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CARBON INTENSITY, WATER EFFICIENCY AND ENVIRONMENTAL PERFORMANCE: A CASE STUDY OF A SLOVAK BREWERY

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Abstract

The article focuses on the analysis of selected environmental and economic indicators of Heineken Slovakia – Hurbanovo Brewery during the period 2019–2024. The research examines the development of water consumption, carbon intensity and CO_2 emissions and evaluates their relationship with the economic performance of the enterprise. Descriptive analysis, Pearson correlation analysis and linear regression analysis were applied to identify statistically significant relationships between environmental and economic variables. The results indicate a significant improvement in environmental efficiency, particularly in the reduction of water consumption and carbon intensity. Regression analysis confirmed that company revenues and CO_2 emissions significantly influence total water consumption. The findings suggest that environmental sustainability measures contribute not only to reducing environmental burdens but also to improving operational efficiency and long-term competitiveness in manufacturing enterprises. The study is based on a single brewery case study covering the period 2019–2024 (N = 6 annual observations); therefore, the findings should be interpreted as exploratory and should not be generalised without further validation.

Keywords: environmental sustainability; brewing industry; water consumption; carbon intensity

1. INTRODUCTION

The current business environment is characterised by significant changes driven by climate change, technological progress and increasing societal pressure for responsible and sustainable business practices. Manufacturing enterprises are increasingly required not only to maintain economic performance and competitiveness, but also to reduce their environmental impact, optimise resource consumption and implement sustainable management approaches. These challenges are closely connected with the concept of sustainable industrial transformation, which emphasises the integration of environmental, technological and economic aspects within modern production systems.

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In manufacturing industries, environmental sustainability has become an important factor influencing long-term competitiveness and operational efficiency. Particular attention is devoted to the reduction of greenhouse gas emissions, efficient water management and optimisation of production processes. The implementation of environmental management tools, carbon footprint monitoring and resource-efficiency measures is therefore becoming an essential component of strategic management in industrial enterprises.

The brewing industry represents a specific sector with high demands on water, energy and raw materials. Consequently, breweries are increasingly implementing measures aimed at reducing environmental burdens and improving production efficiency. Monitoring environmental indicators such as water consumption, carbon intensity and CO_2 emissions provides valuable information about the sustainability performance of production systems and the effectiveness of environmental strategies.

Although previous studies have examined environmental sustainability in manufacturing and the brewing industry, relatively few empirical studies combine water consumption, carbon intensity and economic performance using internal company-level data. Furthermore, evidence from Central European breweries remains limited. This case study addresses this research gap by analysing six years of environmental and economic data from a Slovak brewery.

The aim of this article is to analyse selected environmental and economic indicators of Heineken Slovakia – Hurbanovo Brewery and to evaluate the relationships between environmental efficiency and the economic performance of the enterprise. The research focuses primarily on the development of water consumption, carbon intensity and CO_2 emissions during the period 2019–2024. In addition, correlation and regression analyses are applied to identify statistically significant relationships between environmental and economic variables.

The article is structured into several sections. The first part presents the theoretical background related to environmental sustainability and environmental performance assessment in manufacturing enterprises. The following section describes the research methodology and analytical methods used in the study. Subsequently, the article presents the results of the environmental indicator analysis together with the outcomes of correlation and regression analyses. The final section summarises the main findings and discusses their implications for sustainable industrial management.

2. LITERATURE REVIEW

The current industrial environment is increasingly influenced by the need to balance economic performance with environmental sustainability. Manufacturing enterprises face growing pressure to reduce greenhouse gas emissions, optimise resource consumption and implement sustainable production processes. These challenges are closely connected with the concept of sustainable industrial transformation, which integrates environmental, technological and economic aspects into modern business management (Ghobakhloo et al., 2023; Yang et al., 2024).

At the European level, sustainability policies are strongly supported by strategic initiatives such as the European Green Deal, which aims to achieve climate neutrality by 2050 and encourages enterprises to adopt low-carbon and resource-efficient production systems. In parallel, digitalisation and process optimisation are becoming important tools for improving industrial efficiency and environmental performance (Szpilko & Ejdys, 2022; D'Amato et al., 2024).

