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TRANSFORMING INDUSTRIAL LANDSCAPES: FROM CHILD-FRIENDLY DESIGN TO SMART, CIRCULAR, AND ECO-EFFICIENT SOLUTIONS

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Abstract. The purpose of the study is to explore the sustainable transformation of industrial landscapes by reimagining them as eco-industrial parks (EIPs) that integrate circular economy principles, smart technologies, and child-friendly design. *The subject of this research* focuses on creating inclusive, resilient, and environmentally sustainable industrial ecosystems that balance economic productivity with community well-being. The study emphasizes the importance of addressing environmental and social dimensions simultaneously, ensuring industrial development aligns with global sustainability goals while meeting the needs of local communities. *Methodology.* The research is based on a multi-dimensional approach that incorporates a detailed review of academic literature, synthesis of case studies from Ukraine and other regions, and analysis of empirical data gathered in crisis-affected areas. The framework explores global challenges driving industrial transformation and examines the role of child-friendly design in enhancing social inclusivity. The analysis also evaluates the impact of technological innovation and circular economy practices in optimizing resource use and minimizing waste. Finally, the study proposes a strategic framework for implementing sustainable practices in industrial parks. A descriptive-analytical method was used, supported by comparative analysis of international experiences. *The aim of the study* is to identify key factors that enable successful eco-industrial park development, such as collaborative governance, public-private partnerships, and the application of innovative technologies. It also explores how child-friendly design principles can strengthen community engagement and inclusivity, ensuring industrial zones foster positive social impacts. Smart technologies and circular economy practices are shown to promote resource efficiency, industrial symbiosis, and long-term sustainability. *The findings* provide actionable insights for policymakers, urban planners, and industry leaders. The proposed framework offers a practical roadmap for transforming industrial landscapes into hubs of sustainability and innovation. Recommendations include adopting inclusive policies, adaptive planning, and leveraging advanced technologies to create resilient industrial ecosystems that benefit both the environment and communities. *Value/originality.* This research contributes to the global discourse on sustainable industrial transformation by presenting a case study of Ukraine alongside broader applications for international contexts. By addressing environmental, social, and economic dimensions, the study provides a comprehensive vision for rethinking industrial zones as engines of sustainability, innovation, and community well-being.

Keywords: eco-industrial parks, circular economy, child-friendly design, smart technologies, sustainable transformation, industrial symbiosis, public-private partnerships

JEL Classification: Q01, Q56, Q57, L52, R11, O18, D85

1. Introduction

The transformation of industrial landscapes into sustainable and inclusive spaces has emerged as a critical priority in addressing the environmental, social, and economic challenges of the 21st century. Traditional industrial parks, often characterized by linear economic models and high resource consumption, are being reimagined as eco-industrial parks (EIPs) to align with principles of circular economy, industrial symbiosis, and green innovation. These transformations hold the potential to enhance

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resource efficiency, reduce environmental impact, and foster greater community well-being.

As the global climate crisis intensifies and urbanization accelerates, the need to repurpose industrial zones as hubs of sustainability and resilience becomes ever more urgent. Innovative approaches, such as integrating child-friendly design, adopting smart technologies, and applying circular economy principles, offer viable pathways for achieving these goals. Beyond their environmental implications, these changes address critical social dimensions, such as community inclusivity and accessibility, ensuring that industrial developments contribute to broader societal well-being.

This paper examines how such strategies can reshape industrial zones by integrating ecological and technological advancements alongside social considerations. Drawing on case studies and empirical evidence from diverse global contexts, it highlights both the opportunities and challenges associated with these transitions. Specific attention is given to creating child-friendly parks in industrial areas and fostering collaborative efforts among stakeholders to achieve green and smart industrial ecosystems.

By synthesizing insights from existing literature, this study provides a comprehensive framework for understanding the multidimensional strategies necessary for the sustainable transformation of industrial landscapes. It underscores the importance of collaborative efforts among government, private sector, and local communities to achieve a balanced integration of economic, environmental, and social goals. Ultimately, this study aims to inspire policymakers, urban planners, and industry leaders to reimagine industrial spaces as engines of sustainability, inclusivity, and innovation.

