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USING ARTIFICIAL INTELLIGENCE TO INCREASE THE ECONOMIC EFFICIENCY OF THE BREWING INDUSTRY

SUMMARY

The brewing industry, as a manufacturing sector that produces beer, should be viewed through the prism of its broader impacts on society as a whole. The brewing industry exhibits continuous growth trends, contributing economically to the broader community by sustaining production, fostering employment, enhancing income, and promoting exports. Raw material costs in beer production account for the largest share of total costs. As these costs increase, greater pressure is placed on the cost price of the final product. Under such conditions, it is challenging in a market economy to strike a balance between production costs and market prices, thereby maintaining competitiveness. In this context, the application of modern software solutions represents a useful tool for achieving more cost-efficient operations. The implementation of such a concept must satisfy a cause-and-effect relationship: optimal cost management while maintaining high production quality. However, within the broader concept of applying artificial intelligence and smart technologies, socially responsible behaviour also plays a significant role. This paper will demonstrate cost trends through the calculation of the coefficient of economic efficiency and the coefficient of profitability, combining conventional business practices with investments in smart solutions. Two parts will be the focus of the inquiry by using the previously indicated computations. The impact of integrating AI with current beer production processes on the environment—that is, the sustainable use of resources—will be

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demonstrated, and financial savings will be computed. Given that the manufacture of beer uses a significant amount of energy, the understudied topic of striking a balance between economic efficiency and the ecological element reflects the uniqueness of AI research and implementation. By testing the hypothesis, the relationship between total costs and investments in AI technology will be examined. The results will focus on variables that indicate business performance and competitiveness, thus generating new knowledge about the integrated relationship of investing in AI technology, and how such investments contribute to optimal energy consumption. This paper aims to provide insights into the economic efficiency and profitability of beer production when using artificial intelligence, and, based on these indicators, to assess the effects reflected in the wider social community.

Keywords: beer production, artificial intelligence, costs, efficiency ratio, profitability ratio

INTRODUCTION

The basic cereal used to make beer is barley. Following harvesting, it is dried advantage on the sugar and uses it to produce carbon dioxide and ethyl alcohol. (Bai *et al.*, 2020). Optimizing efficiency in critical food processes such as grain drying is essential for long-term storage and economic viability. By introducing AI, managers can plan until its moisture content falls below 13% in order to prepare it for further processing. After that, the grains are steeped in a specific volume of water and allowed to germinate for a while—typically a week. Many biological and metabolic activities occur during this process, producing an enzyme-rich malt. Drying stops the germination process, and the newly formed enzymes in the grains break down the starch to produce sugar. The yeast then feeds as the foundation for both the creation of beer and whisky. Other cereals, like as wheat, oats, millet, and rye, can be used to make malt in addition to the most popular barley (Rajičić *et al.*, 2020; Salanta *et al.*, 2020a; Rakašćan *et al.*, 2021; Milunović *et al.*, 2022; Popović *et al.*, 2020; 2024; 2025; Simić *et al.*, 2025; Kosev *et al.*, 2025). Two-rowed and six-rowed barley types are cultivated specifically to produce malt for brewing. Additionally, their qualities and characteristics differ. Although malt production standards vary, they all aim to produce the best beer possible (Malešević *et al.*, 2011; Popović *et al.*, 2010; 2025).

New technologies bring numerous advantages to business operations, including time reduction, more efficient data processing, faster information exchange, easier storage of data and documentation, quicker access to information, faster money transfers, and, more recently, more precise management of production processes. These advantages reduce costs, increase economic efficiency, and contribute to overall business success (Babić, 2000).

Artificial intelligence (later in the text referred as AI) has a positive impact on the optimisation of business processes by facilitating access to new knowledge, enabling the engagement of experts through remote work, and

allowing for the monitoring of business processes (Dounis, 2010), which can also be performed remotely. Overall business operations generate a large amount of communication and documentation, making it important to create synergy that transforms and organizes operations in order to achieve greater competitive advantage (Bai *et al.*, 2020).

With the introduction of AI, managers can plan more precisely, manage resources more effectively, identify market threats promptly, recognise risks, and quickly resolve emerging problems (Cugurullo, 2020). However, it is important to emphasise that the application of AI also presents certain challenges for the business sector. These include implementation costs, the need for qualified personnel, and risks related to employees' adaptation to new concepts. In addition, ethical issues related to transparency and accountability in AI-generated decision-making further complicate the integration process (Cugurullo, 2020). AI involves a number of ethical concerns that may have profound social implications (Dounis, 2010):

- Discrimination – certain groups of people may be disadvantaged in employment, financial stability, and legal protection.
- Privacy – the functioning of AI technologies requires deep intrusion into individuals' privacy due to the large volume of data needed, posing a serious risk to personal data protection and requiring adequate safeguards against misuse.
- Manipulation of information and video content – represents a serious societal risk, as it enables the spread of false information.