One of the most important approaches for evaluating environmental impacts is Life Cycle Assessment (LCA). LCA represents a systematic method for assessing the environmental impacts of products and processes throughout their entire life cycle, from raw material extraction to final disposal. According to ISO 14040 and ISO 14044 standards, LCA enables the identification of

environmental hotspots related to energy consumption, emissions and resource use, thereby supporting more sustainable industrial decision-making (Bowler et al., 2024; McDonagh et al., 2024).

In industrial practice, particular attention is devoted to the assessment of carbon footprint and water footprint indicators. The carbon footprint represents the total amount of greenhouse gas emissions associated with organisational activities and is commonly measured in CO_2 equivalents. According to the GHG Protocol methodology, emissions are divided into three categories: Scope 1 (direct emissions), Scope 2 (indirect emissions from purchased energy) and Scope 3 (other indirect emissions within the value chain). Monitoring carbon emissions enables enterprises to identify emission-intensive processes and implement strategies aimed at reducing environmental impacts and improving energy efficiency (Stavropoulos & Panagiotopoulou, 2022; Panagiotopoulou & Stavropoulos, 2023).

The water footprint is another important environmental indicator, particularly in water-intensive industries such as brewing and food production. It measures both direct and indirect water consumption associated with production activities and reflects the overall pressure placed on water resources. Effective water management has become a significant component of environmental sustainability strategies in manufacturing enterprises (Diro et al., 2024; Nydrioti & Grigoropoulou, 2025; Bjedov et al., 2026).

Environmental management systems also play a key role in sustainable industrial development. Standards such as ISO 14001 provide a framework for systematic environmental management, continuous improvement and compliance with environmental legislation. The implementation of environmental management systems contributes to more efficient resource utilisation, pollution prevention and improved environmental performance of enterprises (Ball & MacBryde, 2022; Rahman et al., 2023; Sozen et al., 2025).

An important concept associated with sustainable industrial development is the circular economy. Unlike the traditional linear economic model based on the "take–make–dispose" principle, the circular economy emphasises waste reduction, recycling and the reuse of materials within production systems. This approach contributes to lower resource consumption, reduced environmental burden and improved long-term sustainability of industrial production (Lodhi, 2024; Ravanal et al., 2024; Fernandes & Silva, 2025).

The brewing industry represents a sector with considerable environmental demands due to intensive consumption of water, energy and raw materials. Water consumption and greenhouse gas emissions are widely recognised as the principal environmental hotspots in brewery operations because brewing requires large amounts of process water and energy throughout production, cleaning and packaging activities. Consequently, breweries increasingly implement environmental measures aimed at reducing water consumption, lowering carbon emissions and improving production efficiency. Monitoring environmental indicators such as water consumption and carbon intensity therefore provides valuable information regarding the sustainability performance of brewing enterprises (Singh et al., 2022; Gokulakrishnan et al. 2023; Serviss et al., 2026).

In the present study, these sustainability concepts are operationalised through three measurable environmental indicators: total water consumption, the water consumption coefficient and carbon intensity. These indicators represent practical measures of resource efficiency and environmental performance that are commonly monitored within environmental management systems and life cycle assessment frameworks.

3. METHODOLOGY

3.1. Data and Variables

The aim of the research was to analyse the development of selected environmental indicators of the Heineken Slovensko – Pivovar Hurbanovo company and to identify the relationships between the

environmental and economic performance of the company. The research focused mainly on the area of water consumption, CO_2 emissions and their interrelationship with the economic indicators of the company.

To achieve the aim of our research, we set the following research question:

To what extent do economic performance and CO_2 emissions influence water consumption and environmental efficiency in a manufacturing enterprise?

In this study, environmental efficiency refers to improvements in resource utilisation measured by total water consumption, the water consumption coefficient and carbon intensity.

The subject of the analysis was the environmental indicators:

- total water consumption,
- water consumption coefficient,
- CO_2 emissions in the scope of Scope 1–2,
- carbon intensity of production,
- and the economic indicator:
- company sales.

