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Research Article

APPLICATION OF ARTIFICIAL INTELLIGENCE (AI) IN ENVIRONMENTAL MANAGEMENT OF INDUSTRIAL PARKS: CURRENT STATUS AND FUTURE PERSPECTIVES

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ABSTRACT

During Vietnam's rapid industrialization, industrial parks (IPs) have significantly contributed to economic growth. However, they face serious environmental challenges such as greenhouse gas emissions, untreated wastewater, and industrial waste. Traditional environmental management methods present limitations, including discontinuous monitoring and a lack of predictive capabilities. Artificial Intelligence (AI) has emerged as a powerful tool to improve environmental monitoring, management, and decision-making. Globally, AI is increasingly applied in monitoring systems, wastewater treatment optimization, emission forecasting, and environmental data analysis. In Vietnam, initial pilot projects are being implemented but remain localized and experimental. This paper synthesizes current AI applications in environmental management in industrial parks - such as real-time monitoring, process optimization, emissions forecasting, and intelligent decision support systems. It also proposes development directions tailored to Vietnam's context, including capacity building, infrastructure enhancement, pilot deployment, systems integration, collaboration, and policy support. The application of AI in this field promises improved environmental protection, reduced operational costs, and enhanced progress toward sustainable development in industrial parks.

Keywords: *Artificial Intelligence (AI), Industrial Parks, Environmental Management, Wastewater Treatment, Emission Monitoring, Vietnam.*

INTRODUCTION

During rapid industrialization, industrial parks (IPs) play a crucial role in Vietnam's economic development. However, this development is accompanied by serious environmental challenges: greenhouse gas emissions, untreated wastewater, industrial and hazardous solid waste. This situation not only affects public health but also hinders sustainable development goals and international integration.... To address the above issues, traditional environmental management solutions are gradually revealing limitations: discontinuous monitoring, lack of predictive capability, reliance on manual labor, and delayed reporting. In this context, artificial intelligence (AI) emerges as a tool with great potential to enhance the efficiency of management, monitoring, and decision-making in the environmental field. Globally, AI has been integrated into environmental monitoring systems, wastewater treatment plant control, greenhouse gas emission forecasting, and big data analysis from sensors, satellites, IoT.... In Vietnam, some initial pilot steps have been implemented in monitoring water and air environments and optimizing energy usage in industrial parks, but these are still localized and experimental. This paper aims to synthesize and analyze the directions for applying AI in environmental management in industrial parks, thereby proposing development orientations suitable for Vietnam's practical conditions.

A. Current status of artificial intelligence applications in environmental management at industrial parks

1. Real-time environmental monitoring and warning using artificial intelligence (AI)

One typical application of AI in environmental management in industrial parks is real-time environmental pollution monitoring and warning. This is done through integrating AI with sensor systems (IoT), cameras, automatic measurement devices, and meteorological data. Machine learning or deep learning models can learn from historical data, detect anomalies in environmental parameters (such as pH, COD, TSS, PM2.5/PM10 concentration, noise), and provide early warnings of exceedances or environmental incidents, helping businesses and authorities respond promptly.

Examples:

• VSIP Hai Phong Industrial Park has applied a sensor system connected to AI to monitor effluent wastewater quality, integrating data on temperature, pH, DO, and flow rate. AI automatically analyzes abnormal trends and triggers warnings [1]

• In Ho Chi Minh City, the Department of Natural Resources and Environment is piloting an industrial exhaust gas monitoring system integrated with AI to analyze and predict air pollution levels in concentrated industrial clusters [2]

• Siemens Group (Germany) developed the Siemens MindSphere solution, applying AI in industrial environmental management to help factories in Europe monitor and optimize real-time emissions [3]

• India's DeepAir system uses deep learning neural networks to analyze air quality data, identify pollution sources, and provide early warnings in industrial areas in Mumbai and New Delhi [4]

2. Optimizing waste treatment systems using artificial intelligence

Operating wastewater and solid waste treatment systems in industrial parks often faces challenges regarding fluctuating load, effluent quality, and operating costs28. Artificial intelligence (AI), especially machine learning algorithms, is proving to be highly effective in predicting wastewater characteristics, automatically adjusting operating processes, and reducing energy and chemical consumption. AI can learn from real-time data on flow rate, pH, BOD, COD, etc., to optimize pump speed, coagulant dosage, aeration speed, thereby enhancing treatment efficiency and saving costs28. Additionally, the system has the capability to predict overload or blockage incidents, thus effectively preventing pollution situations.