All of the above raises the issue of legal responsibility. In situations where AI makes decisions or causes harm, legal responsibility remains insufficiently defined due to the lack of clear protocols, procedures, and ethical guidelines, which may lead to intentional misuse with unethical consequences (Dounis, 2010).

Investment in the brewing industry through technical-technological systems and the improvement of knowledge and practices enables significant long-term savings in material production costs, resulting in increased production volume and higher productivity of labour and land (Mankiw, 2006). Costs are defined as the monetary value of resources consumed in the production of new value (Pavić, 2015). Although often compared with expenses, there is a significant difference between these terms (Kostić *et al.*, 1993). Four related concepts can be distinguished (Grubišić, 2013): Consumption – represents all inputs used in production; Cost – represents the product of consumption and the price of all production inputs; Expenditure can be defined as a decrease in cash or funds in a bank account or cash register; Expenses – represent the negative component of a company's financial result. They are compared with revenues in the income statement to determine business performance at the end of an accounting period. Expenses are a broader concept than costs and represent a decrease in economic benefits during an accounting period in the form of asset

outflows or the incurrence of liabilities, resulting in a reduction of equity (Markovski, 2004).

According to production functions, costs are divided into (Pindyck *et al.*, 2005): Production costs – related to the production process (materials, labour, overhead costs); and Non-production costs – typically categorised into administrative costs, selling costs, and research and development costs.

Depending on how costs respond to changes in production volume, they are divided into (Kostić *et al.*, 1993): Fixed costs – do not depend on the level of production (e.g., rent, depreciation, interest, taxes); and variable costs – depend on the volume of production (raw materials, packaging, transport, labour, etc.).

As production increases, the relationship between fixed and variable costs changes within the cost structure (Pindyck *et al.*, 2005). Reducing business costs implies transforming production management as a complex process that must be carefully planned in order to achieve positive outcomes (Arthur *et al.*, 2005).

This topic is highly relevant today, as domestic beer producers face constant pressure from global market trends and competitors with lower production costs, who, often supported by import lobbies, can more easily place their products on the domestic market. Therefore, the use of AI in cost management and optimisation can significantly improve production efficiency.

This study points to the current state of beer production and the possibility of improving the economics of the brewing industry through more innovative operational planning. Accordingly, this paper aims to determine the economic efficiency and profitability of beer production using AI and, based on these indicators, to assess the broader impacts on society.

MATERIAL AND METHODS

The study of the social benefits and prospects of using AI in beer production business was conducted with the aim of analyzing the scope, dynamics, and areas of AI technology application during 2023 and 2024. Beer production is significant for the domestic market and, as such, represents a manufacturing sector targeting consumers who prefer beverages with low or zero alcohol content.

The study employed a quantitative approach based on secondary analysis of official data, combined with mathematical-statistical methods, using an inductive reasoning method and a descriptive-analytical approach. Data were collected through a survey questionnaire and by reviewing websites and business reports from beer producers: Zagreb brewery, Heineken Croatia, Carlsberg Croatia, and Daruvar brewery. There were fifteen questions in all, divided into three sections of the survey. The perception of economic efficiency was measured using a five-point Likert scale, ranging from 1 (I do not agree at all) to 5 (I absolutely agree). Twenty professionals from the brewing business participated in the study that created the questionnaire. The study was carried out between June and August of 2025. Production operations directors, IT department managers, logistics managers, and process engineers and technicians are among the essential

personnel at the four breweries under analysis. The aforementioned experts provided direct primary data via a standardised survey questionnaire, with an emphasis on operational modifications and perceptions of efficacy.

Three criteria are established in order to categorise investment expenditures from business reports as "investment in AI":

1. Autonomous decision-making: the use of software and machine learning systems that independently affect the manufacturing process (e.g., temperature and pressure changes in fermentation tanks based on sensor data).
2. Software programs and algorithms designed to forecast future occurrences, identify issues or demand trends, and schedule beer distribution based on weather forecasts.
3. Intelligent automation on the filling line that detects and eliminates damage (bottles, labels, caps, etc.).

Secondary data was gathered by examining manufacturers' official websites, their yearly financial reports, audit reports, and publicly accessible ESG sustainability reports (for the years 2023 to 2024).

These sources were selected for their methodological reliability and public availability. The data include general economic indicators, cost data, and information on investments in AI. Quantitative indicators were aggregated for all producers and presented in tables and graphs.

