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ARTICLE

INTELLIGENT SENSOR PLATFORMS AS SUSTAINABLE COMPETITIVE INTELLIGENCE SYSTEMS FOR STRATEGIC NATURAL RESOURCE MANAGEMENT

PLATAFORMAS INTELIGENTES DE SENSORES COMO SISTEMAS SUSTENTÁVEIS DE INTELIGÊNCIA COMPETITIVA PARA A GESTÃO ESTRATÉGICA DE RECURSOS NATURAIS

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ABSTRACT

Purpose: To examine the role of Internet of Things (IoT) technologies in enhancing environmental monitoring and enabling the precise management of natural resources within sustainability frameworks.

Methodology/approach: The study employs a systematic review of scientific literature, case study analysis, and general scientific methods (analysis, synthesis, induction, deduction), combined with a comparative assessment of IoT platforms, sensor types, software tools, and policy documents at national and European levels.

Originality/Relevance: The research emphasizes the integrated use of IoT sensors, cloud computing, and data analytics as a holistic mechanism for real-time environmental monitoring and evidence-based decision-making.

Key findings: IoT-based systems allow continuous monitoring of environmental indicators, early detection of risks, and improved data accuracy. Cloud technologies enhance storage and processing, while machine learning increases predictive capabilities. Nonetheless, adoption remains limited due to high costs, lack of standardization, and infrastructure constraints.

Theoretical/methodological contributions: The study systematizes the application of IoT in environmental management, demonstrating its potential to advance eco-innovation, optimize resource allocation, and support the development of effective environmental policies and governance strategies.

Keywords: Internet of Things. IoT. Ecology. Energy efficiency. Environmental and economic modelling. Sustainable use of resources. Development of coastal destinations. Maritime areas.

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RESUMO

Objetivo: Examinar o papel das tecnologias da Internet das Coisas (IoT) na melhoria da monitorização ambiental e na gestão precisa dos recursos naturais no âmbito da sustentabilidade.

Metodologia/abordagem: O estudo utiliza uma revisão sistemática da literatura científica, análise de estudos de caso e métodos científicos gerais (análise, síntese, indução, dedução), combinados com uma avaliação comparativa de plataformas IoT, tipos de sensores, ferramentas de software e documentos de políticas a nível nacional e europeu.

Originalidade/Relevância: A investigação enfatiza o uso integrado de sensores IoT, computação em nuvem e análise de dados como um mecanismo holístico para a monitorização ambiental em tempo real e a tomada de decisões baseada em evidências.

Principais resultados: Os sistemas baseados em IoT permitem a monitorização contínua de indicadores ambientais, a deteção precoce de riscos e a melhoria da precisão dos dados. As tecnologias de computação em nuvem melhoram o armazenamento e o processamento, enquanto a aprendizagem automática aumenta as capacidades preditivas. No entanto, a adoção permanece limitada devido aos elevados custos, à falta de padronização e às restrições de infraestrutura.

Contribuições teóricas/metodológicas: O estudo sistematiza a aplicação da IoT na gestão ambiental, demonstrando o seu potencial para promover a eco-inovação, otimizar a alocação de recursos e apoiar o desenvolvimento de políticas ambientais eficazes e estratégias de governação.

Palavras-chave: Internet das Coisas. IoT. Ecologia. Eficiência energética. Modelação ambiental e económica. Uso sustentável dos recursos. Desenvolvimento de destinos costeiros. Áreas marítimas.

1 INTRODUCTION

In the digital economy, environmental data have become a strategic resource for governments, regions and organizations. The ability to collect, process and interpret real-time ecological information increasingly determines the quality of natural resource management, risk prevention and sustainable competitive positioning. Therefore, intelligent sensor platforms should be analysed not only as technological tools for environmental monitoring, but also as information systems capable of generating sustainable competitive intelligence.

In the current digital economy, governments, regions and organizations are increasingly competing on the basis of access to and quality of information, in which real-time information has become a crucial enabler. The potential to acquire and process environmental information into strategic knowledge not only influences the efficient use of natural resources but also the opportunity to create long-term competitive advantages. Sustainable development at the global level is influenced by a variety of factors and their interactions between environmental conditions, economic development, education, agriculture, and industrial activities (Illiashenko et al., 2022; Kalina et al., 2022; Bielialov et al., 2023). Above all, the environment has been identified as the most strongly weighted factor in this list, as a clean and safe environment is necessary for human health, quality of life and sustainable socio-economic development. Environmental monitoring is an essential instrument to tackle ecological issues, allowing for the control of natural disasters, pollution abatement and the mitigation of environmental harm. It is a form of monitoring different indicators such as water and air quality, levels of radiation, climate and seismic activity, while taking into account that pollution can be induced by natural or human sources (Zinchenko & Filenko, 2020).

In this regard, the Internet of Things (further – IoT) has become more and more important as a technology basis for observation of the environment and management of its resources. Several literature suggest the potential of IoT to serve in monitoring ecosystems, make efficient use of natural resources and enable sustainability goals. For example, Bilovus and Tolstousova (2018) mention that gathering information in real time by IoT devices increases the opportunity to identify environmental issues at an early stage and take effective measures (Lüdeke-Freund, 2020). In this context, intelligent sensor platforms based on the Internet of Things (IoT) should be interpreted not only as tools for environmental monitoring, but also as infrastructures for generating strategic information. These systems continuously collect large volumes of environmental data, which can be transformed into actionable intelligence for decision-making.

However, the existing literature still focuses mainly on the technological and ecological functions of IoT-based monitoring systems. Much less attention is paid to the question of how environmental data are transformed into strategic intelligence, how this intelligence is used by decision-makers, and how it contributes to sustainable competitive advantage. This gap limits the theoretical understanding of intelligent sensor platforms as sustainable competitive intelligence systems.

Nevertheless, it is also the case that business development is heavily impacted by the interplay between technological innovation and environmental sustainability. The study of Boiarynova and Bychkovska (2020) reveals challenges and opportunities for enterprises to become eco-innovative, showing that the use of high technologies can decrease pollution and at the same time contribute to the economy. Kharchenko (2021) also believes that environmental innovation is a principal factor for sustainable development.