The research was carried out on the basis of internal data of the Heineken Slovensko – Pivovar Hurbanovo company for the period 2019 – 2024. The analysis was based on six time observations (N = 6), with the data processed in the form of a time series.

3.2. Analysis

The following methods were used within the methodological procedure:

- analysis and synthesis,
- comparison,
- Pearson correlation analysis,
- linear regression analysis.

Descriptive analysis was used to identify development trends of environmental indicators in the monitored period. Subsequently, correlation analysis was carried out to identify the strength and direction of relationships between economic and environmental variables. Pearson correlation coefficient together with p-values was used to assess the statistical significance of relationships.

Linear regression analysis was subsequently applied to quantify the impact of economic and environmental factors on water consumption. The dependent variable was total water consumption, while the independent variables were company sales and CO_2 emissions (Scope 1–2). When evaluating the regression model, the value of the coefficient of determination, the statistical significance of the model and the significance of individual regression coefficients were monitored.

Company revenues were selected as a proxy for the firm's economic performance, while CO_2 emissions (Scope 1–2) represent the environmental burden associated with production activities. Other potential explanatory variables, such as production volume, were not included because consistent annual data were unavailable and because revenues already reflect changes in production activity.

The results of the analysis were interpreted with regard to the environmental efficiency of production processes and the principles of sustainable development in industrial enterprises. Since the regression analysis is based on only six annual observations (N = 6), the results should be interpreted with caution. Small samples reduce statistical power and increase the risk of overfitting; therefore, the regression findings should be regarded as exploratory rather than confirmatory.

4. RESULTS

The research focused on the analysis of selected environmental and economic indicators of Heineken Slovensko - Pivovar Hurbanovo in the period 2019 - 2024. The main goal was to identify trends in water consumption and CO_2 emissions and subsequently analyze the relationships between the company's economic performance and environmental indicators through correlation and regression analysis.

Table 1. presents the annual values of all analysed environmental and economic variables used in the subsequent descriptive, correlation and regression analyses.

Table 1 Annual values of the analysed variables (2019–2024)

Year	Revenues (€)	Total water consumption (m^3)	Scope 1–2 CO_2 emissions (kg CO_2e)	Water consumption coefficient
2019	127 406 812	702 031	8 160 260.56	4.14
2020	116 177 273	580 834	6 965 564.13	3.32
2021	102 867 171	534 365	8 480 840.12	3.10
2022	115 114 746	559 170	7 942 901.06	3.29
2023	124 933 005	521 373	4 991 487.01	3.37
2024	128 626 552	578 127	5 335 283.75	3.37

Source: Authors' processing based on the company's internal environmental and financial data.

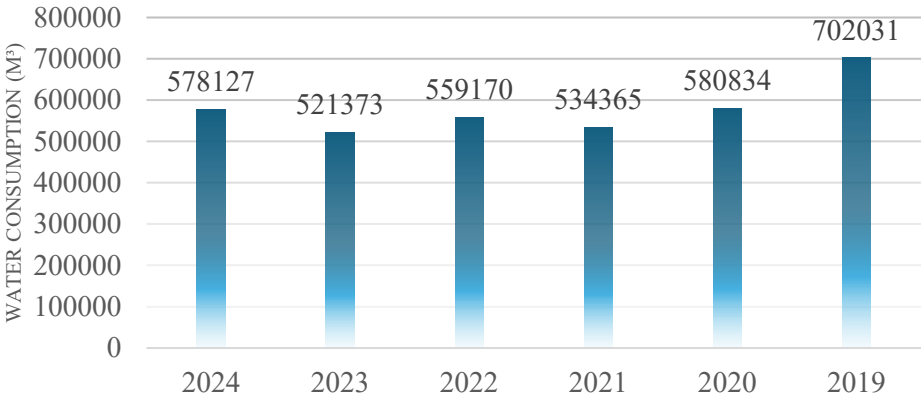


Figure 1 Total water consumption (m^3), 2019–2024

Source: Own analysis based on the company's internal data

The analysis of the development of total water consumption shows a significant improvement in the environmental efficiency of the company in the monitored period. The highest water consumption was recorded in 2019, when the company consumed approximately 702 thousand m^3 of water. In the following years, there was a significant decrease in consumption, with the minimum being reached in 2021 at approximately 534 thousand m^3.

