

Enhancing critical infrastructure resilience through artificial intelligence: insights from energy and transportation sectors in Romania

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Abstract. Critical infrastructure is essential for sustaining the functioning and well-being of the society, while also ensuring the continuity of economic activities and public services. Its resilience has become increasingly important in the face of technological, environmental and operational risks. Artificial intelligence (AI) is widely known as a powerful tool to strengthen resilience, offering predictive analytics, anomaly detection, automation and data-driven decision-making. The growing implementation of AI in different infrastructure sectors shows its potential to improve operational efficiency, safety and continuity of important services, while considering differences specific to each sector and potential barriers such as costs, data limitations, or the need for specific personnel. This paper explores the role of AI in enhancing the resilience of critical infrastructure in Romania, focusing on the energy and transportation sectors. The research is based on secondary data, using annual and sustainability reports of some major companies, as well as official information from their websites, to examine how AI is integrated into operational processes, safety systems, logistics management and risk monitoring. The results demonstrate that AI significantly improves resilience by enabling predictive maintenance, real-time risk detection, operational optimization and efficient use of the resources. In the energy sector, AI strengthens grid monitoring, fault prediction and service continuity, while in transportation it supports safety systems, fleet management and logistics, reducing risks for both passengers and goods. Although some challenges to AI adoption exist, Romanian companies are actively using AI, which shows its relevance and effectiveness in practice. This paper contributes to a better understanding of the application of AI in Romanian critical infrastructure by specifying how it supports sustainable development, improves safety and strengthens resilience. Additionally, it provides useful information that can assist managers and policymakers in making well-informed choices regarding the integration of AI into important services.

Keywords: artificial intelligence, critical infrastructure, resilience, energy sector, transportation sector, predictive maintenance, operational efficiency.

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Introduction

Modern businesses struggle to develop effective responses against disruptions which impact their critical infrastructure operations.

Societies depend on critical infrastructure sectors which include energy, water supply, transportation and healthcare systems for their basic operation. Modern infrastructure systems face multiple risks which include cyberattacks, natural disasters and pandemics. The complex nature of modern infrastructure systems creates a situation where disruptions in one sector lead to widespread impacts across multiple sectors thus requiring effective resilience plans. [1] [5][6]

Artificial Intelligence helps critical infrastructure by enabling predictive maintenance, which can foresee equipment failures, reduce downtime and improve resource efficiency. By using machine learning with real-time data from IoT sensors, operational logs, and edge devices, AI supports timely interventions and better decision-making. Intelligent data orchestration ensures fast processing and analysis, while cloud-native architectures make systems more

scalable, flexible, and resilient. Combined with 5G and future 6G networks, AI enhances reliability and prepares infrastructure for future autonomous management and optimization. [2]

The adoption of AI in cybersecurity faces several obstacles. The integration of AI with existing systems and the need for vast quantities of high-quality data are examples of technical challenges. AI is not always transparent in its decisions and is prone to error, which diminishes trust. Biased algorithms and threats to personal data give rise to ethical and privacy issues. Because AI is developing more quickly than the law, regulatory and compliance issues are also a problem. Changing rules about security and privacy make it hard for organizations to stay compliant, especially when AI processes large amounts of data. [3]

This paper aims to explore the role of AI in enhancing the resilience of critical infrastructure. The main research question is: How can AI technologies help improve the resilience of critical infrastructure systems? The hypotheses considered are: H1. AI enhances resilience through predictive analytics and anomaly detection. H2. Application of AI varies by sector. H3. There are barriers to the full implementation of AI in critical infrastructure.

Due to the capacity of artificial intelligence to handle complex challenges, the EU and Romanian authorities have adopted directives and national strategies to regulate its use and ensure safe, efficient implementation. The literature review begins with a review of relevant European Union directives, including the AI Act (Regulation (EU) 2024/1689), as well as Romania's national AI strategy. It then examines how AI is implemented to support critical infrastructure, providing examples from the energy and transportation sectors.

Literature review

In this research, the legislation of Romania and the European Union is first addressed, which sets the foundation for the secure and reliable use of artificial intelligence. Based on these regulations, the research then focuses on the application of AI in two key sectors: energy and transportation, to demonstrate how it enhances the resilience of critical infrastructure.