Examples:

• At an industrial wastewater treatment plant in Malaysia, Artificial Neural Network (ANN) algorithms are used to predict BOD concentration and adjust operating modes in real time, helping increase treatment efficiency by 20% and reduce chemical costs by 15% [5]

• In Vietnam, a pilot model at Amata Industrial Park (Dong Nai) showed that AI combined with the SCADA system can reduce operational errors and enhance effluent water stability [6]

Key benefits:

• Energy Saving: Models like Random Forest or LSTM can optimize pump operation, reducing electricity costs [7]

• Rapid Response to Load Fluctuations: Using machine learning models with data from monitoring stations to predict water quality indicators [8]

• Easy Integration with Existing Technology: AI can integrate with existing SCADA, PLC, and automatic monitoring systems.

3. Forecasting and controlling air emissions, wastewater, and solid waste using AI

One of the major challenges in environmental management in industrial parks is the difficulty in continuously controlling emission volumes, due to fluctuating input data and the prevalence of manual monitoring systems31. Artificial intelligence helps bridge this gap through its ability to learn from historical and real-time data to forecast emission volumes based on cycles, seasons, or types of production.

Examples:

• Machine learning models such as Support Vector Machine (SVM), Random Forest, or recurrent neural networks like LSTM can forecast emissions of NOx, SOx, CO_2 from industrial boilers based on data regarding fuel, temperature, equipment operation, and climatic conditions [9]

• AI can connect with wastewater management models like ASM1/ASM2 to predict BOD/COD concentration at the outlet, thereby supporting plants in adjusting treatment processes before violating standards occurs [10]

• Some solid waste management systems in industrial parks in Japan have applied AI to forecast hazardous waste generation volume based on production output, helping proactively plan collection and treatment [11]

Key benefits:

• Real-time Emission Forecasting: AI helps estimate emission levels in advance before environmental

incidents occur, minimizing the risk of penalties or damage [12]

• Supporting Emission Reduction Planning: Based on forecast results, businesses can develop appropriate emission reduction strategies for each workshop and time period.

• Combining with Simulation Tools and GIS: AI can integrate with air quality modeling software (AERMOD, CALPUFF) and GIS maps to identify areas most heavily affected [13]

4. Intelligent environmental management decision support system in industrial parks

In the era of digital transformation, artificial intelligence is not only used for data processing but also plays a role as a Decision Support System (DSS). It helps industrial park management boards and environmental management agencies make optimal decisions based on big data analysis, trend forecasting, and environmental scenario simulation [14]

Examples:

• In China, smart eco-industrial parks like Suzhou IP have deployed DSS integrated with AI to analyze environmental data and provide priority warnings with proposed solutions for each enterprise [15]

• In Vietnam, the Ministry of Natural Resources and Environment's project on developing eco-cities and eco-industrial parks mentions integrating AI into environmental decision support platforms for pilot IPs in Ninh Binh and Can Tho [16]

Role of ai in decision support:

• Synthesizing and analyzing multi-source data from sensors, monitoring reports, violation history, weather models, and industrial production data.

• Assessing environmental risks in real time and classifying intervention priority levels based on the degree of risk.

• Simulating development scenarios, such as factory expansion, changes in production technology, or impacts of natural disasters, to support sustainable environmental planning.

Key benefits:

• Timely, Accurate, and Objective Decision Making, instead of relying on subjective assessment or fragmented data.

• Increased Transparency and Traceability of Pollution Sources, serving smart inspection and monitoring.

• Supporting the Development of Flexible Environmental Policies, suitable for each type of production and business scale.

