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# Global Challenges:
# Artificial Intelligence and Sustainability

Editors:
**Candida Duarte Manuel, Maria Rosario Anjos, Ljiljana Pericin**

June, 2025

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April, 2025

# CONTENTS

# ARTIFICIAL INTELLIGENCE APPLICATIONS IN MODERN ENERGY SYSTEMS

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### ABSTRACT
*The global energy sector is under growing pressure to meet increasing demand while minimizing environmental impact. This paper explores the integration of artificial intelligence (AI) into energy systems, with a focus on both conventional and renewable energy sources. Analyses show that in conventional systems—such as those based on fossil fuels and natural gas—AI enhances demand forecasting, optimizes supply chain management, and reduces operational costs. For renewable sources including solar, wind, and hydro power, AI is employed to predict weather patterns and energy output, facilitating the integration of variable energy into the grid. The paper also highlights the superiority of advanced AI models over traditional statistical methods. By processing large volumes of data, AI enables better decision-making, supports real-time energy management, and contributes to a more resilient and efficient energy infrastructure. These developments underscore AI's pivotal role in the ongoing transformation of the energy sector towards greater sustainability.*
***Keywords:*** *artificial intelligence, energy systems, sustainability*

## 1. INTRODUCTION

One of the major challenges facing the world today is ensuring an adequate energy supply while simultaneously protecting the environment. In recent years, global energy demand has increased significantly (Twaha & Ramli, 2018). Currently, global energy supply is still predominantly dependent on conventional sources such as coal, natural gas, and crude oil (Ghoddusi et al., 2018). The growing frequency of sudden weather changes, coupled with the rising costs of traditional energy sources, has prompted many countries to adopt innovative energy solutions and strategies that promote more efficient and sustainable use of energy resources—particularly renewable energy sources such as wind, hydro, and solar power (Jha et al., 2017). In recent years, we have witnessed significant breakthroughs in scientific fields such as big data processing, artificial intelligence (AI), robotics, and the Internet of Things (Guo et al., 2022). These advancements are closely tied to improvements in computational power. As computational resources have become more powerful and widely accessible, research in AI and machine learning has progressed considerably. Consequently, the use of AI has expanded into the energy sector. Currently, AI applications in the energy sector are most commonly found in forecasting and plant maintenance. AI enables the prediction of equipment failures, allowing for more efficient maintenance planning and reducing unexpected outages. It is also used to forecast energy demand and consumption by analysing consumption data and generating predictions of future usage. This supports more effective planning for energy production and distribution. Furthermore, AI is applied in detecting anomalies in energy use and optimizing the performance of renewable energy sources such as solar and wind power, by forecasting weather patterns and energy demand (Magazzino et al., 2021). The aim of this paper is therefore to examine the application of AI in the energy sector. The paper is structured as follows. Section 2 presents the application of AI in both conventional and renewable energy sources.

For each energy source, the frequency of use of various AI models is also provided. Section 3 analyses the impact of AI in the energy sector in terms of economic and environmental effects, user-related aspects, the robustness of AI models, and future development trends. Finally, the main findings are summarized in the conclusion.

## 2. APPLICATION OF AI IN THE ENERGY SECTOR

The energy sector is becoming increasingly complex due to the growing number of energy sources and the multitude of factors influencing both supply and demand. AI offers powerful tools for managing this complexity by enabling more accurate and timely forecasting of energy demand and resource availability. Machine learning algorithms are particularly well-suited for processing the vast volumes of data generated in the energy domain, including weather patterns, consumption trends, and supply chain logistics. Compared to traditional methods, AI-based approaches provide significant advantages in terms of precision, adaptability, and efficiency.