2. Problem Statement and Objectives

The rapid industrialization witnessed over the past century has led to significant environmental degradation, social challenges, and inefficient resource utilization. Traditional industrial parks often operate under a linear economic model, which perpetuates the "take-make-dispose" paradigm, contributing to unsustainable practices and long-term ecological damage (Duman & Aydın, 2023). Furthermore, the lack of integration of social considerations, such as child-friendly spaces, exacerbates the disconnect between industrial activities and community well-being (Nugraha et al., 2024).

This study seeks to address the following research questions:

1. What is the role of child-friendly designs in improving the social integration of industrial landscapes?
2. Which role do technological innovation and circular economy principles play in transforming industrial zones?
3. What is the framework for policymakers, industry leaders, and community stakeholders to promote sustainable and inclusive industrial practices?

By answering these questions, this paper aims to contribute to the ongoing discourse on sustainable industrial transformation and offer actionable insights for future implementations.

3. Literature Review

The concept of eco-industrial parks (EIPs) has evolved significantly over recent decades, driven by the need for more sustainable industrial practices. Early studies highlighted the inefficiencies of linear economic systems, which often result in excessive waste and environmental degradation. Researchers like Duman and Aydın (2023) emphasized the necessity of transitioning to circular economy models, characterized by the "recycle-reuse-reduce" paradigm. This approach seeks to minimize waste and maximize resource efficiency by fostering symbiotic relationships between industries.

Van Beers et al. (2020) provided a comprehensive analysis of 50 industrial parks across eight countries, identifying key factors that contribute to the successful transformation of traditional parks into EIPs. Their findings underscore the importance of public-private partnerships, as well as the integration of environmental and social performance indicators into park management. Notably, parks managed by private entities or through collaborative governance models demonstrated higher compliance with international EIP frameworks compared to those managed solely by public authorities.

Social considerations, such as the inclusion of child-friendly spaces, have also gained attention in recent literature. Nugraha et al. (2024) conducted a spatial analysis of neighborhood parks in Jakarta, Indonesia, highlighting the challenges

posed by proximity to industrial activities. Their study revealed that park quality and accessibility are often compromised in such settings, underscoring the need for innovative design approaches to create more inclusive environments.

Technological innovation plays a pivotal role in the development of EIPs. Genc and Kurt (2024) explored the application of biomimicry in optimizing industrial networks, demonstrating how natural ecosystem principles can be leveraged to enhance resource cycling and energy efficiency. Similarly, the integration of smart technologies, as discussed by Mikhno et al. (2023), has been shown to enhance the functionality and sustainability of industrial parks by promoting green intellectual capital and fostering collaborative resource management.

Finally, Ukrainian researchers developed an idea of collaborative governance for optimizing governmental solutions by the integration of smart technologies (Matveieva, Mamatova, Borodin, Gustafsson, Wihlborg, & Kvitka, 2024).

These studies collectively highlight the multifaceted nature of EIP development, emphasizing the need for interdisciplinary approaches that combine ecological, social, and technological perspectives. The following sections build upon these insights to propose practical strategies for transforming industrial landscapes into sustainable and inclusive ecosystems.

4. Child-Friendly Design in Industrial Landscapes

Integrating child-friendly design into industrial landscapes represents a vital step toward enhancing social inclusivity in eco-industrial park development. Neighborhood parks, as analyzed by Nugraha et al. (2024), offer a critical insight into the challenges and opportunities of creating spaces that cater to diverse community needs within industrial areas. Their research in Jakarta revealed that the quality of parks is significantly influenced by their proximity to industrial activities, traffic flow, and surrounding land use.

Key findings from Nugraha et al. (2024) indicate that the strategic use of urban planning tools, such as GIS-based spatial analysis, can identify optimal locations for park development. This approach ensures equitable access to green spaces and mitigates adverse impacts of industrial proximity. Additionally, the implementation of child-friendly design elements – such as safe play areas, shaded seating, and pollution barriers – can transform underutilized spaces into vibrant community hubs.

Challenges remain in addressing the socio-environmental trade-offs associated with park development in industrial zones. Parks with moderate or poor quality often face issues related to high traffic density and industrial pollution. Nugraha et al. (2024) emphasize the importance of collaborative efforts among local governments, urban planners, and industrial stakeholders to overcome these barriers and prioritize community well-being.

By incorporating child-friendly principles into eco-industrial park design, stakeholders can bridge the gap between industrial functionality and social sustainability. These efforts not only improve community health and well-being but also enhance the overall attractiveness of industrial zones as integrated and inclusive ecosystems.

