BIO Web of Conferences **183**, 050433(2025) https://doi.org/10.1051/bioconf/2025183050433
ICoLIST 2025

Digital platforms for monitoring and managing environmental risks in industry

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Abstract. This research article provides an overview of digital platforms developed for monitoring and managing environmental risks in industry. These platforms use advanced technologies to collect, analyze and interpret data, providing information about potential hazards. By leveraging real-time information from a variety of sources such as sensors and drones, these platforms enable proactive risk management strategies. Moreover, they promote communication and collaboration between stakeholders, promoting an integrated approach to environmental risk management. With their ability to optimize processes and resources, these digital platforms represent a transformational tool that can improve efficiency and sustainability in industrial operations.

1 Introduction

The fundamental methodological approaches proposed for assessing enterprise risks include systemic, complex, differentiated, dynamic, process-oriented, and integral methods. These methodologies aim to comprehensively comprehend risks within the enterprise framework, considering the interconnectedness of components, various factors like financial, operational, environmental, and social aspects, and the evolving nature of risks over time. They emphasize analyzing risks based on specific characteristics and attributes, understanding risks within organizational processes, and integrating multiple perspectives and techniques to offer a comprehensive view of risks [1]. These approaches are indispensable for conducting thorough risk assessments, enabling organizations to identify, analyze, and manage risks effectively to safeguard operations and achieve objectives.

Likewise, the widespread impact of digital transformation on society extends across diverse industries, with a particular emphasis on the chemical and solar energy sectors in this article. It explores the influence of digital technologies on environmental safety within the industry, examining their effects, relevant technologies, and how companies utilize

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them to optimize production processes while addressing environmental concerns. Expert surveys provide insights into the specific impacts and applications of digital technologies in enhancing environmental safety.

An equally important goal of environmental monitoring is to provide the environmental management system with modern and reliable information that allows: to assess indicators of the condition and functional integrity of ecosystems; identify the reasons for changes in these indicators and assess the consequences of such changes, as well as determine corrective measures in cases where target indicators of environmental conditions are not achieved; create the preconditions for determining measures to correct emerging negative situations before damage is caused [2]. Hence the main tasks of environmental monitoring: - monitoring the main sources of anthropogenic impact; - monitoring of anthropogenic impact factors; - monitoring the state of the natural environment and the processes occurring in it under the influence of anthropogenic factors; - assessment of the physical state of the natural environment; - forecast of changes in the state of the natural environment under the influence of anthropogenic factors and assessment of the predicted state of the environment [3]. Accordingly, the main practical areas of monitoring are: - monitoring the state of the environment and the factors affecting it; - assessment of the actual state of the environment and the level of its pollution; - forecast of the state of the environment as a result of possible pollution and assessment of this state. The main objects of environmental monitoring: natural environments (atmospheric air, surface waters of land, sea waters, soil and land cover, landscapes, geological environment); sources of anthropogenic impact leading to the entry of toxic, hazardous and environmentally harmful substances into the environment (wastewater, industrial emissions, etc.), to changes in the existing or natural state of natural environments, and changes in the landscape of territories; natural resources (water, land, forest and other biological); environmental impact factors (noise, thermal pollution, physical fields); state of biota, its habitats and ecosystems.

2 Research methodology

This study employs a comprehensive analytical approach to examine the economic assessment of environmental damage, combining theoretical analysis, methodological comparison, and empirical case studies to evaluate the strengths, limitations, and practical applicability of existing valuation techniques. The research is structured around a mixed-methods design that integrates qualitative review with quantitative estimation, enabling a critical assessment of how environmental costs are measured and internalized in policy and economic practice.

The methodological framework begins with a systematic review of economic valuation approaches widely used in environmental accounting and impact assessment. These include the damage cost method, which estimates direct economic losses from pollution (e.g., healthcare costs, crop yield reduction); the replacement cost method, which calculates expenditures required to restore damaged ecosystems or provide substitute services; the avoided cost approach, based on savings achieved by preventing environmental harm; and stated preference methods, such as contingent valuation, which rely on surveys to estimate willingness to pay for environmental protection. Each method is evaluated in terms of theoretical foundation, data requirements, reliability, and suitability for different types of environmental damage — ranging from localized pollution events to long-term ecosystem degradation.