The process of brewing involves the regulated interaction of water, yeast, starch, and hops to produce beer as the final result. Beer is created when glucose is fermented in yeast cells to produce carbon dioxide gas and ethyl alcohol (ethanol). The following describes the overall chemical reaction (Goyal *et al.*, 2023):



To compare AI usage among the producers, the data were normalized according to cost structure and value. The analysis included: 1.) Comparative analysis – comparing beer producers according to economic indicators and the intensity of AI technology use; 2.) Mathematical analysis – calculating coefficients of economic efficiency and profitability; 3.) Statistical analysis – using a correlation test of two variables to test the hypotheses: a.) that there is no significant correlation between total costs and AI technology investment, i.e., $H_0: p=0$; b.) that there is a relationship between total costs and AI technology investment, i.e., $H_1: p \neq 0$; 4.) Inductive analysis – drawing general conclusions on the effects of AI technology application on the broader society.

The analytical framework is based on the assumption that AI implementation in production processes can positively impact: operational efficiency, financial rationality and the social dimension.

Through the conceptual model, three dimensions are linked: the degree of digital transformation of beer producers, the intensity of AI technology application, and the achieved financial and social benefits (e.g., cost reduction,

investment in renewable energy, reduction of waste generation, and lower emissions of harmful gases into the atmosphere).

Table 1. Beer Production Indicators in 2023 and 2024

Indicators	2023				2024			
	Zagreb brewery	Heineken Croatia	Calsberg Croatia	Daruvar brewery	Zagreb brewery	Heineken Hrvatska	Calsberg Croatia	Daruvar brewery
Production volume in mil. ha	1.84	1.37	1.04	0.74	1.86	1.38	1.04	0.77
Number of emplo-yees	580.00	344.00	341.00	105.00	574.00	351.00	340.00	98.00
Revenue, EUR mil.	199.10	141.30	70.30	26.30	205.50	146.30	74.80	22.25
Investment in smart (AI) technology, EUR mil.	26.00	19.00	5.00	3.70	21.00	18.50	5.70	2.50
Fixed costs, EUR mil.	64.00	42.60	23.00	6.90	61.30	40.60	23.50	5.99
Variable costs, EUR mil.	101.35	77.20	40.70	14.10	96.97	74.44	37.80	11.35
Production costs, EUR mil.	98.54	72.40	44.00	15.10	98.54	72.40	44.00	15.10
Non-production costs, EUR mil.	67.90	41.30	21.00	6.00	67.90	41.30	21.00	6.00

Source: Survey questionnaire, data from websites, and business reports

The data from the table present a comparative overview of beer production by Zagreb brewery, Heineken Croatia, Carlsberg Croatia, and Brewery Daruvar. According to the presented indicators, it can be seen that Zagreb brewery achieved a production volume with a market share of 38.5% of the total analyzed production during the analyzed period. The production volume values show that all producers (except Carlsberg Croatia) increased their production in 2024 compared to 2023 by an average of 1.5%. Revenue data indicate that, for the observed period, revenues ranged from €22.25 million (Brewery Daruvar) to €205.50 million (Zagreb brewery).

When observing market share, Zagreb brewery achieved 46% of the revenues relative to other producers. Revenues in 2024 show an average growth of 3.1% compared to the previous year, except for Brewery Daruvar, which experienced a 6.7% decline in total revenues. Overall costs for all producers decreased on average by 3.5%. Investments in AI technology during the observed period ranged from €2.5 million to €26.0 million.

The cost ratio (comparison of nominal cost amounts) shows that the share of fixed costs ranges from 26% (Brewery Daruvar) to 33% (Carlsberg Croatia). The share of variable costs in operations ranges from 50% (Zagreb brewery) to 58% (Carlsberg Croatia). Total costs in 2024 compared to 2023 decreased by 4.28% for Zagreb brewery and by 3.77% for Carlsberg Croatia. Total costs in 2024 compared to 2023 increased by 1.79% for Heineken Croatia and by 1.77% for Brewery Daruvar.