However, despite the rapid development of IoT technologies, most existing studies focus on their technical and environmental applications, while insufficient attention is paid to their role as systems of sustainable competitive intelligence. As a result, the transformation of environmental data into strategic knowledge, and further into competitive advantage, remains underexplored.

There is a significant research interest on the application of digital technologies and circular economy models in environmental sustainability. Horbal and Plish (2021) demonstrate that circular business models make it possible for Ukrainian companies to improve their environmental performance, while Komchatnykh (2021) highlights the importance of digital solutions in the green efficiency of logistics. Other articles deal with particular technological implementations, such as the exploitation of IoT for air and water quality monitoring (Kok et al., 2021), Water Condition Assessment Using IoT (Ighalo et al., 2020), and air quality prediction through artificial intelligence (further – AI) (Kok et al., 2021). However, despite the extensive literature on IoT technologies and environmental monitoring systems, most studies remain focused on technological applications and ecological outcomes. Much less attention is paid to how environmental data are transformed into strategic intelligence and how such intelligence contributes to sustainable competitive advantage. This gap limits the understanding of intelligent sensor platforms as sustainable competitive intelligence systems.

Nevertheless, though IoT technologies are rapidly evolving, the majority of current research is centered around technical and environmental applications with limited focus as systems for sustainable competitive intelligence. Therefore, the conversion of environmental information to strategic knowledge and then to competitive advantage is under investigated.

The combination of IoT and cloud computing is considered as the core enabler for the emergence of next generation environmental monitoring systems as well as smart city solutions. For instance, Jiang (2020) states that the integration approach is crucial to the improvement of system performance, and Bharati and Soma (2021) argue that it is an essential requirement for the development of intelligent monitoring systems. Ukrainian scholars, as well, highlight increasing environmental system connectivity within the digital economy. Kovtonyuk et al. (2023) deal with the ecological -information system synthesis, while Koblianska et al. (2021) are concerned with the creation of software for environmental innovation planning on the enterprise level.

In this regard, the concept of sustainable competitive intelligence becomes particularly relevant. It refers to a systematic process of collecting, processing, analysing and using information to support strategic decision-making. In environmental management, this implies transforming real-time ecological data into knowledge that guides resource allocation, risk reduction and long-term sustainability strategies.

Sustainable competitive intelligence is a strategic and proactive information management process that enables an organization to receive and use knowledge that facilitates the sustainability of its competitiveness. In terms of environmental management, the meaning of the concept is the conversion of real-time environmental data into strategic imagery to direct the deployment of resources, the management of risk, and the formulation of policies for future growth.

Also international practice confirms the possibility of using digitalisation to enhance air protection in other areas. The authors Dona and Drancenco (2021) suggest that digital transformation could serve as an enabler for economic growth and environmental sustainability. In the post-war reconstruction setting, eco-innovations are progressively perceived as a means to form business strategies that facilitate the full economic recovery and the enhancement of environmental performance (Illiashenko et al., 2022).

Despite occasional moments of technology and flashy graphics the series provides significant coverage of the legal and regulatory implications of digital transformation. Studies by Dutchak et al. (2020) and Khatniuk et al. (2023) highlight the need for development of strong legal regimes to promote accountable and sustainable deployment of enabling technologies such as IoT and artificial intelligence.

Other studies further emphasizes the importance of IoT in the improvement of decision making process based on real-time data. Kovalenko (2023) presents the ways in which IoT systems lead to better and more timely decisions by managers, while Kosovych (2021) highlights the possibility of fostering environment-friendly business in Ukraine via innovation. The overall conclusion of these reports suggests a significant opportunity to develop IoT based technologies to enhance environmental monitoring and resource management systems (Potwora et al., 2023).

Within this logic, intelligent sensor platforms operate as elements of an intelligence cycle that includes data collection, analytical processing, interpretation, dissemination and strategic use. Only through this transformation process can environmental data become a source of competitive advantage rather than merely a monitoring output.

In this context, the intelligent sensor platforms are functioning through a multi-step intelligence cycle. In a first step, environmental information is gathered from distributed sensor networks, satellites and unmanned aerial vehicles. In the second stage, the data are processed and analyzed with cloud computing, artificial intelligence, and machine learning (ML) algorithms. At the third level, analyzed data are turned into actionable intelligence. In the fourth phase, this intelligence is distributed to those that make the decisions. And at the fifth stage, it is applied to support strategic decisions that lead to greater resource efficiency, a reduction in risk, and a more sustainable competitive advantage.

Thus, the value of IoT-based environmental monitoring systems lies not only in their ability to observe environmental conditions, but also in their capacity to reduce informational asymmetry, improve decision quality and enhance the strategic positioning of organizations and territories.

However, although the theoretical and empirical advantages of IoT are strong and clear, in practice its application is still scarce.This shows a clear need for more focus on the application of such solutions, especially in Ukraine, where their capabilities to transform the environment and economy are still untapped (Zinchenko & Filenko, 2020).

Therefore, this study proposes to reinterpret intelligent sensor platforms as sustainable competitive intelligence systems and to develop a conceptual framework that explains how environmental data are transformed into strategic resources for natural resource management.

The central research question of this study is: under what conditions can intelligent sensor platforms be conceptualized as sustainable competitive intelligence systems for strategic natural resource management? The aim of this article is to develop and justify a conceptual framework that explains the transformation of IoT-generated environmental data into sustainable competitive intelligence for strategic natural resource management.

The contribution of this study lies in shifting the analytical focus from the technological capacity of IoT systems to their strategic role in the intelligence cycle, demonstrating how environmental data can be transformed into actionable intelligence that supports sustainable competitiveness. Importantly, this study does not assume the effectiveness of IoT systems a priori, but critically evaluates their potential and limitations in generating strategic intelligence and supporting decision-making processes.