After 2021, a slight increase in water consumption can be observed, but the values remained significantly lower compared to 2019. This trend indicates the implementation of measures aimed at more efficient use of water resources and optimization of production processes. From an environmental point of view, this is a positive development, as reducing water consumption is a significant factor in the sustainability of production in the food industry.

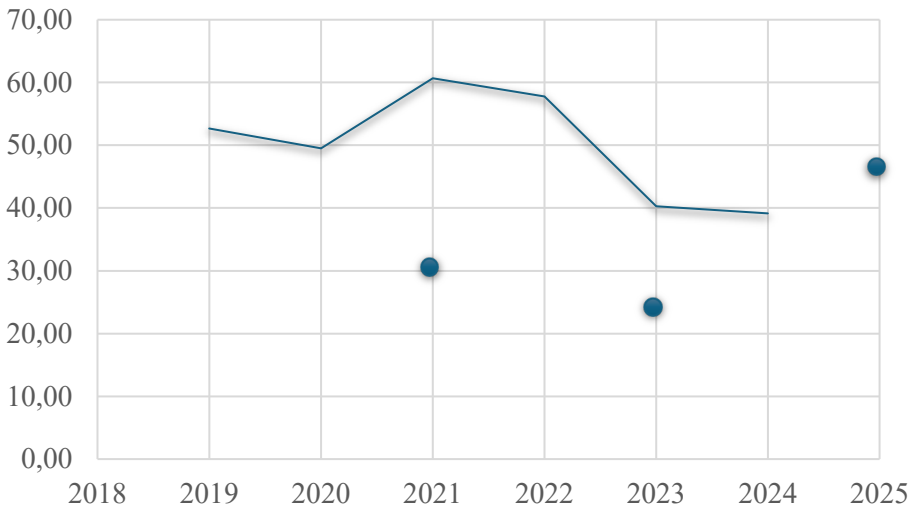


Figure 2 Scope 1–2 carbon intensity (kg CO_2/hl), 2019–2024

Source: Own compilation based on the company's internal data

The development of the carbon intensity of production points to a gradual increase in the emission efficiency of the company. In the period 2019-2021, a fluctuating trend was recorded with a maximum in 2021, when the carbon intensity reached approximately 60 kg CO_2/hl of production. However, since 2022, there has been a significant decrease in the indicator. In 2024, the carbon intensity reached its lowest value of approximately 39 kg CO_2/hl, which represents an improvement of approximately 26% compared to 2019. This development indicates an increasing energy efficiency of production processes and more effective management of CO_2 emissions. At the same time, the decrease in carbon intensity indicates that the company is able to reduce the environmental burden without a negative impact on production performance.

Table 2 Pearson correlation coefficients between selected variables

Variables	r	p-value
Revenue – Total water consumption	0.466	0.352
Revenue – CO_2 emissions (Scope 1–2)	-0.620	0.189
Water consumption coefficient – Total water consumption	0.928	0.008

Source: Own analysis based on the company's internal data

Pearson correlation analysis was performed to identify the relationships between economic and environmental indicators. The results of the analysis indicated the existence of several relationships between the monitored variables.

The strongest and at the same time statistically significant relationship was identified between the water consumption coefficient and total water consumption ($r = 0.928$; $p = 0.008$). This is a very strong positive correlation, which confirms that the efficiency of water resource use significantly affects the overall environmental burden of the company.

A moderately strong positive correlation was identified between sales and total water consumption ($r = 0.466$), which, however, was not statistically significant ($p = 0.352$). The result indicates that the growth of the company's economic performance may be accompanied by higher water consumption due to the growth of production volume.

An interesting result was recorded in the relationship between sales and CO_2 emissions, where a negative correlation was identified ($r = -0.620$). This trend may indicate a gradual increase

in the energy efficiency of production processes while simultaneously increasing the economic performance of the company. However, due to the low number of observations, the statistical significance of the relationship was not confirmed (p = 0.189).