Table 2. Comparative Overview of Cost Structure in 2023 and 2024

Indicators	2023				2024			
	Zagreb brewery	Heineken Croatia	Calsberg Croatia	Brewery Daruvar	Zagreb brewery	Heineken Croatia	Calsberg Croatia	Brewery Daruvar
Fixed costs (EUR/million)	64.00	42.60	23.00	6.90	64.20	40.60	23.50	5.99
Machinery maintenance costs	13.00	10.30	4.10	0.90	13.20	9.60	4.10	0.80
Equipment depreciation	8.70	5.20	2.70	0.21	8.70	5.00	2.70	0.33
Energy costs	21.00	14.00	10.40	3.80	21.00	13.30	10.50	2.80
Building maintenance costs	11.00	7.00	3.10	1.21	11.00	6.60	3.30	1.20
Building depreciation	7.00	3.60	1.60	0.18	7.00	3.60	1.60	0.21
Interest costs	0,90	0,70	0,40	0,25	0,90	0,70	0,60	0,25
Service costs (consulting, accounting, etc.)	2.20	1.80	0.70	0.35	2.40	1.80	0.70	0.40
Variable costs (EUR/million)	101.35	77.20	40.70	14.10	96.97	74.44	37.80	11.35
Raw material costs	36.65	28.40	14.10	5.40	34.65	26.84	13.10	4.25
Packaging costs	12.70	10.20	6.50	2.10	11.70	9.40	5.80	2.05
Water costs	21.80	15.60	9.90	2.50	20.70	15.10	9.10	2.20
Transportation costs	9.20	6.80	3.50	1.20	8.62	6.40	3.10	1.15
Workforce costs	21.00	16.20	6.70	2.90	21.30	16.70	6.70	1.70

Source: Survey questionnaire and data from websites

The values from Table 1 and Table 2 will be used as material for further analysis in the study. The results presented in the study will demonstrate the efficiency and profitability of the business process, show the relationship between total costs and investments in AI technology, and highlight the effects of using AI technology in the beer production process.

RESULTS AND DISCUSSION

Beer is a traditional alcoholic leisure beverage that is well-liked all around the world. It is made through the brewing process, which entails the enzymatic

fermentation of a mixture of water, starch, and hops by yeast under particular conditions. Grain treatment, malting, mashing, lautering, filtering, fermentation, maturation, finishing, and packaging were some of the processes involved in making beer from cereal grains. The quality, flavour, aroma, consistency, and alcoholic content are all significantly impacted by the brewing process (Goyal *et al.*, 2023). The main method of making beer is fermentation with the aid of yeast utilising grain and water (Campbell, 2017). The Nile Valley is where this fermentation process first appeared thousands of years ago (Meussdoerffer, 2009). Around 5000 BC, the Egyptians are said to have been the first to chronicle the brewing process (Aroh, 2019). Raihofer *et al.*, (2022) recently offered the holistic history of 10,000 years of beer brewing together with the most significant discoveries and advancements in this sector. This industry now forms the foundation of the economies of several European nations as a result of its enormous expansion and advancement. Over 32 million hectolitres of beer were exported from the European Union (EU)-28 nations outside the EU in 2018, according to a recent analysis on the importance of beer to the European economy (Salantă *et al.*, 2020). This accounts for over 8% of the overall production. Increasing investment in innovation is essential for further growth in this industry, especially to create new brew kinds or flavours and expand their manufacturing lines.

The data in the Figure 1 shows the share of costs (fixed, variable, production and non-production) in the value of business turnover at Zagreb brewery, Heineken Croatia, Calsberg Croatia and Daruvar brewery

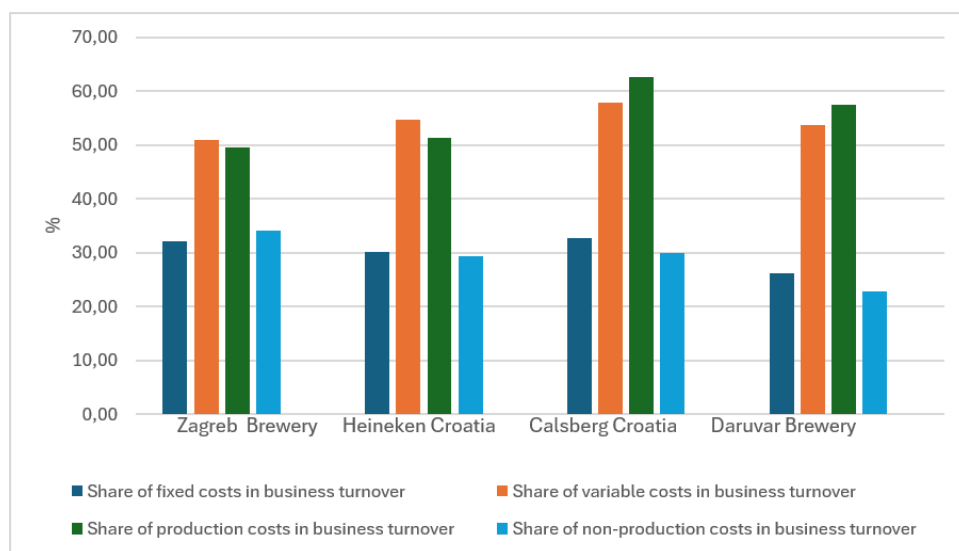


Figure 1. Comparative overview of the share of costs in the value of business turnover for Zagreb brewery, Heineken Croatia, Calsberg Croatia and Daruvar brewery, expressed as a percentage