European Union and Romanian relevant AI directives

There are three main EU legislative acts relevant to the use of AI: the AI Act, the NIS2 Directive, and the Critical Entities Resilience Directive. In Romania, the only policy adopted is the National AI Strategy for 2024-2027.

The AI Act (Regulation (EU) 2024/1689) is the main European law on artificial intelligence. Its purpose is to “promote the uptake of human-centric and trustworthy artificial intelligence (AI) while ensuring a high level of protection of health, safety and fundamental rights”. In simpler words, it sets out rules to make sure AI is safe, trustworthy and used in a way that protects people. The law pays special attention to high-risk AI systems, such as those in hospitals or energy grids, where mistakes could have serious consequences. [4]

NIS2 (Directive (EU) 2022/2555) is focused on cybersecurity. It gives authorities the power to check how critical entities protect their networks and essential services. While it does not manage AI directly, it is very relevant because AI systems rely on secure networks to work correctly. For example, if hospitals or energy companies use AI, they also need to follow NIS2 rules to keep their systems protected from cyberattacks. [5]

The Resilience Directive (Directive (EU) 2022/2557) provides minimum rules to strengthen the ability of critical entities to keep operating in times of crisis. It covers sectors like energy, transport and health. Although AI is not named directly, the directive makes clear why technologies such as AI are important, because they can help critical entities handle disruptions and recover more quickly. [6]

Romania has also adopted its own National AI Strategy for 2024-2027. The goal is “to promote the development and adoption of artificial intelligence technologies in Romania, ensuring competitiveness, innovation and alignment with European values and regulations”. This means supporting the safe use of AI in areas that matter most for society. [7]

Examples of AI integration in critical infrastructure sectors

In order to show how artificial intelligence contributes to the resilience of critical infrastructure in Romania, this research focuses on two important sectors: energy and transportation. Both sectors depend on reliable, safe and efficient operations and are essential for the country's economic stability and national security.

The energy sector:

Every country relies on its energy sector to sustain both its economy and everyday life. Without energy, the world wouldn't be where it is now, as the discovery of energy skyrocketed economic growth and helped other industries like healthcare, transportation and education develop into what they are today. Electricity generation, transmission and distribution systems are directly linked to national security, industrial performance and the well-being of citizens. As the energy sector faces new challenges because of global warming, the use of sustainable practices, meaning the integration of renewable sources, is vital for the environment. Moreover, considering the implementation of artificial intelligence (AI) in almost everything, companies are even more susceptible to cyber threats than before, forcing them to adopt AI to enable resilience and modernization.

This section analyzes three major companies operating in Romania's energy sector: Electrica, Transelectrica and Schneider Electric, and examines how they have integrated artificial intelligence (AI) technologies into their operations, based on their 2023-2024 sustainability and annual reports, as well as official information available on their websites.

Electrica

Electrica is one of the largest electricity companies in Romania, with activities in distribution, supply, services and renewable energy development. It manages an important share of the country's electricity distribution network, supplying around 3.9 million users. [8]

In its 2023 Sustainability Report, the company states that it will “focus on the full infrastructure digitalization, the widespread use of artificial intelligence to optimize operations”. AI is linked directly with predictive maintenance, automation and the integration of smart grid elements such as sensors, smart meters and SCADA (Supervisory Control and Data Acquisition) systems, all aimed at improving reliability and operational efficiency. [9]

The 2023 Directors' Report highlights Electrica's involvement in the ELECTRON project. This EU-financed program develops digital tools and AI methods to improve the resilience of energy systems by detecting anomalies, assessing risks and restoring operations after failures. Within this project, Electrica, Transelectrica and Politehnica University of Bucharest worked together to create a cybersecurity testbed that integrates real Intelligent Electronic Devices (IEDs) with AI tools that simulate attacks on distribution networks, providing a realistic and safe environment to test defenses. This testbed marks a significant step forward in protecting critical infrastructure, as substations and power grids become more interconnected and dependent on digital communication. By supporting ongoing cybersecurity research, the laboratory offers valuable insights that help protect substations against potential threats and demonstrates how AI and digital solutions are becoming central to resilience and security in the energy sector. [10] [11]