2 TEORETICAL FRAMEWORK

Sustainable competitive intelligence represents a systematic process of collecting, processing, analysing, disseminating and using information in order to support strategic decision-making that simultaneously enhances competitiveness and sustainability. In contemporary conditions, competitive intelligence extends beyond traditional market analysis and includes environmental, technological and institutional data that influence long-term development trajectories of organizations and territories. From a theoretical perspective, the concept of sustainable competitive intelligence is closely related to the Resource-Based View (RBV), which emphasizes that sustainable competitive advantage is derived from valuable, rare, inimitable and non-substitutable resources. In the context of digital transformation, data and information become strategic resources, while the ability to process and interpret them determines organizational competitiveness.

At the same time, the Knowledge-Based View (KBV) considers knowledge as the most important strategic asset. Within this framework, environmental data collected by intelligent sensor platforms can be transformed into knowledge through analytical processing and artificial intelligence, and further into strategic intelligence that supports decision-making.

The Dynamic Capabilities approach complements these perspectives by highlighting the ability of organizations to integrate, build and reconfigure internal and external competencies in rapidly changing environments. In this sense, IoT-based monitoring systems enable organizations and governments to sense environmental changes, seize opportunities and transform their resource management strategies.

Thus, sustainable competitive intelligence can be conceptualized as a multi-stage process that transforms raw data into strategic value. In environmental management, this process includes the collection of ecological data, their analytical processing, interpretation in the form of actionable intelligence, dissemination among stakeholders and strategic use for improving resource efficiency and reducing risks.

2.1 Sustainable Competitive Intelligence and Environmental Decision-Making

The conclusion of that review was that the application of Internet of Things (IoT) technology in environmental monitoring and natural resource management is significant. Researchers are also exploring numerous other applications of the IoT in the monitoring of pollution, resource use and sustainability.In particular, IoT-based systems enable environmental data collection in real-time, enhancing the detection of emerging problems and the response efficiency (Bilovus & Tolstousova, 2018; Lüdeke-Freund, 2020).

Meanwhile, it is the modern business and science is the proof of that the environment plays an active role in evolving its viability. Research of Boiarynova and Bychkovska (2020) reveals challenges and possibilities for realization of eco-innovations in companies and proves that technology development can mitigate environmental harm and promotes economic development. Also, Kharchenko (2021) underlines ecological innovation to be a significant instrument of building a sustainable corporates.

There is a large amount of literature on the adoption of circular economy concepts by digital technologies in the field of environmental protection. For instance, Horbal and Plish (2021) prove that circular economy business models give the possibility for Ukrainian companies to improve their environmental performance, and Komchatnykh (2021) highlights to role of digital tools in promoting sustainability practices in the transportation industry. Other research deals with the use of IoT in air and water quality monitoring. Ighalo et al. (2020) review IoT-based water quality monitoring, while Kok et al. (2021) explore artificial intelligence for prediction of air quality.

The synergies of IoT and cloud computing have been broadly considered as the enabler of the new generation of smart city applications and services, as well as a key driver of innovative urban system and green management (Jiang, 2020; Bharati & Soma, 2021). In the Ukrainian case, scholars underpin the need for converging ecological and digital formations. Kovtonyuk et al. (2023) discuss the dynamics between ecological and information systems and Koblianska et al. (2021) discuss software tools for the organization of environment-friendly solutions in enterprises. In addition, Kalina et al. (2022) address the question, how sectors like mining can learn from international experience in digital environmental protection.

Worldwide experience consistently demonstrates the possibility of transformation of environmental and economic processes by means of digitalisation. Digital technologies are reshaping the economy and enabling sustainable development (Bielialov et al., 2023) and ecotechnology is a major contributor to post-war economic recovery (Illiashenko et al., 2022). At the same time, legal scholars like Dutchak et al. (2020) and Khatniuk et al. (2023) stress the necessity of legal frameworks to guard against abuse of such technologies as IoT, artificial intelligence, etc.

Elsewhere, research is directed towards the integration of IoT with data management platforms that enable resource governance. For example, Kovalenko (2023) proves that IoT technologies improve decision-making due to real time information access, but Kosovych (2021) investigates the impact of innovation on green entrepreneurship development in Ukraine. In general, the IoT technology provides great benefits in monitoring environmental and managing resources, is well proven in the literature (Potwora et al., 2023). Nevertheless, in contrast to these advantages, the realization is far from straightforward, pointing to a need for more focus on their deployment translating particularly in Ukraine (Zinchenko & Filenko, 2020).

In recent years there have been studies that also highlight the transformative effects of the IoT within digitalisation and Industry 4.0 as whole. Early results indicate that applications using IoT devices for quick data transmission enhance the quality of decision making processes (Nižetić et al., 2020). Several researchers link these trends to the Fourth Industrial Revolution where production systems and supply chains are becoming increasingly dependent on connected sensors and cloud-based infrastructures (Malik et al., 2021).

Recent developments in smart environmental monitoring show that low-cost sensors are suitable for monitoring air, water and soil quality. Empirical work indicates that these types of instruments are capable of delivering reliable data, when applying Machine Learning (further – ML) methodologies for signal processing and integration (Okafor et al., 2020; Sunny et al., 2020). In addition, state-of-the-art data fusion techniques can dramatically decrease error rates and lead to real-time alert systems (Ullo & Sinha, 2020).

Although the cross-sector applications were enumerated, the specific applications illustrate even more clearly the flexibility of the nature of IoT technologies. These include “Forest 4.0” initiatives that leverage wireless sensor networks to monitor forest conditions, including fire risk, poaching and wildlife patterns (Singh et al., 2022). IoT technology has also been applied to smart city applications, such as managing traffic flow, waste collection, and air pollution (Jiang, 2020). In the industry, robust sensor networks are deployed in hostile environments for contamination detection and the information is sent to cloud platform (Sunny et al., 2020).

There is also importance in policy frameworks and economic instruments to promote eco-innovation.So does the literature that environmental regulations and taxes can provide firms with incentives to adopt cleaner technologies and reduce energy use (Shao et al., 2020; Shahzad, 2020). Furthermore, studies on circular economy concepts demonstrate that digital technologies, including IoT, contribute to the improvement of resource reuse and recycling processes (Suchek et al., 2021).

