REVIEW OF SUSTAINABLE GREEN SERVICES FOR INDUSTRIAL PARKS

ОГЛЯД СТАЛИХ ЗЕЛЕНИХ СЕРВІСІВ ДЛЯ ІНДУСТРІАЛЬНИХ ПАРКІВ

This study presents a comprehensive approach to evaluating the economic sustainability of green services within eco-industrial parks, with a focus on practical applications. Through a detailed assessment using an evaluation matrix, this study highlights the benefits of various green services, such as solar panels, green roofs, and electric buses, in industrial parks. The findings demonstrate that green services provide economic, environmental, and social advantages. Furthermore, the integration of green services fosters social well-being, health, and community engagement. The analysis uses a weighted scoring system to evaluate the technical, economic, environmental, and social feasibility of different green services. By providing a ranking of the services for the sustainable transformation of industrial parks, this study offers actionable insights for decision-makers.
Key words: *green services, evaluation matrix, industrial parks, eco-industrial parks, infrastructure services, market demand.*

У статті представлено результати дослідження впровадження сталих зелених сервісів в індустріальні парки з метою підвищення їхньої економічної, екологічної та соціальної стійкості. Зелена інфраструктура, що включає такі рішення, як сонячні панелі, зелені дахи, електричні автобуси, компостування та переробка відходів, здатна покращити екологічні показники індустріальних парків, одночасно створюючи економічні вигоди та підвищуючи соціальний добробут. Дослідження акцентує увагу на необхідності переходу до екологічно сталих моделей розвитку в умовах сучасних викликів, таких як глобальна зміна клімату, вичерпність природних ресурсів та високі рівні забруднення. Основою дослідження є матриця оцінювання, що дозволила провести детальний аналіз технічної, економічної, екологічної та соціальної доцільності впровадження різних зелених рішень в індустріальні парки. В результаті, оцінено такі критерії, як капітальні інвестиції на впровадження, експлуатаційні витрати, рентабельність інвестицій, кліматична стійкість, підтримка громади, естетична цінність, а також вплив на здоров'я та соціальне благополуччя. В роботі застосовано систему зваженого оцінювання, яка дозволяє порівняти зелені сервіси за їхньою ефективністю та доцільністю, забезпечуючи раціональний вибір відповідних рішень для впровадження. Результати дослідження демонструють, що деякі зелені рішення, такі як LED-освітлення, сонячні панелі та переробка відходів, є найбільш ефективними з точки зору екологічної та економічної стійкості. Вони не тільки знижують енергоспоживання та витрати на обслуговування, але й сприяють покращенню якості життя громади, зменшенню забруднення та підвищенню загальної ефективності парків. Водночас деякі рішення, як вітрові турбіни, мають нижчу економічну ефективність через високі капітальні інвестиції та низький рівень рентабельності інвестицій, особливо у контексті обмеженого фінансування в умовах війни. В дослідженні підкреслено важливість інтеграції зелених сервісів в індустріальні парки для забезпечення відповідності міжнародним вимогам сталого розвитку, таким як міжнародні рамкові положення для екоіндустріальних парків. Впровадження зелених рішень сприяє створенню екологічно чистих виробничих процесів, знижуючи негативний вплив на навколишнє середовище та підвищуючи ефективність використання ресурсів. В статті надано практичні рекомендації для прийняття рішень щодо розвитку індустріальних парків на основі інтеграції сталих зелених сервісів, що забезпечують баланс між економічними вигодами та екологічною відповідальністю. Таким чином, в дослідженні запропоновано інструмент вибору раціональних зелених сервісів для промислових підприємств та державних органів, що прагнуть модернізувати індустріальні парки та перетворити їх на екоіндустріальні парки, які сприятимуть стійкому економічному зростанню, збереженню довкілля та покращенню соціального добробуту.
Ключові слова: *зелені послуги, матриця оцінювання, індустріальні парки, екоіндустріальні парки, інфраструктурні послуги, ринковий попит.*

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Introduction. This study aims to assess the opportunities for implementing green infrastructure and services in eco-industrial parks, underscoring their potential to deliver tangible benefits. This assessment is discussing the method for estimation of the sustainability for green services in industrial parks. By prioritizing practical solutions with measurable benefits, this study will serve as a roadmap for transforming industrial operations into models of sustainability and efficiency, setting a standard for the industry to follow. The implementation of green services in the parks will support them to to comply with the following prerequisite of International Framework for Eco-Industrial Parks (EIPs): "A market demand and feasibility study, supported by a business plan for specific "green" infrastructure and services has been undertaken to justify planning and implementation in the industrial park". This creates the demand and value for the results of the study.