In 2024, Electrica launched the “Development of artificial intelligence algorithms and advanced numerical methods for real-time energy footprinting of main receivers in a commercial building”, with the acronym AI-AE, together with the Technical University of Cluj-Napoca and the startup Renergia. The system combines sensors, cloud storage and AI algorithms to track energy use in real time at the company's headquarters. It shows which devices consume the most electricity and offers automatic recommendations for improving efficiency through an online dashboard. Electrica plans to extend this solution to all its buildings, making it the first company in Romania to utilize an AI system to measure and optimize the energy footprint of its headquarters. [8]

Transelectrica

Transelectrica's Development Plan for the Electrical Transmission Grid (2024–2033) shows that electricity networks are very complex and need quick decisions in real time. This is made possible with the help of Big Data and Artificial Intelligence (AI). Besides network analysis and management, AI is also utilized in renewable energy for tasks such as predicting energy consumption and maintaining equipment in optimal condition through predictive maintenance. To leverage these benefits, Transelectrica's DigiTEL projects will test and apply AI and Big Data solutions, creating expert systems with advanced algorithms and cloud-based tools. [12]

In addition, the Annual Report of the Administrators 2024 highlights the implementation of AI-powered robotic assistance and technical supervision in the DigiTEL Green: Mostiștea project. This initiative introduces, for the first time in the Electrical Transmission Grid, technologies using physical robots and autonomous drones for monitoring and supervising critical infrastructure. [13]

Schneider Electric

Schneider Electric explains that it uses condition-based and predictive maintenance supported by analytics and AI. These methods make it possible to monitor equipment closely, check for stress, wear or ageing parameters, and prevent failures from accelerating equipment ageing. This keeps equipment running for longer, reduces the risk of sudden breakdowns and avoids carbon emissions by eliminating the manufacturing of new equipment.

The 2023 report also describes how further data, software and tools enabling virtual descriptions, known as digital twins, can be combined with AI and machine learning. This combination helps predict and guide decisions about how systems work. It makes operations more efficient, reliable and resilient. [14]

Schneider Electric has explored various applications of AI and machine learning. These include real-time process control, quality assurance, traceability and cutting down on administration tasks. The company says it has identified hundreds of possible AI applications in its operations. [14] [15]

The transportation sector:

The transportation sector is a key part of Romania's infrastructure, responsible for moving people and goods and supporting the economy. It includes railways, roads, airports and ports, all essential for trade and daily life. Advances in digital technology have made transportation faster and more efficient, but they also bring new challenges. Connected and complex systems are more vulnerable to cyber threats that can disrupt services or even endanger safety. Artificial intelligence (AI) is increasingly used to address these risks, helping companies strengthen operations and improve reliability. [16]

This section analyzes three major companies operating in Romania's transportation sector: DP World, DPD (Geopost) and Compania de Transport Public (CTP) Iași, and examines how they have integrated artificial intelligence (AI) technologies into their operations, based on their 2023-2024 sustainability and annual reports, as well as official information available on their websites.

DP World

DP World has expanded its operations in Romania to become a vital European trade hub while supporting East-West trade activities. The company implements artificial intelligence to transform its worldwide logistics operations while maintaining its position as a key European trade center. The company uses artificial intelligence throughout its operations to enhance operational efficiency while minimizing environmental effects and delivering better customer experiences. The company achieves its transformation through CARGOES, which includes proprietary technologies that automate terminal operations, simplify customs clearance and track shipments from start to finish. The TOS+ platform functions as a digital twin within this system to offer real-time port operation data and enables organizations to test new practices through simulations that do not affect current trade activities, like opening gates and alerting the employees if the equipment is in need of maintenance. [17] [18]

DP World implements AI-powered route optimization and energy-efficient warehousing solutions in addition to port and terminal automation to create a sustainable logistics network. The implemented tools minimize waste while decreasing emissions and maintaining trade flow stability through difficult times. [19]

Moreover, the company explores Metaverse technology for virtual training and testing which provides enhanced safety and faster innovation through its advanced capabilities. The combination of AI solutions with these initiatives allows DP World to rapidly respond to disruptions while boosting its operational capacity and maintaining uninterrupted global supply chain operations. [18]

DPD (Geopost)

Since 2021, DPD had already been utilizing AI to improve customer interactions. One good example is the AI-enabled chatbot that offers faster and more personalized answers to inquiries and enables the firm to retain leadership in digital innovation in parcel delivery. [20]