The values in the Figure 1 show the following cost shares for the beer producers: Zagreb brewery – 32.14% fixed costs, 50.90% variable costs, 49.90% production costs, and 34.10% non-production costs. Heineken Croatia – 30.15% fixed costs, 54.64% variable costs, 51.24% production costs, and 29.23% non-production costs. Carlsberg Croatia – 32.72% fixed costs, 57.89% variable costs, 62.59% production costs, and 29.87% non-production costs. Brewery Daruvar – 26.24% fixed costs, 53.61% variable costs, 57.47% production costs, and 22.81% non-production costs. The following Figure 1 shows a comparative overview of the efficiency and profitability ratios.

The values in the Figure 2 show an increase in the efficiency ratio in 2024 compared to 2023 for all beer producers. The growth ranges from 2.46% for Daruvar brewery, 7.82% for Heineken Croatia, 7.83% for Zagreb brewery, to 10.57% for Carlsberg Croatia. The increase in efficiency was achieved by increasing production while reducing water, raw material, and transportation usage, as well as by increasing the use of self-generated energy.

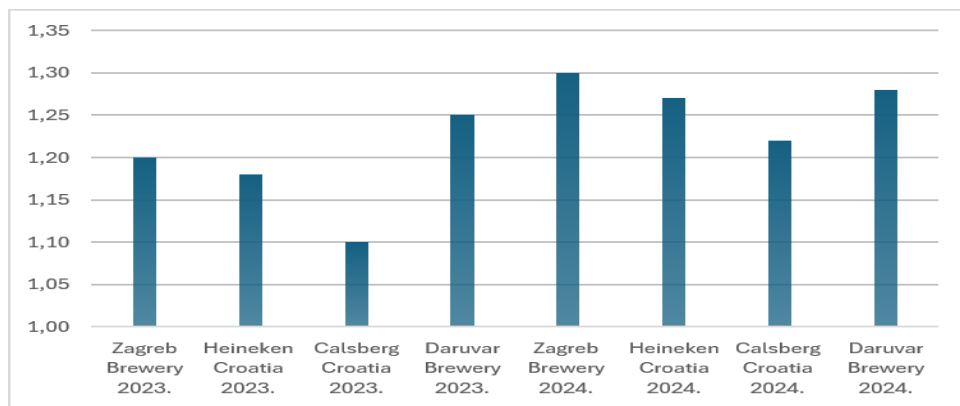


Figure 2. Overview of efficiency ratios in for Zagreb Brewery, Heineken Croatia, Calsberg Croatia and Daruvar Brewery

In other words, the values show the ratio of revenue to expenses, indicating that in 2023 Zagreb brewery achieved 1.20%, Heineken Croatia 1.18%, Carlsberg Croatia 1.10%, and Daruvar Brewery 1.25% revenue per unit of expense. During 2024, Zagreb brewery achieved 1.30%, Heineken Croatia 1.27%, Carlsberg Croatia 1.22%, and Daruvar Brewery 1.28% revenue per unit of expense. For both years, it can be concluded that production was efficient, Figure 2.

The values show an increase in the business profitability rate. For Zagreb brewery, the profitability rate in 2023 was 33.12%, Heineken Croatia 28.81%, Carlsberg Croatia 16.33%, and Daruvar brewery 39.01%. In 2024, the profitability rate increased to 49.26% for Zagreb brewery, 42.27% for Heineken Croatia, 36.11% for Carlsberg Croatia, and 43.02% for Daruvar brewery, Figures 3 and 4.

The increase in profitability was supported by production diversification, which included the generation of the company’s own electricity. The calculated values indicate that all resources were used efficiently and purposefully.