Problem statement. Industrial parks play a crucial role in economic development but often face significant environmental challenges, such as high energy consumption, resource depletion, pollution, and waste generation. As the global demand for sustainable development grows, industrial parks are under increasing pressure to transition to more eco-friendly models, specifically eco-industrial parks (EIPs). However, implementing green services and infrastructure within these parks presents numerous challenges, including high upfront costs, technical feasibility issues, and a lack of comprehensive evaluation frameworks. Therefore, there is a critical need for methods to estimate the economic sustainability of green services that can guide

industrial parks toward more sustainable practices while balancing financial viability with environmental and social benefits.

Formulation of the goals of the article. The task of this research is the identification of practical green services, such as solar panels, recycling programs, and electric buses, and the evaluation of their economic, environmental, and social impacts by using an evaluation matrix methodology.

Methodology. The methodology employed in this article is centred around a comprehensive evaluation matrix designed to assess the sustainability of green infrastructure services in eco-industrial parks. The matrix evaluates each service across four key categories: technical, economic, environmental, and social feasibility. These categories encompass a wide range of criteria, such as site suitability, engineering and maintenance requirements, initial and operational costs, return on investment (ROI), environmental impact, climate resilience, community support, and health benefits. Each criterion is assigned a score from 1 to 5, with 1 representing low feasibility or benefit and 5 representing high feasibility or benefit. The scores are weighted based on the relative importance of each criterion to the overall sustainability goals of the park. A weighted average is then calculated to determine the total score for each service, providing a quantitative comparison of the feasibility and impact of different green solutions. This systematic approach enables the identification of the most sustainable and economically viable services for implementation in eco-industrial parks.

Literature review. Green infrastructure refers to a network of natural and semi-natural systems that provide environmental, economic, and social benefits [1]. It includes practices like green roofs, permeable pavements, rain gardens, and urban forests along with services that reduce carbon footprint [2].

Industrial parks are critical for economic development but often pose significant environmental challenges [3]. Green infrastructure can mitigate these challenges by managing stormwater, reducing energy consumption, and improving air quality [1], transforming industrial parks into eco-industrial parks, when other EIP requirements are met as well.

By adopting green infrastructure and other EIP strategies [4], industrial parks can enhance their sustainability while driving economic, environmental, social growth and stability. The example of the benefits is below.

Economic benefits:
– Cost Savings,
– Increased Property Value,
– Job Creation.

Environmental benefits:
– Improved Air Quality,
– Water Conservation,
– Reduced Pollution.

Social benefits:
– Health and Well-being.
– Community Engagement.

To enhance the sustainability and environmental performance of industrial parks, various possibilities should be evaluated to identify the most sustainable green infrastructure and services. To do this, the evaluation matrix [5] is proposed as a method for comprehensive analysis of green infrastructure services' sustainability.

By using this method, the example matrix was developed to identify the most feasible and impactful green infrastructure solutions to enhance the sustainability, resilience, and overall quality of industrial park. Each item is evaluated based on technical feasibility, economic feasibility, environmental feasibility, and social feasibility, considering factors such as site suitability, engineering requirements, maintenance needs, costs, return on investment, funding opportunities, environmental impact, climate resilience, sustainability, community support, aesthetic and recreational value, and health benefits. The breakdown of the logic behind the matrix is below:

Criteria Categories and Specific Criteria:

1. Technical Feasibility:

– Site Suitability: Evaluates whether the physical characteristics of the site are conducive to implementing the strategy.

– Engineering Requirements: Assesses the complexity and practicality of the engineering work required for implementation.

– Maintenance Requirements: Considers the long-term maintenance needs and the availability of expertise to manage the infrastructure.

2. Economic Feasibility:

– Initial Costs: Estimates the upfront costs for materials, labour, design, and permitting.

– Operational Costs: Assesses ongoing costs for maintenance and operation.

– Return on Investment (ROI): Calculates the payback period and overall ROI, considering potential savings and increased property value.

– Funding and Incentives: Identifies available grants, subsidies, and other financial supports.

3. Environmental Feasibility:

– Environmental Impact: Evaluates the potential positive and negative environmental effects.

– Climate Resilience: Assesses how the infrastructure improves resilience to climate change impacts.

– Sustainability: Ensures that the materials and practices used align with broader sustainability goals.

4. Social Feasibility:

– Community Support: Gauges the level of support from stakeholders, including employees and local residents.

– Aesthetic and Recreational Value: Considers the enhancement of the area's aesthetic appeal and potential for recreational use.

– Health Benefits: Evaluates improvements in air quality, noise reduction, and access to green spaces.

Scoring System:

– Each criterion is scored on a scale from 1 to 5, where 1 indicates low feasibility or benefit, and 5 indicates high feasibility or benefit.

– Scores are based on detailed assessments and relevant data, providing a quantitative measure for comparison.

Weighted Average Calculation:

– Each category is assigned a weight based on its importance to the overall project goals.

– The weighted average score is calculated by multiplying each criterion's score by its respective weight and summing these values.