Thus, child-friendly design in industrial landscapes involves such key characteristics which embrace security considerations, accessibility, and inclusivity (Table 1).

Based on these characteristics, the role of child-friendly design in industrial landscapes lies, firstly, in enhancing social inclusion, as it creates bridges between industrial zones and the surrounding community by offering recreational and educational spaces; ensures that industrial development considers the needs of the vulnerable groups, promoting equitable urban development. Secondly, it builds community-industrial synergies through demonstrating that industrial zones can coexist with community-focused spaces, breaking down negative perceptions of industry. Thirdly, it serves for promoting sustainability and awareness by incorporating eco-friendly materials and green spaces, showcasing the potential of sustainable industrial practices. Finally, it attracts stakeholders and investment by enhancing the appeal of industrial areas for businesses, employees, and residents by integrating socially and environmentally conscious designs, at the same time contributing to corporate social responsibility goals, attracting industries committed to sustainable and inclusive development.

Table 1
Characteristics of child-friendly design in industrial landscapes

Characteristics	Overview
1. Security characteristics	– secure boundaries to prevent access to hazardous industrial zones; – child-safe play equipment and non-toxic materials; – traffic-calming measures to minimize risks from industrial vehicles;
2. Accessibility	– easy access to parks and recreational spaces for children and families; – pathways designed for strollers, wheelchairs, and bicycles; – proximity to residential areas to ensure equitable access
3. Environmental quality	– green infrastructure such as trees and vegetation to reduce pollution and noise; – air quality control measures like vegetative buffers to protect children from industrial emissions; – ample shaded areas to mitigate heat and create comfortable spaces for play;
4. Inclusive design	– spaces designed to accommodate children of all ages and abilities; – multifunctional areas for diverse activities such as sports, arts, and quiet recreation; – facilities that reflect cultural and community values;
5. Educational components	– interactive installations or exhibits to teach children about sustainability and the environment; – integration of learning opportunities, such as community gardens or renewable energy demonstrations;
6. Community integration	– collaborative design processes involving local families and children; – spaces that encourage social interaction and foster a sense of community; – opportunities for families to participate in the maintenance and evolution of the space.

5. Technological Innovation and Circular Economy in EIP Development

Technological innovation and circular economy principles are fundamental to the sustainable transformation of industrial landscapes. The transition from linear economic models to circular systems requires the integration of advanced technologies and innovative approaches that enhance resource efficiency, minimize waste, and foster collaboration among industries.

Genc and Kurt (2024) highlighted the application of biomimicry in EIP development, emphasizing how natural ecosystem principles can inform the design of industrial networks. Their research demonstrated that optimizing industrial network connectance enhances resource cycling, reduces energy consumption, and improves overall sustainability. The study underscored the importance of cyclicality (λmax) as a key metric for evaluating energy and material savings within industrial systems.

Similarly, Mikhno et al. (2023) explored the role of smart technologies in promoting green intellectual capital within EIPs. Their findings revealed that the integration of digital tools and data-driven systems facilitates collaborative resource management, enabling industries to share resources, reduce costs, and achieve environmental goals. Smart projects, such as the implementation of CO2-free mobility hubs (Sihvonen & Weck, 2023), illustrate how technological advancements can support zero-emission transportation and enhance the sustainability of industrial operations.

Circular economy principles further complement technological innovation by redefining the "take-make-dispose" paradigm. Duman and Aydın (2023) advocated for a shift towards "recycle-reuse-reduce" practices, which prioritize resource efficiency and waste minimization. By fostering industrial symbiosis, where industries collaborate to exchange by-products and resources, EIPs can create self-sustaining ecosystems that benefit both the environment and the economy.

The successful implementation of these strategies requires coordinated efforts among policymakers, industry leaders, and community stakeholders. Governments play a crucial role in providing the necessary infrastructure, regulatory frameworks, and incentives to support technological innovation and circular practices. Collaborative governance models, as highlighted by Van Beers et al. (2020), have proven effective in enhancing EIP performance and achieving sustainable development goals.

Consequently, the strategic vision for integrating technological innovation and circular economy principles into eco-industrial park (EIP) development intends to create intelligent, resilient, and resource-efficient industrial ecosystems that serve as global benchmarks for sustainability.