DPD has introduced Typewise, an artificial intelligence writing assistant designed to help its customer service and sales teams. It helps staff efficiently respond to enquiries more effectively, at a time when the growing volume of parcels also brings a rising number of customer requests. Through this AI-based tool, DPD is better equipped to process communication needs while ensuring faster and more accurate answers and maintaining the level of service. [21]

Artificial intelligence also enables logistics optimisation across the wider Geopost group. The 2024 Sustainability Report highlights the use of artificial intelligence and data science to improve road networks and trailer capacity in France, and the plan to extend such initiatives to other markets during 2025. At the same time, the Geopost Innovation Lab is advancing the use of autonomous delivery robots in the United Kingdom and parcel-sorting robots in Estonia, initiatives that are changing the way parcels are distributed and improving operational efficiency. [22]

Compania de Transport Public (CTP) Iași

The Compania de Transport Public (CTP) Iași has undertaken significant measures directed at reinforcing the security of public transport through the implementation of artificial intelligence. Over 140 buses were installed with state-of-the-art anti-collision and driver assistance systems supported by camera systems capable of detecting pedestrians and cyclists and other vehicles and recognizing them even in areas of restricted visibility. Such systems, based on machine vision and artificial intelligence, can also judge driver behavior such as cell phone use or lack of attention and failure to wear a seatbelt and provide real-time advisories and information to the administration. This initiative sponsored by the National Recovery and Resilience Plan also incorporates 150 trams, whereby similar systems were installed alongside the assistance of Bosch Engineering GmbH. This initiative places Iași as the first Romanian city to bring forth AI-enabled safety technologies to the public transport system, noticeably strengthening the city's resilience and the safety of commuters. [23] [24]

Methodology

This paper is based on qualitative research using secondary data—sustainability reports, annual reports, press releases, and official company information—supplemented by European Union and Romanian documents on artificial intelligence that provide regulatory and strategic context [4][7]. The research examines two infrastructure sectors (energy and transportation) and three companies per sector, selected for their market importance and the availability of information on AI use. Sources include sustainability and annual reports, official press releases, investor materials, and EU/Romanian policy documents that frame AI-related requirements and good practices [4][7]. No primary data were collected.

The analysis explores (H1) how artificial intelligence contributes to increased resilience, (H2) how its use differs between sectors, and (H3) which implementation challenges are visible. In line with these objectives, for each case, we extracted concrete mentions of AI use (purpose, context, stated benefits, and any noted constraints) and

assessed them against the three research questions: how AI contributes to resilience, how uses differ across sectors, and which implementation challenges are visible. Evidence was summarized in a brief table, comparing use cases and reported outcomes across companies.

Because the analysis relies exclusively on publicly available secondary sources, some implementations may be under-reported or described in broad terms. To mitigate this, key statements were cross-checked across at least two independent public documents whenever possible; nevertheless, reporting bias may persist. The study uses no personal data and raises no human-subjects ethical concerns. Future work should complement this desk review with semi-structured interviews with key persons from relevant companies to validate and contextualize the findings and to explicitly link technical performance to resilience and business continuity management (BCM) outcomes.

Results and further discussions

The results of this research confirm that artificial intelligence is becoming a key factor in improving resilience in critical infrastructure, with particularly strong evidence in transportation. The cases of DP World, DPD and CTP Iași demonstrate how AI impacts predictive functions, operational effectiveness and safety monitoring. International reports, such as those of the OECD, also underline the ability of AI to improve traffic safety management by using predictive models to identify areas with higher risks of incidents. This supports the first hypothesis, that AI enhances resilience through predictive analytics and anomaly detection. These findings are summarized in Table 1, which shows the main AI applications, technologies and benefits for both the energy and transportation sectors. [25]

The secondary hypothesis, which states that artificial intelligence applications vary across sectors, is also proved. As shown in Table 1, the energy sector focuses on grid stability, optimization of generation processes and predictive maintenance, while the transportation sector prioritizes safety, logistics optimization and service delivery.

The third hypothesis, concerning the barriers to the full implementation of AI, is only partly supported. OECD reports talk about issues such as limited availability of data and a shortage of skilled professionals to manage AI systems. However, the Romanian cases analyzed do not put accent on these barriers in their reports. Instead, they show concrete progress and ongoing implementation of AI solutions, the challenges shown in international studies, this suggests a discrepancy between the challenges reported in international studies and those observed in our analysis., where barriers may exist but the companies may have chosen not to report them. [25]

The results indicate that artificial intelligence has already been incorporated into practice in Romania, particularly within the transportation sector, where its impact on safety and efficiency is evident. These findings have significance for both policymakers and industry executives, as they suggest that artificial intelligence directly enhances resilience even before the complete implementation of regulatory frameworks, such as the EU AI Act.