In the case of Ukraine, analogous trends are observable, but a number of barriers persist.Reports suggest progress in pilot digital monitoring programmes for air and water quality, but widespread adoption is constrained by high costs and weak internet infrastructure in rural areas (Manko & Hanshyn, 2023). However, experts claim that integration of world best digital practices in the national system can significantly improve national results in sustainability (Bielialov et al., 2023; Vlasenko & Maistruk, 2023).

The latest technology developments ares also new sensing approaches that include flexible Surface-Enhanced Raman Spectroscopy (further – SERS) materials for the detection of hazardous agents (Bharati & Soma, 2021), and reflectance spectroscopy in the Operating System (further – OS) area that is related to machine learning techniques for the prediction of heavy metals content in soils (Zhao et al., 2022). Additionally, novel materials and systems were developed to monitor and mitigate oil spills in real-time (Sabadash, 2025).

Together, the outcomes of the studies show the following: cost is decreased, and access to data is increased with IoT technologies for monitoring; data quality and predictive capabilities are improved by machine learning; regulatory regimes stimulate the development of green information technologies; and demonstration works show applicability and gaps in infrastructure, finance, and standardisation.

2.2 Intelligent Sensor Platforms as Data-Driven Strategic Infrastructure

Intelligent sensor platforms based on the Internet of Things (IoT) can be considered as key elements of data-driven strategic infrastructure. These systems enable continuous data collection from multiple environmental sources, including air, water, soil and climate parameters, using distributed sensor networks, satellites and unmanned aerial vehicles.

Unlike traditional monitoring systems, IoT platforms provide real-time data flows, which significantly reduce informational asymmetry and allow decision-makers to respond to environmental changes more quickly and effectively. The integration of cloud computing and artificial intelligence further enhances the analytical capabilities of these systems, enabling pattern recognition, anomaly detection and predictive modelling.

Within the framework of sustainable competitive intelligence, IoT platforms perform not only technical but also strategic functions. They transform environmental data into actionable intelligence that can support decision-making at different levels, including organizational, regional and national. This allows stakeholders to optimize resource use, anticipate risks and improve environmental governance.

Furthermore, these platforms contribute to the formation of sustainable competitive advantage by improving the quality, speed and reliability of information flows. Organizations and territories that effectively utilize IoT-based intelligence systems are better positioned to adapt to environmental challenges, comply with regulatory requirements and implement sustainable development strategies.

Therefore, intelligent sensor platforms should be interpreted as integral components of sustainable competitive intelligence architecture, where data-driven insights become the basis for strategic resource management and long-term competitiveness.

Based on these theoretical considerations, the following sections examine the working of intelligent sensor platforms and the interpretation of their functionalities in the sustainable competitive intelligence logic more closely.

3 METHOD

The study is based on an integrated research design, in which aspects of systematic literature review, conceptual analysis and comparative evaluation are combined. The methodology is designed to explore whether intelligent sensor platforms may be viewed as sustainable competitive intelligence systems in environmental management and strategic decision-making. The study design is informing by precedent-based logic-based reasoning and includes several phases: data collection, screening, analysis, and conceptual synthesis. This perspective enables a holistic view of the evolving environmental data to strategic intelligence process and its use in enhancing sustainable competitiveness.

3.1 Data Collection and Selection Criteria

The data collection process was conducted through a structured search in major scientific databases, including Scopus, Web of Science, ScienceDirect, SpringerLink and Google Scholar. The search covered the period from 2015 to 2025 in order to capture recent developments in IoT technologies, environmental monitoring and competitive intelligence.

The main keywords used in the search included: “Internet of Things environmental monitoring”, “intelligent sensor platforms”, “sustainable competitive intelligence”, “environmental intelligence”, “data-driven decision-making”, “natural resource management” and “digital transformation”.

The initial search resulted in 312 publications. After removing duplicates and screening titles and abstracts, 124 articles remained. Following full-text analysis, 68 studies were selected for final inclusion.

The selection process followed a PRISMA-inspired logic, including identification, screening, eligibility and inclusion stages, ensuring methodological transparency and consistency of the review.

The inclusion criteria were: peer-reviewed articles, book chapters and conference papers focusing on IoT, environmental monitoring, artificial intelligence, competitive intelligence and sustainability. The exclusion criteria included duplicate publications, studies without full-text access, and purely technical papers without strategic or managerial implications.

The quality of the selected studies was evaluated based on relevance, methodological rigor, citation impact and contribution to the fields of environmental management and competitive intelligence.

3.2 Screening and Analytical Procedure

The analytical procedure included qualitative synthesis, comparative analysis and conceptual modelling. Initially, the selected studies were grouped according to their thematic focus, including technological applications, environmental monitoring systems, decision-making processes and competitive intelligence aspects. Comparative analysis was applied to identify similarities and differences across IoT applications in various environmental domains, such as air, water, soil and industrial monitoring. This allowed for the evaluation of their strategic relevance and contribution to sustainable competitiveness. Conceptual modelling was used to develop a framework that explains the transformation of environmental data into actionable intelligence and its integration into decision-making processes.

3.3 Systems and Conceptual Approach

he study adopts a systems approach, considering environmental management as a complex socio-technical system integrating technological, institutional and ecological components. Within this framework, IoT platforms are analysed as elements of a broader intelligence system connecting data collection, processing and decision-making.

This approach allows identifying the role of intelligent sensor platforms in reducing informational asymmetry, improving decision quality and enhancing adaptive capacity in dynamic environmental conditions.

This study adopts a structured research design combining elements of systematic literature review, conceptual analysis and comparative assessment. The objective of the methodological approach is to identify how intelligent sensor platforms can be interpreted as sustainable competitive intelligence systems within the context of environmental management.

The research process follows a multi-stage logic, including data collection, screening, analysis and conceptual synthesis. This approach ensures transparency, reproducibility and analytical consistency in the interpretation of the selected literature.

3.4 Methodological Limitations

Nonetheless, the study is not without limitations. It is based upon secondary data sources and does not involve primary empirical testing of IoT systems. Secondly, the conceptual model proposed in this study needs to be validated empirically in future research through case studies or survey research. Third, the translation of IoT platforms into competitive intelligence systems may also differ between institutional and technological environments.