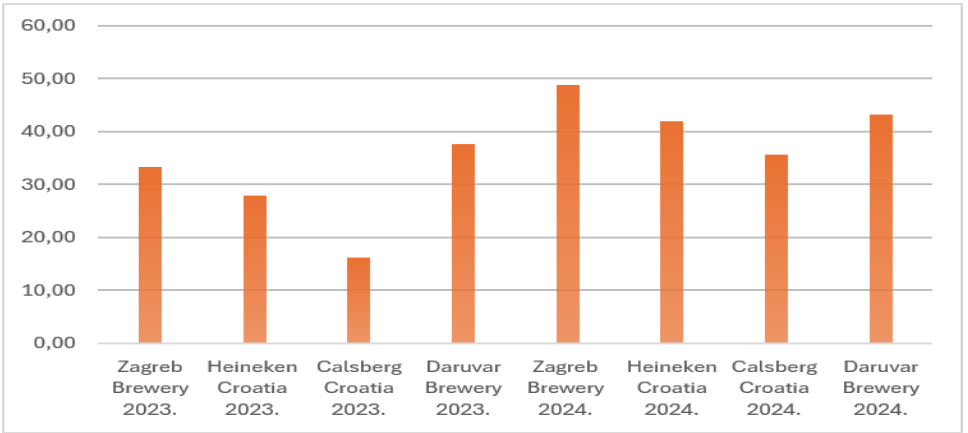
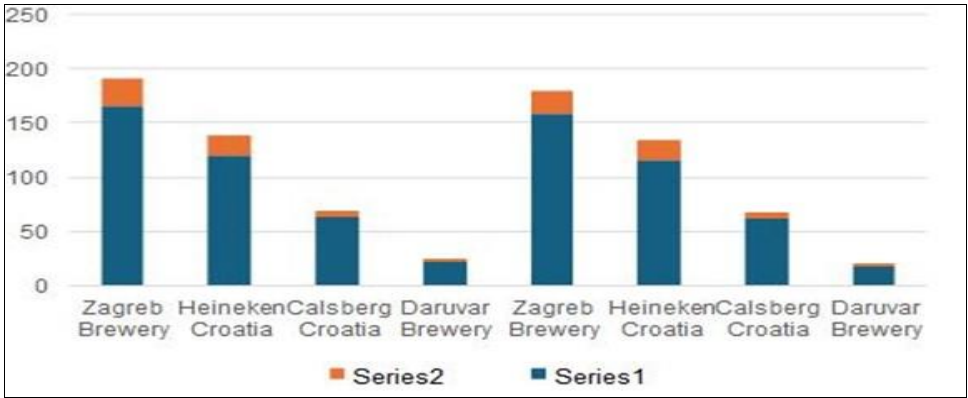


Figure 3. Overview of profitability ratios

The data show investments in AI technology in relation to total costs. Average values for the beer producers over both years indicate that, relative to total costs, Zagreb brewery invested 14.52% of funds in AI technology, Heineken Croatia 16.31%, Carlsberg Croatia 8.57%, and Daruvar brewery 16.17%, Tables 3-5.



*Series 1- Total Costs; Series 2- Investing in AI Technology

Figure 4. Investment in AI technology versus total costs during 2023 and 2024

More efficient and profitable production results from investments in production optimization systems and energy infrastructure. The effects of AI technology investments are reflected in their contribution to the wider community. The results are presented in the following table.

Table 3. Comparative overview of the effects of investments in AI Smart Technology during 2023 and 2024

Effects of Investments in AI Smart Technology	Year 2022/2023				Year 2023/2024			
	Zagreb brewery	Heineken Croatia	Calsberg Croatia	Daruvar Brewery	Zagreb brewery	Heineken Croatia	Calsberg Croatia	Daruvar Brewery
CO ₂ Emissions in tons	-8486	-6903	-3351	-1104	-9027	-7208	-3712	-1196
Electricity Costs in Thousands of EUR	-544	-327	-104	-71	-591	-381	-140	-92
Waste Production in Tons	-512	-328	-254	-108	-454	-336	-232	-101
Water Consumption in Thousands of Liters	-277	-648	-314	-681	-321	-689	-336	-699
Electricity Production from Renewable Energy Sources (Wind and Solar Panels) in MWh	4044	2922	1131	776	4201	2998	1156	797

Source: Author's calculation based on data from the survey questionnaire and business report

The values from the table show the positive effects of using artificial intelligence in the beer production process, which manifest as reductions in harmful gas emissions, electricity consumption, waste generation, and water usage. On the other hand, these effects are complemented by investments in facilities for generating electricity from the company's own wind and solar power sources. The benefits are multiple, resulting in operational efficiency, business rationality, and environmental care.

Table 4. ANOVA of tested parameters

Parameters	Df	SS	MS	F	Significance F
Regression	1	574.54593	574.54593	90.98339	7.578E-05
Residual	6	37.889065	6.3148442		
Total	7	612.435			

Parameters	Coefficients	Std. Error	t-Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-1.46009	1.7278224	-0.8451	0.430486	-5.6879	2.76773	-5.6879	2.7768
Total expenses	-0.15660	0.0164244	9.5385	7.578E-05	0.11647	0.19685	0.11648	0.1969

Table 5. Statistical analysis of the ratio of investment in AI technology and total costs

Regression Statistics	
Multiple R	0.968573041
R Square	0.938133736
Adjusted R Square	0.927822692
Standard Error	2.51293538
Observations	8

To explore the relationship between total costs and investments in AI technology, a correlation test between the two variables was conducted. The correlation value between total costs and AI technology investments is 0.97. At a significance level of 0.05, there is a statistically positive correlation between total costs and AI technology investments. The dependent variable (investment in AI technology) and the independent variable (total costs) have a very strong linear relationship, as indicated by the correlation coefficient. With a coefficient of determination of roughly 93.8%, the independent variable can account for up to 93.8% of the variance in the dependent variable, Figure 5.