Table 3 Model Fit Measures

Overall Model Test						
Model	R	R^2	F	df1	df2	p
1	0,951	0,905	14,3	2	3	0,029

Note: Models estimates using sample size of N=6

Source: Own processing based on the company's internal data

Table 4 Model coefficients- Total water consumption

Predictor	Estimate	t-value	p-value
Revenue	0,00738	4,95	0,016
Scope 1-2	0,04556	4,66	0,019

Source: Own processing based on the company's internal data

To quantify the impact of economic and environmental factors on water consumption, a linear regression analysis was performed. The dependent variable was total water consumption, while the independent variables were the company's sales and CO_2 emissions (Scope 1–2).

The regression model achieved a high explanatory power of $R^2 = 0.905$, which means that the model explains more than 90% of the variability in water consumption. The overall statistical significance of the model was confirmed by the F-test (F = 14.3; p = 0.029).

The results of the regression analysis showed that the company's sales have a statistically significant positive impact on water consumption (β = 0.00738; p = 0.016). This result indicates that the growth of the company's economic performance is accompanied by an increase in the need for technological water.

Similarly, CO_2 emissions showed a statistically significant positive relationship with water consumption (β = 0.04556; p = 0.019). The results confirm the interdependence of energy and water intensity of production processes. Overall, it can be stated that the environmental performance of the company is closely linked to the economic and energy intensity of production. The results also indicate that the implementation of environmental measures can contribute to increasing the efficiency of production processes and to gradually reducing the environmental burden of the company.

5. DISCUSSION

5.1. Water efficiency

The results of the research indicate that environmental performance in Heineken Slovakia – Hurbanovo Brewery has improved significantly during the analysed period, particularly in the areas of water consumption efficiency and carbon intensity reduction. The findings confirm that environmental sustainability and economic performance are increasingly interconnected within manufacturing enterprises, especially in resource-intensive industries such as brewing.

One of the most important findings of the study is the substantial reduction in total water consumption between 2019 and 2021, followed by a relatively stable trend in the subsequent years. This development suggests that the company successfully implemented measures aimed at

improving water efficiency and optimising production processes. Similar trends have been identified in previous studies focused on sustainable manufacturing and brewery management, which emphasise water efficiency as one of the key sustainability priorities in the brewing industry. Brewing production is highly dependent on water resources, not only as a production input but also in cleaning and technological processes. Consequently, reductions in water consumption represent both environmental and economic benefits for breweries.

5.2. Carbon performance

The findings related to carbon intensity also demonstrate a positive environmental trend. Despite fluctuations during the first part of the analysed period, carbon intensity significantly decreased after 2022, reaching its lowest value in 2024. This result may indicate improvements in energy efficiency, optimisation of production technologies or implementation of environmental measures focused on emission reduction. Similar conclusions are presented in studies addressing carbon management in industrial enterprises, where improvements in production efficiency and technological modernisation are strongly associated with lower greenhouse gas emissions.

5.3. Relationships between environmental and economic indicators

An important contribution of the research is the identification of relationships between environmental and economic indicators through correlation and regression analyses. The strongest statistically significant relationship was observed between the water consumption coefficient and total water consumption. This finding confirms that improvements in operational water efficiency directly affect the overall environmental burden of the enterprise. The result is consistent with previous research highlighting water efficiency indicators as essential tools for evaluating sustainability performance in manufacturing industries.

The correlation analysis also revealed a negative relationship between revenues and CO_2 emissions, although the relationship was not statistically significant. This trend may nevertheless suggest that the company has gradually improved its production efficiency while maintaining or increasing its economic performance. Similar relationships have been discussed in the literature on sustainable industrial management, where investments in cleaner technologies and process optimisation contribute simultaneously to environmental improvements and economic competitiveness. However, this relationship was not statistically significant ($p = 0.189$), and therefore should not be interpreted as evidence of a systematic association. A larger dataset would be required to confirm whether this pattern reflects a genuine relationship.