Despite the structured approach, the study has certain limitations. It is based on secondary data sources and does not include primary empirical testing of IoT systems. In addition, the proposed framework is conceptual and requires further validation through empirical studies and quantitative analysis.

4 RESULTS AND DISCUSSION

The results of this study are interpreted through the lens of sustainable competitive intelligence. Rather than considering IoT technologies solely as tools for environmental monitoring, this section analyses how intelligent sensor platforms generate, process and transform environmental data into strategic intelligence that supports decision-making and enhances sustainable competitiveness.

The analysis shows that IoT-based systems operate at multiple decision-making levels. At the operational level, they enable real-time responses to environmental changes. At the tactical level, they support resource allocation and risk management. At the strategic level, they contribute to long-term planning and sustainable competitiveness of organizations and territories.

This multi-level impact distinguishes intelligent sensor platforms from traditional monitoring systems and confirms their role as sustainable competitive intelligence infrastructures.

From this perspective, environmental monitoring systems should be understood as data-driven infrastructures that reduce uncertainty and enable proactive governance. Their strategic value lies not in data collection itself, but in the ability to transform data into actionable intelligence.The sustained progress of a nation is largely determined by the new generations of its people and their capacity to take advantage of the tools of the time, currently digital technologies. Digitalization of science and strong digital literacy are necessary for scientific, technical and economic progress as well as for social well-being (Potwora et al., 2023; Bharati & Soma, 2021).

Current environmental monitoring systems are based on development of advanced technology and instrument and that increase the accuracy of measurements, reduce errors and provide a flexible integration in both spatial and temporal domain. Such systems organize collection and processing of environmental information, and the result can be used as a base for decision support.

Monitoring is more than just watching; it is the procedure of collecting, storing, processing and interpreting information. An orderly monitoring system enables scientists and policy makers to enhance the understanding of environmental states, foresee future changes and to formulate suitable management options (Kosovych, 2021; Potwora et al., 2023).

Reliable environmental monitoring/surveillance systems are founded upon several key principles, such as ensuring reliability and objectivity of data, having potential to evaluate different environmental components at multiple levels, transparency in organizing data, and prompt reporting of information to decision makers. Matters of adherence to prescribed standards and technical routines are important as they concern the effectiveness of the system.

However, a majority of existing systems for monitoring are still ill-equipped and unintegrated with modern technology. This constrains their ability to deliver a full knowledge of the environment and makes the prediction of its variation and the selection of the best resource management more difficult. In comparison, the adoption of IoT technologies greatly enhances monitoring precision and supports creation of digital models that can forecast the dynamics of ecosystems.

Advanced technologies, including IoT and artificial intelligence (AI), have been gradually applied to environmental related research. These are to be observed, for example, in the monitoring of climate conditions, of forest quality, and of water use and contamination. Real-time monitoring is possible via distributed sensor networks, with the results presented on maps, graphs or other digital formats to facilitate visualization and communication of the environmental information.

Let me be clear, AI works through a defined process of input, processing, and output generation of data. It is on the data sets gathered from thousands or millions of ”things” made possible by IoT technology that AI systems are developed that enable pattern recognition, anomaly detection, and predictive insights. Such as, satellite images or data from drones can be used by machine-learning models to identify sources of pollution or environmental damage.

Currently, certain analysis methods like visible and near-infrared (Vis-NIR) spectroscopy have proven to be very effective tools for environmental monitoring. These methods are eco-friendly, inexpensive and can detect contaminants such as heavy metals in soil at the level of large areas and long periods. Research shows that the integration of such approaches with machine learning algorithms leads to a substantial improvement in prediction performance as compared to conventional methods (Popescu et al., 2024).

Moreover, new techniques like Surface-Enhanced Raman Scattering (SERS) allow to detect dangerous agents at very low levels. Flexible substrates employed in SERS open the possibility of in situ application for detection of hazardous chemicals, pesticides and pollutants (Bharati & Soma, 2021).

Data is required for functioning of AI enabled systems. Persistent harvesting from IoT device such as satellites, drones and ground sensors enhances the quality of analytical models. These solutions combine real and historical data for comprehensive situational awareness.

Among other things, ML algorithms could analyze enormous amounts of environmental data to identify hazards, including pollution events or spills. They enable the development of early warning systems and automated monitoring systems providing rapid response to environmental threats. In particular neural networks have been shown to be very accurate in modelling and predicting environmental processes.

There have been recent efforts to use high resolution aerial imagery and machine learning for the mapping of soil contamination. These methods are far more precise than conventional statistics, and enable cross-ecosystem investigations at the scale of the environment.

The digitization of environmental management also facilitates collaboration between stakeholders, including government agencies, organizations, and environmental groups. Digital technologies allow for a new degree of data sharing, analysis, and decision-making which may improve environmental governance.

IoT lends itself well to environmental monitoring. Sensors deployed in nature gather data continuously and thus offer a view of environmental change in real time. These services enable decisions on human activities that are less harmful.

Also, today IoT solutions are at times coupled with mobile applications and users can be immediately notified about the environment. Technologies like WiF i, GPS, and Bluetooth are used for transferring data, which are now applied for air, water and soil quality monitoring, people and institutions can keep an eye on these in friendly digital widgets.

Real-life examples of IoT products range from the Air Quality Egg, a sensor that tracks the level of pollutants in the air in real time, to BigBelly, a smart waste management system that optimizes garbage collection routes. The application of these technologies in Ukraine is illustrative of the fact that they have potential to contribute to cleaner air and less environmental contamination; this is only one example of how IoT can be deployed to make not only cities, but also rural areas, ecologically better places to live.

Despite the obvious advantages of these technologies, their usage is still immature. IoT has a huge potential, particularly in enabling precise monitoring and effective management of natural resources. It serves processing of such critical tasks in environmental protection, as automated gathering and analyzing data, quantifying and evaluating natural resources, detecting sources of pollution and evaluating anthropogenic impact, forecasting changes in environment and supporting decision making in sustainable development and good resource management.