Despite the limited sample size, the corrected R2 is approximately 92.8%, indicating that the model is extremely stable. The real data deviates from the regression line by roughly 2.51 units. The regression model is statistically significant since the statistical significance value of 0.0000758 is smaller than the conventional significance limit of 0.05. There is no random correlation between the variables. The dependent variable's theoretical value at zero total costs is represented by the y-intercept of -1.4600. With a slope coefficient of 0.1567, an increase of one unit in the total cost variable results in an average rise of roughly 0.1567 units in the dependent variable (investment). The test statistic value is 2.4469, and since this value is greater than zero, the null hypothesis (that there is no relationship between the analyzed variables) is rejected, and hypothesis H1 is accepted.

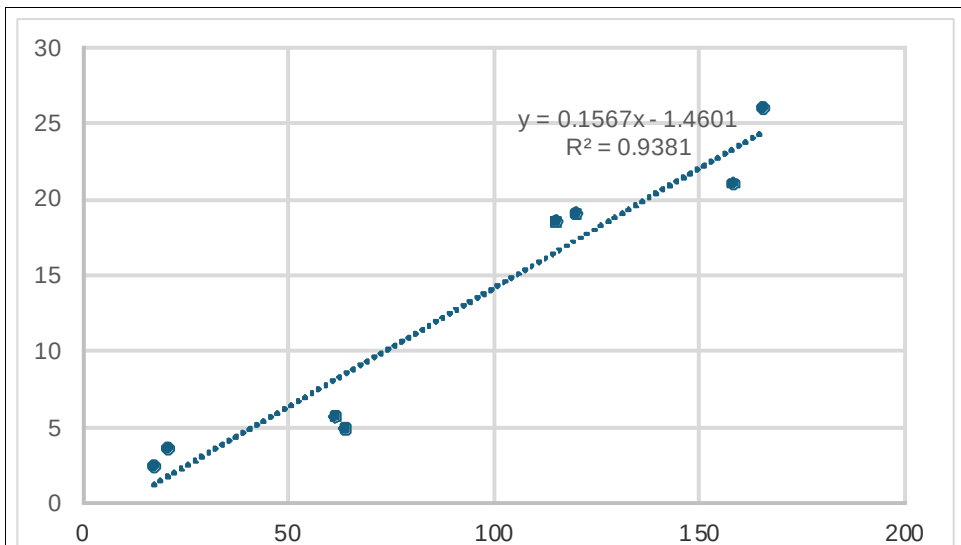


Figure 5. Regression model for the dependent variable (investment in AI technology) and the independent variable (total costs)

Isolating the effects of artificial intelligence is necessary to give management a comprehensive understanding of the internal efficiency brought

about by AI and to accurately separate it from external market factors like inflation, declining purchasing power, increased competitiveness, etc.

In order to isolate AI effects, cost decomposition is the most crucial stage. It is implied by this process that financial indicators will give way to physical (natural) ones. As a result, the effects of price fluctuations and inflation on the market are entirely offset, which raises productivity regardless of price rises.

When all factors change at the same time, the econometric model of multiple regression analysis makes it possible to isolate the impacts. The model examines past data at the production decades or month level. Because of economies of scale, higher production volume inevitably lowers fixed costs per litre of beer.

A separation matrix showing the proportion of investments made in AI technology as opposed to more advanced industrial technology. Even in the absence of AI, the new equipment itself has lower loss and greater energy efficiency than the old equipment.

Counterfactual analysis method, which involves testing and controlling multiple manufacturing lines, one of which is guided automatically (AI control) and the other by hand.

Temperature control is based on real-time yeast behaviour. It isolates the AI influence by examining the production yield of both production lines.

Indexing is the standardisation of market impacts. By comparing the outcomes with the industry average against a base period (the time frame prior to the introduction of AI, for example, a year), this procedure allows for precise determination of the return on investment of AI. This model shows management the precise proportion of competitive advantage in the market and isolates extraneous impacts by concentrating on operational rather than financial measures.

Increased effectiveness in utilizing the potential of (digital) technologies in beer production, as well as increased product diversification, contributes to more economical and successful operations, with the important note that its implications provide a significant contribution to the wider social community.

By lowering processing costs and times with improved processing efficiency and a more promising environmentally friendly approach, a number of emerging and sustainable technologies related to beer processing, particularly for high-pressure processing, ohmic heating, pulsed electric fields, ultrasound, thermosonication, and glucose electrochemical biosensor, can significantly contribute to the development of currently used brewing methodologies.