B. Proposing development orientations and future work for ai application in environmental management of industrial parks in vietnam

To effectively apply artificial intelligence (AI) in environmental management of industrial parks, Vietnam needs to develop suitable strategies tailored to its practical conditions. The following proposals aim to optimize the application of AI in monitoring, forecasting, and addressing environmental challenges, while improving management efficiency and minimizing the negative impacts of industrial activities:

Enhance training and raise awareness:

To apply AI successfully, it is crucial to have a well-trained workforce proficient in both AI technology and environmental management. Collaboration between universities, research institutions, and businesses is essential for training personnel and deploying pilot projects.

Develop infrastructure and environmental data:

The implementation of AI requires a solid infrastructure. Industrial parks must deploy sensor systems and IoT technologies to collect real-time data. This data will serve as the foundation for AI prediction and decision-making systems, enabling effective monitoring and management.

Promote pilot projects in key industrial parks:

Pilot projects in industrial parks with modern infrastructure are critical for evaluating AI applications. These projects will provide valuable insights into the feasibility, scalability, and effectiveness of AI-driven solutions in environmental management.

Integrate ai into existing management systems:

AI can be integrated into existing systems like SCADA and PLC to optimize operations, predict incidents, and reduce costs. This integration will not only improve efficiency but also allow industrial parks to make use of their current infrastructure.

Encourage collaboration among businesses, government agencies, and international organizations:

To accelerate the application of AI, cooperation between businesses, government agencies, and international organizations is essential. Learning from developed countries' experiences in AI-driven environmental management can help implement synchronized solutions, providing technological and financial support for industrial parks.

Build policies and legal frameworks supporting ai:

The government should introduce policies that encourage the application of AI in environmental management, including financial support for businesses adopting AI technologies and regulations on data protection and information security.

Future Work:

In the future, AI applications in environmental management within industrial parks should focus on expanding their scope beyond current pilot projects. The following steps are proposed for further research and development:

Scaling ai applications:

Expanding AI applications to more industrial parks and areas with different environmental and operational conditions is crucial for assessing the broad applicability of these technologies.

Integration with advanced ai models:

Future research should explore the use of advanced AI models such as Deep Learning and Reinforcement Learning to enhance decision-making capabilities, improve predictive accuracy, and optimize environmental monitoring in real time.

Development of regulatory frameworks:

Continued development of regulations and standards is necessary to guide the application of AI in industrial environmental management, ensuring its alignment with sustainability goals and international best practices.

Long-term monitoring and data collection:

Establishing long-term data collection systems will enable AI systems to improve over time by learning from more extensive data sets, resulting in more accurate predictions and better decision-making capabilities.

Exploring ai-driven circular economy models:

Research should focus on using AI to support the transition to a circular economy in industrial parks, such as optimizing resource use, reducing waste, and promoting recycling initiatives.

By addressing these future work areas, AI can further enhance its role in environmental management, contributing to the long-term goal of sustainable development in Vietnam's industrial parks.

CONCLUSION

Artificial Intelligence (AI) offers significant opportunities to enhance environmental management in industrial parks. By integrating AI into various aspects of environmental monitoring, such as real-time pollution detection, waste treatment optimization, and emission forecasting, AI can provide more accurate, efficient, and timely solutions compared to traditional methods. This technological advancement not only holds the potential to reduce operational costs but also to minimize the environmental footprint of industrial activities, thereby contributing to the achievement of sustainable development goals.

In the context of Vietnam, while AI applications in industrial parks are still in the pilot phase, the results from early-stage projects show promising outcomes, particularly in water quality monitoring and waste treatment optimization. However, to fully unlock the potential of AI, it is crucial to focus on several key areas, including infrastructure development, capacity building, and cross-sector collaboration. Further research should aim at scaling AI applications, integrating advanced AI models such as deep learning, and developing regulatory frameworks that align with international best practices.

As Vietnam continues its industrialization process, the widespread adoption and integration of AI in environmental management will be critical in reducing environmental risks and enhancing the sustainability of industrial parks. The shift towards AI-driven management systems will significantly contribute to the development of a circular economy, optimize resource utilization, and reduce waste generation. Ultimately, AI can help create a more sustainable industrial environment that benefits both the economy and society.

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