The results indicate that IoT-enabled environmental monitoring system serves as a sense-making engine, which facilitates multiple levels of decision making. At their operational levels they allow for real time responses to changes in the environment. At the tactical level, they help with the allocation of resources and risk management. And on the higher strategic level are based on/determined by long-term planning, sustainable development and competitive positioning of territories and organizations.

Therefore, the conversion of environmental data into intelligence establishes a direct connection between digital technologies and competitive advantage. Those companies that have mastered such systems will be better positioned to predict risk, make the best use of their resources and adjust more quickly to changes in their environments and in regulation.

Use of IoT in this regard aligns our work with the leading European standards in environment management. Further adoption of these technologies in Ukraine would enable not just the improvement of national environmental monitoring systems, but also the better facilitation of international cooperation and compliance with worldwide environmental standards.

In order to grasp the working manner of IoT systems, we need to look at their structural layers. Most environmental monitoring applications rely on microcontrollers – small computers that carry out programmed instructions and manage the functions of attached sensors. They can be attached to various peripherals such as sensors, cameras, and data transmission modules to capture and transmit environmental data to digital networks.

A conventional system also features a visual front end enabling capture of images or acquisition of video streams. These systems in general work following a sequential algorithm: the sensors collect data from the environment, this data is sent to the controller and processed information is sent to external systems or users.

This design guarantees uninterrupted real-time sampling the data and fast response of the system, which is very important for the decisions issued in environmental management (Figure 1).

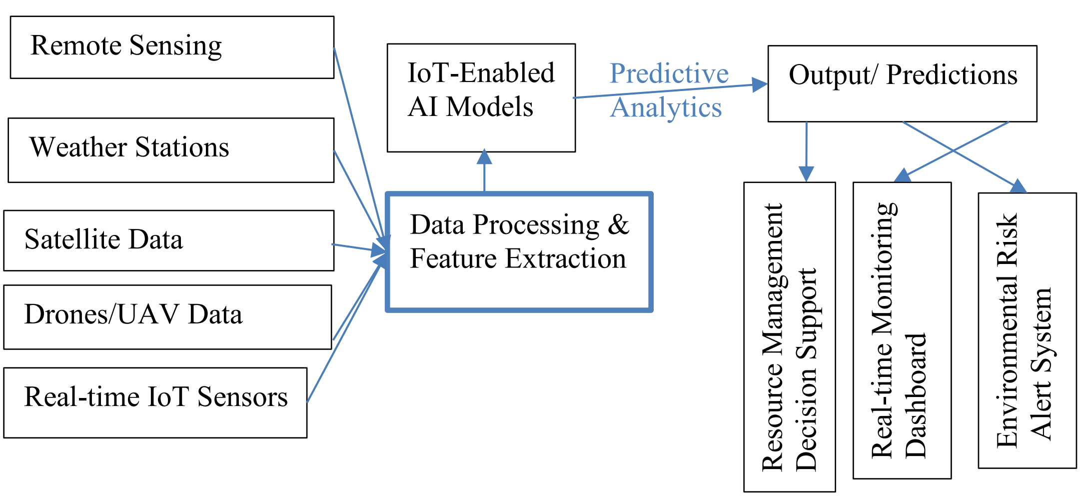

Figure 1. IoT-Driven Environmental Monitoring and Decision-Making Framework

The IoT use in environmental monitoring and decision making The above figure shows how the Internet of Things (IoT) contributes to enabling Spatial Decision-Making Systems (further – SDM). It is a two-stage process in the sense that. The input processing, so called input stage, is the place where we got the environmental data from. Among these are remote sensing systems based on satellites or aircraft that sense the surface of the Earth, and meteorological stations that measure essentials like temperature, humidity, and wind. Besides, satellite systems offer large-scale images and environmental information from the space, and drones or unmanned aerial vehicles gather high resolution data in the air. Real-time IoT sensors (small devices deployed in the environment that continuously collect data on air quality, water levels, and other ecological parameters) are also part of this stage.

4.1 Data processing

Everything was run through a central processing system that had a couple of key steps. In the beginning, the data is preprocessed by cleaning, formatting, and extracting useful features, which enables the system to separate the most useful information from raw inputs.

After this, the information is processed by means of analysis, in which IoT-based AI models use complex algorithms to understand patterns and correlations of the data. These smart systems can learn from the data at hand and produce insights based on data.

In the last step, predictive analytics is applied to predict possible changes in the environment and to detect potential risks. This allows the system to predict future events and to facilitate proactive decisions in the environment.

4.2 Output/Predictions

The system outputs are used in a few important ways. It provides the basis for resource management decisions to encourage the efficient and sustainable utilization of the natural environment by means of quantitative, information-rich assessments. Second, a tool for real time monitoring of live updated environmental information to facilitate tracking and analysis of environmental information is provided with interactive dashboards. Third, its early warning systems to detect and respond rapidly to potential environmental hazards, such as flooding or pollution events.

The first table provides an overview of various technological instruments that may be used for these jobs. This information is collected from multiple sources and transformed by AI and analytical processing. Thus, raw data are transformed into actionable intelligence, which the experts use to protect the environment through timely and informed decisions.

Figure 1 shows the working principle of the sensor environmental monitoring system. The system is made of a set of sensors, connected in a network, designed to capture the environmental parameters such as air quality, pollution, humidity and temperature. These sensors send data to a central processing unit that operates like a computer by gathering, formatting, and organizing the data it receives.

An infrastructure model is based on cloud to support high-performance data storage and management, typically consisting of locally managed servers with unique IP addressing. This set-up allows the user to access environmental data remotely from just about anywhere, providing an easy-to-use and scalable solution for a wide user base. Based on cloud computing technology, environment management applications can be monitored in real time and executed remotely.

To process high rates of incoming data, dedicated software modules run on the system controller. These programs, e.g. for data extraction, processing or computation of key figures, contribute to a smooth working of the system and reliable results.

A survey of related work on the use of IoT technology for environmental monitoring shows that there is a large heterogeneity in the use cases and solutions proposed. The results of Table 1 reveal that the IoT is being used in various domains for soil, air, water and marine monitoring, agriculture, healthcare and factories of the future.

