo climático." *Prospectiva*, 11(2): 78–87.

RAYABHARAPU, V. K.; RAMPUR, V.; JYOTHI, N. M.; TRIPATHI, V.; BHASKAR, T. & K. B. GLORY. 2022. "IOT sensor-based pollution management control technique". *Measurement: Sensors*, 24: 100513. Disponible en: https://doi.org/10.1016/j.measen.2022.100513.

RESOLUCIÓN A/76/L.75, 22-11599 1. 2022. Disponible en: https://digitallibrary.un.org/record/3982508?ln=es.

ROCHA-ROMÁN, L.; OLIVERO-VERBEL, J. & K. R. CABALLERO-GALLARDO. 2018. "Impacto de la minería del oro asociado con la contaminación por mercurio en suelo superficial de San Martín de Loba, sur de Bolívar (Colombia)". *Revista Internacional de Contaminación Ambiental*, 34(1): 93-102. Disponible en: https://doi.org/10.20937/RICA.2018.34.01.08.

ROZO-GARCÍA, F. 2020. "Revisión de las tecnologías presentes en la industria 4.0". *Revista UIS Ingenierías*, 19(2): 177-191. Disponible en: https://doi.org/10.18273/revuin.v19n2-2020019.

SILVA, M. V. G. DA & C. F. ROCHA. 2020. "Avaliação do Nível de Maturidade da Indústria 4.0: O Caso de uma Empresa Estratégica de Defesa". *Future Studies Research Journal: Trends and Strategies*, 12(1): 31-59. Disponible en: https://doi.org/10.24023/FutureJournal/2175-5825/2020.v12i1.455.

SUN, Z.; HU, Y. & H. CHENG. 2020. "Public health risk of toxic metal(loid) pollution to the population living near an abandoned small-scale polymetallic mine". *Science of The Total Environment*, 718: 137434. Disponible en: https://doi.org/10.1016/j.scitotenv.2020.137434.

TANG, L.; RUAN, J.; BO, X.; MI, Z.; WANG, S.; DONG, G. & S. J. DAVIS. 2022. "Plant-level real-time monitoring data reveal substantial abatement potential of air pollution and CO2 in China's cement sector". *One Earth*, 5(8): 892-906. Disponible en: https://doi.org/10.1016/j.oneear.2022.07.003.

TAYLOR, S.; EDWARDS, S. J. & T. R. WALKER. 2020. "A toxicity-based analysis of Canada's National Pollutant Release Inventory (NPRI): a case study in Nova Scotia". *Environmental Science and Pollution Research*, 27(2): 2.238-2.247. Disponible en: https://doi.org/10.1007/s11356-019-06933-x.

WORLD ECONOMIC FORUM. 2021. *Digital Culture: The Driving Force of Digital Transformation* (Number June). Disponible en: disponible en:

http://www3.weforum.org/docs/WEF_Digital_Culture_Guidebook_2021.pdf.

WORLD ECONOMIC FORUM. 2018. "The Future of Jobs Report". *Centre for the New Economy and Society*, 31(2): 164-173. Disponible en: http://reports.weforum.org/future-of-jobs-2018/.

WORLD ECONOMIC FORUM. 2021. *Digital Culture: The Driving Force of Digital Transformation* (Number June). Disponible en: http://www3.weforum.org/docs/WEF_Digital_Culture_Guidebook_2021.pdf.

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