– This approach ensures that the most critical aspects of feasibility are given appropriate emphasis.

Total Score:

– The total score for each strategy is the average of its weighted scores across all criteria categories.

– Options are then ranked based on their total scores, identifying the most feasible and impactful options.

Main results. The analysis of green services, which are widely implemented by (eco-) industrial parks and zones all over the world are presented in the Table 1.

The green infrastructure services with the score higher then 4,0 are identified as promising and sustainable. The services with the score from 3,0 to 4,0 are the services which recommended for implementation when budget allows. The services with the score lower then 3,0 are not recommended for the implementation because of lack of sustainability. The evaluation matrix presented in this study provides a structured approach to assessing the feasibility and sustainability of various green infrastructure solutions within eco-industrial parks. Each service is evaluated across several criteria, including site suitability, engineering and maintenance requirements, costs, return on investment (ROI), environmental impact, and social factors. The scoring system, which assigns values from 1 to 5, allows for a clear comparison of the different services. Among the evaluated solutions, LED lighting and recycling programs achieved the highest total scores of 4,6 and 4,5, respectively. These services are highly feasible from both economic and environmental perspectives, offering significant cost savings, improved sustainability, and ease of implementation. Additionally, water-efficient truck washing, composting facilities, and electric buses scored favourably, with total scores ranging from 4,0 to 4,1, indicating strong potential for contributing to the industrial park's sustainability goals. In contrast, wind turbines received the lowest score of 2,8, mainly due to higher initial costs, lower ROI, and fewer social and environmental benefits. Although wind turbines provide a renewable energy source, their economic feasibility in this context is limited, especially during wartime. The matrix highlights the services that are both highly feasible and impactful, such as solar panels, which score 4,0, and green roofs, which also

Table 1

Opportunities evaluation matrix

Infrastructure and services	Site Suitability	Engineering Requirements	Maintenance Requirements	Initial Costs	Operational Costs	ROI	Funding and Incentives	Environmental Impact	Climate Resilience	Sustainability	Community Support	Aesthetic and Recreational Value	Interest from MC, residents	Feasible during wartime	Income/Savings	Total Score (1–5)
Green Roofs [6]	5	4	4	3	4	2	1	5	5	4	5	5	5	3	Savings+ Income	3,9
Solar Panels [7]	4	3	4	3	4	4	4	5	5	5	4	4	5	2	Income	4,0
Wind Turbines [8]	2	3	4	3	4	2	2	4	5	5	1	1	1	2	Income	2,8
LED Lighting [9]	5	4	5	4	5	5	4	5	5	5	4	4	5	5	Savings	4,6
Water efficient truck washing [10]	3	4	4	3	4	5	3	5	5	5	4	3	3	3	Income	3,8
Recycling Programs [11]	5	5	5	4	5	4	4	5	5	5	4	4	3	5	Savings	4,5
Composting Facilities [12]	4	4	4	3	4	3	4	5	5	5	4	4	2	5	Savings	4,0
Rainwater Harvesting [13]	4	4	4	3	4	2	3	5	5	5	1	1	2	3	Savings	3,2
Electrical bus service [14]	4	5	3	3	3	4	3	5	5	5	5	4	5	4	Income	4,1
Noise Barriers [15]	4	4	4	2	4	1	3	5	5	5	4	5	1	2	Savings	3,5

score 4,0. These solutions, while offering moderate financial returns, present strong environmental and social benefits.

Conclusions. This article addresses the identified problem by developing and applying an evaluation matrix to assess the feasibility and sustainability of various green infrastructure services in eco-industrial parks. The matrix provides a structured method for decision-makers to compare green services based on multiple criteria, such as costs, return on investment, environmental impact, and community support. By completing this task, the study offers actionable insights and recommendations for the successful implementation of green infrastructure, guiding industrial parks toward more sustainable and economically viable practices.

The strategic assessment of green services within eco-industrial parks reveals several key insights into achieving economic and environmental sustainability. The research identifies LED lighting and recycling programs as the most promising green solutions, providing the greatest balance of feasibility and benefits. These services offer significant cost savings, low maintenance requirements, and strong environmental impacts, making them ideal for immediate implementation. Other services, such as solar panels and electric buses, also demonstrate high potential for supporting the industrial park's sustainability efforts, particularly in terms of energy efficiency and reducing carbon emissions. However, the economic feasibility of wind turbines is questionable, suggesting that this service may not be suitable for immediate deployment in all contexts, particularly during periods of financial or infrastructural constraints. Overall, the study emphasizes the importance of integrating a range of green services that address both economic and environmental challenges. By adopting a tailored approach to green infrastructure, industrial parks can enhance their resilience, improve their environmental performance, and foster economic growth, positioning themselves as leaders in sustainable industrial development. The findings of this study serve as a valuable resource for policymakers and stakeholders looking to transform industrial parks into sustainable eco-industrial parks.

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