For soil monitoring, wireless sensor networks are widely used to monitor crop conditions and study the effect of green house gas emission. In ocean, dedicated IoT communication protocols were developed to reduce power consumption and increase data transmission efficiency. Air quality monitoring systems use multiple types of sensors, which can be deployed over large areas, but accuracy of data and signal-to-noise issues are still of concern.

Certain solutions, such as IoT-Mobair systems or the MQ3 sensor together with Raspberry Pi, provide the option to monitor pollution in real time, but they may be too technical or constrained by the precision of the readings. In smart agriculture, and particularly fish farming, the IoT is used to optimize management of water and energy usage albeit such solutions being quite energy hungry.

Technologies to monitor radiation and dust can be designed to cover vast areas but are subject to environmental influences such as temperature or have high costs associated with their deployment. In the healthcare industry, IoT along with artificial intelligence is used in multi-agent and e-health systems to identify emergency situations resulting from environmental fluctuations.

Other uses are systems for climate monitoring in extreme winter conditions, with special attention to battery performance under radiation and cold. In smart city solutions, IoT is used to track temperature, humidity, energy usage of data centers.

Table 1 – IoT-based Environmental Monitoring as Sustainable Competitive Intelligence Systems

Application area	**Type of collected data**	**Analytical capability**	**Supported decisions**	**Competitive advantage**	**Sustainability impact**
Air quality monitoring	Pollution levels, emissions	Real-time anomaly detection	Urban policy, emission control	Reduced uncertainty for authorities	Improved public health
Water monitoring	pH, contaminants, turbidity	Risk forecasting	Resource allocation	Faster crisis response	Safe water usage
Agriculture	Soil moisture, temperature	Predictive optimization	Irrigation planning	Cost efficiency	Reduced resource waste
Forest monitoring	Fire risk, biodiversity	Early warning systems	Disaster prevention	Territorial resilience	Ecosystem protection
Industrial monitoring	Toxic emissions, waste	Compliance analytics	Environmental regulation	Reputation & compliance advantage	Pollution reduction

The table illustrates that various forms of data produced by IoT-based monitoring systems can lead to strategic intelligence dependent on the applied analytical potential. The processing of these data and the transformation into decision support tools is facilitated by embedding the analysis into a cloud system, together with the artificial intelligence techniques.

Notably, these findings highlight that the strategic value of IoT solutions extends beyond environmental monitoring. The eventual result of enhanced quality of information, reduction in uncertainty and better support for proactive decision-making is a sustainable competitive advantage. This supports the notion that intelligent sensor platforms need to be viewed as critical components in competitive intelligence systems.

The competitive impact of IoT-based intelligence systems lies in their ability to create informational advantages. Actors that have access to real-time environmental intelligence can make faster and more accurate decisions compared to those relying on delayed or fragmented data. This advantage directly influences resource efficiency, regulatory compliance and strategic positioning.

The findings reveal a strong exploitation of IoT solutions in environmental monitoring systems for soil, air, water and ocean environments. Besides these core sectors, application of IoT solutions can be found in smart agriculture, industrial solutions, and health care oriented monitoring systems.

In agriculture, wireless sensor networks are also used for monitoring of soil for a continuous evaluation of the conditions of crops and to assess the impact of greenhouse emissions on plants. Specialised IoT communication protocols within marine environments optimise data transmission to good vibration while minimizing energy consumption, but some coverage limitations exist.

One of the key findings of the study is the ability of IoT-based systems to reduce informational asymmetry between environmental conditions and decision-makers. Traditional monitoring approaches are often limited by delayed or incomplete data, which increases uncertainty and reduces decision effectiveness.

In contrast, intelligent sensor platforms provide continuous and real-time information flows, enabling more accurate, timely and evidence-based decisions. This significantly enhances the adaptive capacity of organizations and territories in the face of environmental and economic challenges.

Air quality monitoring equipment consists of various types of sensors and instruments that can be distributed out in the field over large areas. Although scalable, such systems have to contend with the presence of noise in measurements. Morecomplex arrangements, for instance using the IoT-Mobair platform or using MQ3 sensor along with Raspberry Pi, provide real time detection of pollution levels but may be technically complicated and/or subject to accuracy limitations.

IoT technologies have also a leading role in water and energy management in smart farm systems and especially in aquaculture, in which monitoring is continuous and enhances efficiency of operations. Meanwhile, solutions for environmental monitoring (radiation, dust) offer wide spatial coverage, however their performance could be hampered by high costs of implementation and by sensitivity to climatic conditions.

In healthcare, multi-agent system and e-health platform based monitoring systems integrate IoT and artificial intelligence to identify emergency events induced by environmental variations. Also some systems are made to confront seasonal issues like analysing sensor and batter performance in cold or in high radiation during winter season.

IoT technologies in smart city infrastructures are used for monitoring environmental parameters in data centers, such as temperature, humidity, and energy consumption to provide an efficient resource management. Communication protocols including ZigBee and LoRa are deployed in industrial environments to detect toxic compounds to improve work environment safety and to aid viable environmental control systems.

At the organizational level, firms can integrate environmental intelligence into key business processes, including supply chain management, risk assessment and sustainability strategies. This transforms environmental monitoring from a regulatory requirement into a source of competitive differentiation.

At the governmental level, IoT-based intelligence systems support evidence-based policymaking, environmental regulation and territorial planning. This enhances national resilience and improves the effectiveness of environmental governance.

A key advantage of IoT-based systems is their ability to reduce informational asymmetry between environmental conditions and decision-makers. Traditional monitoring systems are often limited by delays and incomplete data, which increases uncertainty. In contrast, intelligent sensor platforms provide continuous, real-time information flows that enable more accurate and proactive decisions.

The findings also indicate that the strategic value of IoT systems emerges only when data are systematically transformed into intelligence and integrated into decision-making processes. Without this transformation, sensor data remain underutilized and do not contribute to competitiveness or sustainability.

5 DISCUSSION

The discussion confirms that the integration of IoT, artificial intelligence and cloud computing technologies creates a new paradigm of environmental management based on sustainable competitive intelligence. This paradigm shifts the focus from reactive monitoring to proactive and strategic decision-making.