Table 1: Artificial intelligence applications in the Romanian energy and transportation sectors

Sector	Company	AI application areas	Technologies used	Results / Benefits
Energy	Electrica	Predictive maintenance, smart grids, energy footprinting, cybersecurity	Smart meters, SCADA, ELECTRON project testbed, AI-AE system with sensors and algorithms	Improved reliability, reduced consumption, better cybersecurity, first AI enabled HQ energy footprint system in Romania
	Transelectrica	Grid management, predictive maintenance, monitoring critical infrastructure	DigiTEL projects, Big Data and AI algorithms, autonomous drones, robotic assistance	Faster decision making, improved supervision, resilience of transmission grid
	Schneider Electric	Equipment monitoring, predictive maintenance, process optimization	AI analytics, digital twins, machine learning, real time process control tools	Increased equipment lifespan, reduced emissions, higher operational efficiency and resilience
Transportation	DP World	Port automation, logistics, route optimization, training and simulation	CARGOES platform, TOS+ digital twin, AI powered route planning, Metaverse tools	Optimized trade flows, reduced emissions, safer operations, faster innovation

Sector	Company	AI application areas	Technologies used	Results / Benefits
	DPD (Geopost)	Customer support, logistics optimization, parcel sorting	AI chatbot, Typewise assistant, data science models, autonomous robots	Faster responses, optimized road networks, improved delivery efficiency
	CTP Iași	Public transport safety, driver assistance, collision avoidance	AI vision systems, anti-collision cameras, driver monitoring, Bosch Engineering systems	Increased commuter safety, accident prevention, AI-enabled smart buses and trams

Source: Authors' own contribution

Before the era of AI, businesses relied on Business Intelligence (BI) tools to identify the problems they might face. At that time, only specialized analysts could read the reports and explain to business owners what potential risks or future challenges existed. Now, thanks to Artificial Intelligence, the reports and charts generated by BI tools are easier to understand, and owners themselves are able to make sense of the information.

A possible direction for future research is to compare how well BI tools worked before the use of AI with how they perform today. This could include examining whether they save more money, provide greater accuracy and support stronger contingency plans. This question is especially important for critical infrastructure, where stronger resilience and faster decision-making can protect essential services and public safety.

Another possible direction for future research could include comparisons of organizations from other countries in the energy and transport sectors to explore how AI enhances the resilience in various contexts. Additionally, future studies could focus on analyzing incidents and risks associated with AI, combined with direct interviews with companies to collect data on the practical experiences and challenges in the implementation of AI.

Conclusion

This research shows that artificial intelligence is pivotal to strengthening the resilience of critical infrastructure in Romania. In the energy sector, AI enables network monitoring, predictive maintenance, and operational optimization, reducing service disruptions and supporting continuity. In transportation, AI enhances security systems, fleet management, and logistics, mitigating risks for people and goods. These findings substantiate H1, confirming that AI-based predictive analytics and anomaly detection deliver measurable benefits for resilience. They also support H2, evidencing sector-specific application patterns (e.g. asset health and grid stability in energy; traffic safety and logistics efficiency in transport).

The practical implications are twofold. First, organizations can leverage AI to better anticipate and manage operational challenges, thereby increasing the continuity and reliability of essential services. Second, AI adoption contributes to resource optimization, lower environmental impact, and improved safety for people and communities. These benefits indicate that integrating AI into critical infrastructure is not merely a technological upgrade but a strategic pathway to operational resilience. If H3 (scalability/transferability across contexts) was posited, our cross-sector evidence partially supports it: while capabilities are portable, effective scaling depends on data availability, governance, and compliance requirements specific to each operator.

The main limitation of this study is reliance on publicly available reports and other secondary sources, which may not capture all implementation challenges or outcomes. Direct engagement with operators would yield a more granular picture of AI deployment and its long-term effects on infrastructure resilience.

Future research should incorporate semi-structured interviews with continuity and operations teams and analyze operational telemetry collected directly from critical-infrastructure operators. This will validate and contextualize the findings and explicitly link technical performance with resilience and BCM outcomes.

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