This vision prioritizes the transformation of traditional industrial zones into dynamic hubs of green innovation and circular practices, leveraging advanced technologies to foster collaboration, reduce waste, and maximize resource utilization.

Key elements of this vision are presented in the Table 2.

By realizing this vision, EIPs can become catalysts for achieving global sustainability goals, balancing economic growth with environmental stewardship and social equity. This transformative approach aims to redefine industrial development as a force for positive change, ensuring a thriving future for industries and communities.

6. Discussion and Conclusion

The findings of this study highlight the potential of eco-industrial parks (EIPs) to serve as transformative solutions for addressing pressing global challenges related to sustainability and urbanization. By integrating smart technologies, child-friendly design, and circular economy principles, EIPs can bridge the gap between industrial functionality and community well-being. However, the transition from traditional industrial models to sustainable ecosystems is not without its challenges.

The sustainable transformation of industrial landscapes is a multifaceted challenge requiring a holistic approach that integrates social inclusivity, technological innovation, and circular economy principles. Child-friendly designs enhance community well-being, while smart technologies and biomimicry optimize resource utilization and energy efficiency. Collaborative governance and public-private partnerships emerge as key enablers of success, as evidenced by international experiences in eco-industrial park development.

This study highlights the importance of interdisciplinary strategies and stakeholder collaboration in achieving sustainable industrial ecosystems. By addressing social, ecological, and economic dimensions, policymakers and industry leaders can create a balanced framework for industrial development that aligns with global sustainability goals. Future research should explore the scalability of these strategies and the long-term impacts of integrated eco-industrial systems.

At the same time, there are several challenges on this way. Firstly, these are policy and regulatory barriers. The lack of coherent regulatory frameworks and incentives for circular economy practices hinders widespread adoption. For that,

Table 2

Elements of strategic vision for technological innovation and circular economy in EIP development

Elements	Overview
1. Smart and connected systems:	– implementing advanced digital tools such as IoT, AI, and big data analytics to enable real-time monitoring and optimization of resource flows, energy consumption, and environmental impacts; – developing interconnected industrial networks that enhance symbiosis by facilitating the seamless exchange of materials, energy, and information among stakeholders
2. Circular economy integration	– designing industrial processes and systems based on the "reduce-reuse-recycle" model to minimize waste and close resource loops; – encouraging industrial symbiosis by fostering partnerships where one industry's by-products serve as another's raw materials
3. Eco-innovation hubs	– establishing EIPs as centers of green technological innovation, where research, development, and implementation of sustainable technologies thrive; – promoting collaboration among academia, industry, and government to drive eco-innovation and develop scalable solutions; – ample shaded areas to mitigate heat and create comfortable spaces for play;
4. Resilient infrastructure	– incorporating renewable energy systems, such as solar and wind power, into EIP operations to achieve carbon neutrality; – building resilient infrastructure to adapt to climate change impacts and ensure the longevity and sustainability of industrial ecosystems;
5. Inclusive and sustainable development	– designing industrial landscapes that prioritize community well-being through inclusive policies and green spaces; – educating stakeholders on the benefits of circular practices and green technologies to ensure widespread adoption.

policymakers must develop and enforce standards that encourage industrial collaboration and environmental stewardship. Secondly, it is high initial costs. The upfront investment required for infrastructure development, smart technologies, and renewable energy systems can deter industries, especially in low- and middle-income countries. Thirdly, it is insufficient stakeholder coordination. Effective collaboration among diverse stakeholders, including governments, industries, and local communities, is essential but often difficult to achieve due to conflicting interests and priorities. And finally, technological gaps still have a place. Limited access to cutting-edge technologies and expertise in certain regions can impede the implementation of smart and sustainable solutions.

Therefore, to overcome these challenges, future efforts should focus on developing robust policy frameworks that incentivize circular economy practices and ensure compliance; promoting public-private partnerships to share the financial burden of EIP development; encouraging innovation through research grants and technology transfer programs; scaling successful pilot projects to demonstrate feasibility and inspire broader adoption; and finally enhancing community engagement to align industrial transformation goals with local needs and aspirations.

Perspectives of further research cover discussion of the importance of interdisciplinary approaches and collaborative efforts to ensure that EIPs contribute meaningfully to global sustainability objectives.

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