Over the course of its more than 8,000-year history, the brewing process has remained largely unchanged. We can now make beer more effectively and sophisticatedly thanks to significant technological advancements. In recent years, craft beers have become increasingly popular worldwide due to the growth of speciality hop varieties. There are currently over 150 recognised beer genres, and craft beers are experiencing an unprecedented period of expansion. Beer production has a major impact on economic development because of the

substantial multiplier effect. It has been demonstrated that rising population incomes and shifting consumer demands for more diversity and distinctive flavours are the causes of the sharp rise in the number of craft breweries (Miller *et al.*, 2019). Also, the tendency to increase the consumption of beer is due to the knowledge about the importance of using beer for health purposes. Beer's health risks can undoubtedly be decreased by lowering its alcohol concentration through improved fermentation conditions, modifications to the mashing schedule, and the use of genetically modified microorganisms. The market for non-alcoholic beers may grow as a result in the near future. In order to lower overall operating costs and enhance beer quality, more research is still required (Goyal *et al.*, 2023). Beer offers certain health benefits when drunk in moderation. According to many studies, beer can improve the body's ability to fight cancer, lower the risk of cardiovascular diseases, control anaemia and hypertension, have anti-aging properties, and prevent gallstones (Kaplan *et al.*, 2000; Kondo, 2004; Salanta *et al.*, 2020). Consuming more than two 12-ounce glasses of beer each day is typically considered unhealthy. Frequent, prolonged beer use can lead to alcoholism and have several negative consequences, including memory loss, cardiac problems, liver failure, etc. (Bamforth, 2002; Jackowski and Trusek, 2018).

Making lager beer from grains other than barley is becoming more and more popular. In Cameroon, sorghum can be effectively and successfully used in the industrial production of beer (Zangué Steve Carly and Jong (2019). A key element in the success of craft beer is hops. The nature of intensely hopped and frequently dry hopped beers is mostly determined by the flavour and aroma of the hops. The intricacy of the sensory profile of several Southern Brazilian craft beer varieties is better understood thanks to the study of da Costa Jardim *et al.*, (2018).

Beer's look, flavour, mouthfeel, and scent are its primary qualities. One non-destructive method used in automated measurement and inspection is computer vision. An overview of the uses and most recent developments in computer vision techniques for assessing beer quality features is provided by Lukinac *et al.*, (Lukinac *et al.*, 2019).

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In order to evaluate the quality and acceptability of beverages, machine learning algorithms—particularly artificial neural networks (ANN)—have gained popularity in recent years due to their capacity to improve accuracy while cutting down on time and expense using analytical and sensory methods. According to Gonzalez Viejo *et al.*, (2019), these models could be utilised as an affordable way to quickly test beers during processing in order to more effectively determine their acceptability. The same team investigates how sound waves affect the sensory qualities and foamability of beers using a machine learning modelling technique (Gonzalez Viejo *et al.*, 2018). They demonstrate how using soundwaves during the brewing process can enhance the quality of beer by

boosting the quantity of tiny bubbles and the foamability without upsetting the yeast or changing the flavour and aroma. The quality and character of the finished product are closely related to the fermentation efficiency during the brewing process.

CONCLUSIONS

Beer production is a very important economic sector in Croatia. In this study, through an analysis of costs and the use of AI, cost trends were presented for the following beer producers: Zagreb brewery, Heineken Croatia, Carlsberg Croatia, and Brewery Daruvar. The results showed that combining conventional production methods with AI technology enables cost reduction.

Through a comparative cost analysis, it was demonstrated that the efficiency ratio increases on one hand due to reductions in raw material, water, and transportation expenses, while on the other hand, its growth is influenced by increased production of energy from the company's own sources (Values of profitability coefficient ranging from 1.10% to 1.30%). The calculated efficiency ratio values are positive and indicate that production was efficient. Profitability ratio values are also positive, showing that resources were used efficiently and purposefully (values of profitability coefficient ranging from 16.33% to 49.26%). Furthermore, the effects of using AI technology in the production process included reductions in harmful gas emissions, electricity consumption, waste generation, water usage, and raw material costs. At the same time, due to investments in facilities for generating electricity from the company's own wind and solar sources, electricity production from renewable sources increased.

A correlation test showed a positive correlation between total costs and investments in AI technology, indicating that these variables are mutually aligned and connected, and the model statistically significant. The regression model shows that an increase in the total cost variable by 1 unit causes an average increase in the dependent variable (investment) by approximately 0.1567 units. Based on the results obtained in this study and the applied methodology, it can be concluded that the research objective has been achieved.

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