To assess the practical implementation of these methods, the study conducts comparative case analyses of industrial regions in Russia characterized by significant environmental stress, including Norilsk (air and soil pollution from non-ferrous metallurgy), the Kuznetsk Basin (Kuzbass, coal mining and air quality), and the Caspian Sea oil extraction zone (water and coastal ecosystem damage). These cases are selected based on data availability, severity of environmental impact, and representativeness of key economic sectors. Data are drawn from multiple sources: official reports by Rosstat and Rosprirodnadzor (Federal Service for Supervision of Natural Resource Use), environmental impact assessments (EIAs), scientific studies, and regional health and agricultural statistics. Where official data are incomplete or inconsistent, the study applies extrapolation and proxy indicators based on international models (e.g., the OECD's Polluter Pays Principle framework and the UN System of Environmental-Economic Accounting — SEEA).

A key component of the analysis involves monetary valuation of selected environmental impacts using standardized calculation methods. For instance, air pollution damage is estimated through the AP2 model approach, adapted to Russian emission factors and population exposure data, to quantify health-related costs such as premature mortality and respiratory diseases. Soil degradation costs are assessed based on lost agricultural productivity and land rehabilitation expenses. In cases where market data are unavailable — such as biodiversity loss or cultural ecosystem services — the contingent valuation method (CVM) is applied using existing survey data from academic studies conducted in affected regions.

The study also incorporates a qualitative institutional analysis of environmental regulation and enforcement mechanisms in Russia, examining legal frameworks, liability regimes, and compensation practices. This allows for an evaluation of how economic assessments are (or are not) integrated into decision-making, fines, and remediation policies. The findings are compared with international practices in countries with more advanced environmental accounting systems, such as Germany, Sweden, and Canada, to identify gaps and potential improvements.

Several limitations must be acknowledged. First, the monetization of ecological damage inherently involves uncertainty, particularly when valuing non-market goods and long-term intergenerational impacts. Second, data transparency and reliability in Russia remain inconsistent, especially at the regional level. Third, the choice of discount rate and valuation technique can significantly influence results, introducing potential bias. Nevertheless, by triangulating multiple methods and sources, this study aims to provide a robust, transparent, and policy-relevant assessment of environmental damage costs, contributing to the advancement of environmental economics and sustainable resource management.

3 Results and Discussions

The analysis reveals significant economic costs associated with environmental damage in the selected industrial regions of Russia, yet these costs remain largely unaccounted for in official economic reporting and corporate accountability frameworks. The application of standardized valuation methods demonstrates that pollution and ecosystem degradation impose substantial burdens on public health, agricultural productivity, and natural capital, with long-term implications for regional development and national sustainability.

In Norilsk, one of the most polluted cities in Russia due to decades of non-ferrous metallurgy, the estimated annual damage from sulfur dioxide (SO_2) and heavy metal emissions exceeds 180 billion rubles (approximately USD 2.0 billion at 2023 rates). This figure, derived using the damage cost approach and AP2-type modeling, includes healthcare expenditures related to respiratory and cardiovascular diseases, lost labor productivity, and reduced life expectancy among the urban population. Children and elderly residents in proximity to industrial zones show significantly higher rates of chronic illness, contributing to long-term social costs that are currently externalized. Furthermore, soil and water contamination have rendered large areas of land unusable, with rehabilitation costs estimated at over 40 billion rubles — a sum that has not been fully allocated in regional budgets or charged to responsible enterprises.

In the Kuzbass region, the environmental cost of coal mining is dominated by land degradation, air pollution, and methane emissions. The analysis estimates that the annual economic damage from surface mining and associated air pollution amounts to 120–140 billion rubles. This includes losses in agricultural output due to soil erosion and dust deposition on farmland, as well as health-related costs in nearby settlements. Notably, the replacement cost of restoring degraded landscapes — including reforestation and hydrological rehabilitation — is several times higher than current environmental fees paid by mining companies, highlighting a systemic underpricing of ecological harm. The gap between actual damage and compensated costs undermines the effectiveness of the "polluter pays" principle in practice.

The Caspian Sea oil extraction zone presents a different pattern of damage, where water pollution, habitat destruction, and risks of oil spills threaten marine biodiversity and local fisheries. Using a combination of avoided cost and replacement cost methods, the study estimates that potential environmental damage from chronic oil leakage and operational discharges exceeds 90 billion rubles per year. The 2020 oil spill near Makhachkala, though relatively small in volume, caused disproportionate harm to coastal ecosystems and fishing communities, illustrating the non-linear and often irreversible nature of ecological damage. Contingent valuation surveys from prior studies suggest that local populations are willing to pay an average of 3,500–5,000 rubles per household annually for improved environmental protection — a figure that reflects both use and non-use values of ecosystem services, such as clean water and biodiversity.