The regression model further confirmed that revenues and CO_2 emissions significantly influence total water consumption. The positive relationship between revenues and water consumption can be considered economically logical, as increased production volumes generally require higher technological water usage. At the same time, the positive relationship between CO_2 emissions and water consumption indicates a close interconnection between energy intensity and water intensity in industrial production processes. These findings support the assumption that environmental indicators in manufacturing enterprises should not be analysed separately, but rather as interconnected components of operational sustainability.

5.4. Interpretation of the research question

The research question focused on examining the extent to which economic performance and CO_2 emissions influence water consumption and environmental efficiency in a manufacturing enterprise. Based on the results of the correlation and regression analyses, it can be concluded that both economic and environmental factors significantly affect water consumption within the analysed

brewery. The regression model confirmed that increases in company revenues are associated with higher water consumption, which reflects the growing production intensity and technological demands of brewing processes. At the same time, CO_2 emissions also demonstrated a statistically significant positive relationship with water consumption, indicating a strong interconnection between energy use, emissions and water intensity in industrial production. Although the enterprise achieved considerable improvements in environmental efficiency during the analysed period, particularly through reductions in carbon intensity and optimisation of water use, the findings suggest that sustainable production management requires the simultaneous monitoring of economic growth and environmental impacts. Therefore, the research question was answered by confirming that economic performance and CO_2 emissions are important determinants of water consumption and environmental efficiency in manufacturing enterprises.

6. CONCLUSION

6.1. Main findings

The aim of this study was to analyse selected environmental and economic indicators of Heineken Slovensko – Pivovar Hurbanovo and to evaluate the relationships between environmental efficiency and the economic performance of the enterprise during the period 2019–2024. The research focused primarily on the development of water consumption, carbon intensity and CO_2 emissions, while correlation and regression analyses were applied to identify statistically significant relationships between environmental and economic variables.

The results of the study confirmed that the company achieved a significant improvement in environmental efficiency during the analysed period. A substantial reduction in total water consumption and carbon intensity was identified, indicating the successful implementation of measures focused on resource optimisation, energy efficiency and sustainable production management. At the same time, the analyses confirmed that economic performance and environmental indicators are closely interconnected. The regression model demonstrated that both company revenues and CO_2 emissions significantly influence total water consumption, highlighting the relationship between production intensity, energy use and environmental burden in manufacturing enterprises.

6.2. Limitations

Despite the valuable findings, the study has several limitations. The main limitation is the relatively small sample size (N = 6), which reduces the statistical robustness and generalisability of the results. The analysis was also limited to a single manufacturing enterprise operating within the brewing industry, which means that the findings may not be fully applicable to other industrial sectors. Another limitation is the restricted number of analysed variables, as the research focused mainly on water consumption, carbon intensity, CO_2 emissions and revenues, while other environmental or operational indicators were not included.

6.3. Future research

Future research could expand the analysis by incorporating a larger dataset covering a longer time period and additional manufacturing enterprises. Comparative studies across multiple breweries or industrial sectors could provide a broader understanding of environmental efficiency in manufacturing industries. Further research may also focus on the role of digital technologies, renewable energy implementation, circular economy practices and environmental management systems in improving sustainability performance. In addition, future studies could include other

environmental indicators such as waste generation, energy consumption or life cycle assessment indicators to provide a more comprehensive evaluation of sustainable industrial development.

6.4. Practical implications

This study also contributes to the broader discussion on sustainable industrial transformation and environmental management in manufacturing enterprises. Current sustainability strategies increasingly emphasise the integration of environmental performance indicators into strategic and operational decision-making processes. The findings of this research support the view that environmental sustainability measures can contribute not only to reducing environmental burdens but also to improving operational efficiency and long-term competitiveness. From a practical perspective, the results suggest that breweries and other manufacturing enterprises should continue investing in technologies focused on water efficiency, energy optimisation and emission reduction. Environmental indicators such as water consumption, carbon intensity and CO_2 emissions can serve as important management tools for monitoring sustainability performance and identifying areas with potential for further improvement. Future research could expand the analysis by including a larger number of observations, additional environmental indicators or comparative analyses across multiple breweries or manufacturing enterprises. Further studies may also examine the impact of digital technologies, renewable energy implementation and circular economy practices on environmental efficiency and sustainable industrial development.

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