The results also highlight that environmental data, when properly processed and interpreted, become a strategic resource that can influence competitiveness at multiple levels. Governments can use such intelligence for policy development, organizations for operational optimization, and regions for strengthening their sustainability and resilience.

The review identifies several ways in which IoT technology can be used in monitoring and managing the environment. The sensors, controllers, and cloud-based platforms combined facilitate the acquisition of large-scale environmental data in a real-time and continuous manner. The integration of IoT with artificial intelligence (AI) opens up a vast range of opportunities for researchers and decision-makers to quickly address environmental challenges. Today, AI has become a norm and it is deeply integrated in numerous fields, such as farming, healthcare, production, mining, and environmental conservation (Suchek et al., 2021). AI in IoT enables better prediction and more accurate pattern analysis. However, several challenges remain to be solved, including the high energy consumption of AI systems, the absence of infrastructure in some regions, and problems relating to data security and privacy, particularly in cloud-based environment. In summary, the present investigation emphasizes the necessity for combination of diverse scientific perspectives for evaluating capabilities of IoT applications for enm in the face of global socio-economic transformation.

Researchers studying digital innovation in all its forms and in particular how it helps in preserving and regenerating natural resources. Emphasis is placed on the significance of space-based and remote sensing technology- satellites, unmanned aerial vehicles, (drones) and spectrometry techniques are efficient, cost-effective, and green, and should be promoted. For example, heavy metals in soil can be detected non-destructively by using visible and near-infrared spectroscopy, which produce exact numbers while protecting the environment.

Among its benefits are processing of data at a higher speed, better decisions, and the possibility to use it for complex tasks automation without direct human intervention. However, its implementation has significant barriersone of the major barriers is the high computational resource required, which results in more energy consumption and more environmental burden (Shahzad, 2020). Possible solutions involve the design of energy efficient computing hardware and the scaling of digital infrastructure.

One challenge that advanced AI technologies have yet to overcome for the potential large-scale use is the existence of a technological gap, especially in developing countries. This calls for stronger regulations, and secure data management. Technologies such as blockchain are being increasingly explored as solutions to guarantee data integrity and to prevent unauthorised access or manipulation (Jiang, 2020). Ethical questions are still very much at play, and include how much we should let AI decide things that affect our lives, its impact on jobs, and concerns around surveillance and privacy.

Nonetheless, the convergence of AI and IoT systems presents great opportunities for the analysis of environmental data. With higher speed and accuracy, AI can analyze large amounts of environmental data, enabling more efficient and effective monitoring and management of environmental activities. But to achieve these gains, the associated technical, ethical and social challenges must also be addressed.

The field of study is dynamic itself, having scholars from various schools of thought on the place of digital technologies in environmental management. For instance, cloud computing is said to have transformative impact on environmental monitoring systems (Jiang, 2020), however traditional resource management techniques still matter (Shahzad, 2020). Some investigators, like Nižetić et al. (2020) believe that digital instruments and information systems act as key enablers for environmental innovations.

In particular, cloud computing is considered a fundamental enabler technology for offering precise, efficient and scalable data processing service (Jiang, 2020; Suchek et al., 2021). Meanwhile, the adoption of digital technologies in environmental management should be a balanced convergence of advancing technology and maintaining environmental sustainability (Salam, 2019).

The acceleration in machine learning and artificial intelligence development has also broadened the types of problems that could be solved in environmental systems. There is growing recognition among researchers that human elements need to be incorporated into technological solutions as behavioural and social factors are integral to processes of environmental change.Studies verify that individuals who lead a sustainable life have a tendency to take advantage of innovative technological solutions in order to support efforts to save the environment (Wang et al., 2020; Allam, 2022).

Therefore, the role of intelligent sensor platforms extends beyond environmental monitoring and becomes central to the formation of sustainable competitive intelligence systems. Their ability to integrate data collection, analysis and decision support creates a foundation for long-term sustainable development and competitive advantage in the digital economy.

6 FINAL CONSIDERATIONS

This study demonstrates that intelligent sensor platforms can be effectively conceptualized processing as sustainable competitive intelligence systems when they integrate environmental data collection, analytical, strategic interpretation and decision-oriented dissemination.

The main theoretical contribution of the research lies in the repositioning of IoT-based environmental monitoring from a purely technological domain to the field of sustainable competitive intelligence. By integrating the Resource-Based View, Knowledge-Based View and Dynamic Capabilities approach, the study shows that environmental data can be considered a strategic resource, while the ability to process and interpret such data determines competitive advantage.

The results confirm that intelligent sensor platforms enable the transformation of real-time environmental data into actionable intelligence that supports decision-making at operational, tactical and strategic levels. This significantly reduces informational asymmetry, improves decision quality and enhances the capacity of organizations and territories to respond to environmental and economic challenges.

From a managerial perspective, the findings indicate that governments, enterprises and regional authorities can use IoT-based intelligence systems to optimize resource allocation, anticipate environmental risks, improve regulatory compliance and strengthen sustainable competitiveness. In this context, digital environmental monitoring becomes a key element of data-driven governance and strategic planning.

However, the study has several limitations. First, it is based primarily on secondary data sources and does not include empirical testing of specific IoT systems. Second, the proposed framework is conceptual and requires further validation through case studies and quantitative analysis. Third, the impact of intelligent sensor platforms on competitiveness may vary depending on institutional capacity, technological infrastructure and financial resources.

Future research should focus on empirical validation of the proposed framework in different sectors, including agriculture, forestry, water management, smart cities and industrial environmental control. Further studies may also develop indicators for measuring the impact of IoT-based intelligence on sustainable competitiveness, resilience and environmental performance.

In conclusion, intelligent sensor platforms should be interpreted not only as tools for environmental monitoring, but as core components of sustainable competitive intelligence architecture, where data-driven insights form the basis for strategic natural resource management and long-term sustainable development.

Therefore, intelligent sensor platforms should be interpreted not only as technological solutions, but as strategic intelligence systems that enable data-driven governance, improve decision quality and support long-term sustainable competitiveness.

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