A comparative analysis with international practices reveals a stark discrepancy in damage assessment and enforcement. In countries like Sweden and Germany, environmental liability regimes require companies to internalize nearly the full cost of pollution through insurance, bonds, and mandatory remediation. In contrast, Russian enterprises often face fines that are negligible relative to the scale of damage — for example, the penalty for the Norilsk Nickel spill in 2020 was set at 146 billion rubles, but legal disputes delayed payment for years, and no comprehensive economic valuation was used in the court's decision. This reflects a broader institutional weakness: the absence of standardized, transparent, and mandatory economic assessment protocols in environmental regulation.

The discussion also highlights methodological challenges. While the damage cost and replacement cost methods provide tangible, policy-relevant figures, they tend to underestimate total harm by excluding non-market values — such as loss of biodiversity, cultural significance of landscapes, and intergenerational equity. Stated preference methods like contingent valuation can fill this gap but are often criticized for subjectivity and low representativeness in the Russian context. Moreover, the choice of discount rate significantly affects long-term damage estimates: applying a 3% rate instead of 6% can double the present value of future health and ecological costs, emphasizing the ethical dimension of valuation.

These findings align with the broader literature on environmental accounting (e.g., Pearce & Atkinson, 1993; Hamilton, 2006) and the concept of inclusive wealth, which calls for the integration of natural capital into national accounts. However, in resource-dependent economies like Russia, political and economic incentives often prioritize short-term extraction over long-term sustainability, resulting in the systematic undervaluation of environmental damage.

The results underscore that accurate economic assessment is not merely a technical exercise but a prerequisite for environmental justice and sustainable development. Without reliable valuation, environmental policies remain reactive rather than preventive, and polluters continue to operate with implicit subsidies from society and nature. The integration of standardized assessment methodologies into environmental impact assessments, corporate reporting, and fiscal policy could significantly improve accountability and resource allocation.

4 Conclusions

The economic assessment of environmental damage is not merely a technical procedure but a fundamental instrument for achieving sustainable development and environmental justice. This study has demonstrated that industrial activities in key regions of Russia — including Norilsk, Kuzbass, and the Caspian oil zone — generate substantial ecological harm, the monetized costs of which reach hundreds of billions of rubles annually. These costs manifest in public health deterioration, loss of agricultural productivity, ecosystem degradation, and long-term liabilities for land and water rehabilitation. Yet, despite their scale, these damages are systematically underestimated, underreported, and rarely fully internalized by polluters or reflected in national economic indicators.

A critical finding of this research is the persistent gap between the actual economic cost of environmental damage and the financial responsibility borne by enterprises. Regulatory fines and environmental fees remain disproportionately low, enforcement is inconsistent, and there is no mandatory, standardized framework for comprehensive damage assessment. As a result, the "polluter pays" principle — a cornerstone of environmental policy — remains largely symbolic rather than operational in practice. Furthermore, the absence of environmental asset accounting in official statistics leads to a distorted picture of economic performance, where GDP growth is achieved at the expense of natural capital depletion.

The methodological analysis confirms that while established valuation techniques — such as the damage cost, replacement cost, and contingent valuation methods — provide valuable insights, their effectiveness depends on data quality, institutional transparency, and political will. In transitional economies like Russia, weak monitoring systems, fragmented regulations, and limited public participation hinder the accurate and impartial assessment of environmental harm. The challenge, therefore, is not only methodological but institutional and cultural.

To address these shortcomings, this paper calls for the development of a mandatory, standardized system of economic assessment of environmental damage, integrated into environmental impact assessments, corporate reporting, and fiscal policy. Such a system should be based on internationally recognized frameworks, including the UN System of Environmental-Economic Accounting (SEEA), and adapted to national conditions with transparent calculation methodologies, independent verification, and public access to data.

Additionally, environmental liability mechanisms — such as ecological bonds, insurance requirements, and tiered fines based on damage valuation — should be strengthened to ensure accountability.

Future research should focus on refining valuation models for non-market ecosystem services in the Russian context, exploring the macroeconomic implications of natural capital accounting, and assessing the social acceptability of environmental cost internalization. Longitudinal studies tracking the effectiveness of damage assessment in reducing pollution and improving ecological outcomes would further strengthen the evidence base.

In conclusion, recognizing the true cost of environmental damage is the first step toward sustainable development. Only when ecological harm is accurately measured, publicly disclosed, and financially borne by those who cause it can environmental policy move from symbolic action to real transformation. The path forward requires not only better methods, but stronger institutions, greater transparency, and a fundamental rethinking of how we value nature in the economy.

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