AI can contribute to the optimization of energy consumption by identifying patterns and trends in usage data and suggesting more effective strategies for managing energy resources. Moreover, it can predict energy production patterns based on meteorological data and other relevant variables, thereby enhancing the management of renewable energy sources and facilitating their effective integration into the power grid. Before the rise of AI, conventional methods were most commonly used for energy forecasting, such as time series models (Kumar & Jain, 2010), regression models (Fumo & Biswas, 2015), and so-called grey models (Wei et al., 2019). Conventional models typically do not require large datasets to identify relationships between energy consumption and dependent variables.

In contrast, AI models rely on large amounts of historical data to generate accurate predictions. There are several review papers that address the application of AI in the energy sector (Mellit et al., 2009; Raza & Khosravi, 2015; Maniatis et al., 2017; Tamba et al., 2018). Given the extensive range of existing review articles on AI applications in energy, our focus in the following sections is on more recent scientific contributions, particularly those published after 2020.

### 2.1 Application of AI in conventional energy sources

A review of the literature shows that AI methods are most commonly implemented for forecasting the consumption of conventional energy sources. Among the most frequently used methods are the Adaptive Neuro-Fuzzy Inference System (ANFIS) and Long Short-Term Memory (LSTM) neural networks, as well as certain statistical techniques such as the Autoregressive Integrated Moving Average (ARIMA) models (Figure 1).

In most cases, the best results are achieved using AI methods, particularly deep learning approaches. Deep learning systems generally outperform classical methods. Traditional techniques are mostly used in modern systems for preprocessing or enhancing deep learning models. The frequency of forecasting methods applied to conventional energy sources in the reviewed studies is shown in Figure 1.
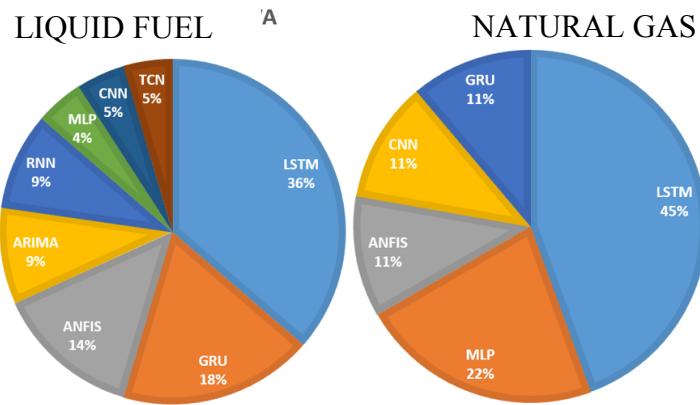
LIQUID FUEL

NATURAL GAS

Note: LSTM - long short-term memory, MLP - multilayer perceptron, GRU - gated recurrent unit, ANFIS - adaptive neuro fuzzy inference system, CNN - convolutional neural network, ARIMA - autoregressive integrated moving average, RNN - recurrent neural network, TCN - temporal convolutional network

*Figure 1: Distribution of forecasting methods used for conventional energy sources.*
*(Source: Author's own work)*

## 2.2 Application of AI in renewable energy sources

The global transition to sustainable energy sources has gained significant momentum over the past decades. Renewable energy, which includes solar, wind, hydro, and other sustainable sources, has emerged as the cornerstone of this transition and represents a future that is less dependent on finite and polluting fossil fuels. The global share of renewable energy use has increased by 10 percentage points since 2010, reaching nearly 30% (Enerdata, 2023).

As the world confronts the challenges of climate change, accurate forecasting of renewable energy consumption is becoming increasingly important (Jha et al., 2017). Such forecasting not only supports the optimization of energy distribution and storage but also plays a key role in strategic planning, infrastructure development, and policy design (Herrera et al., 2022). Currently, AI is most frequently applied in the management of wind, solar, and hydro energy (Díaz-Vico et al., 2017). The frequency of forecasting methods used for renewable energy sources in the reviewed studies is shown in Figure 2. From Figures 1 and 2, it can be observed that among all forecasting methods, LSTM and ANFIS are the most dominant.
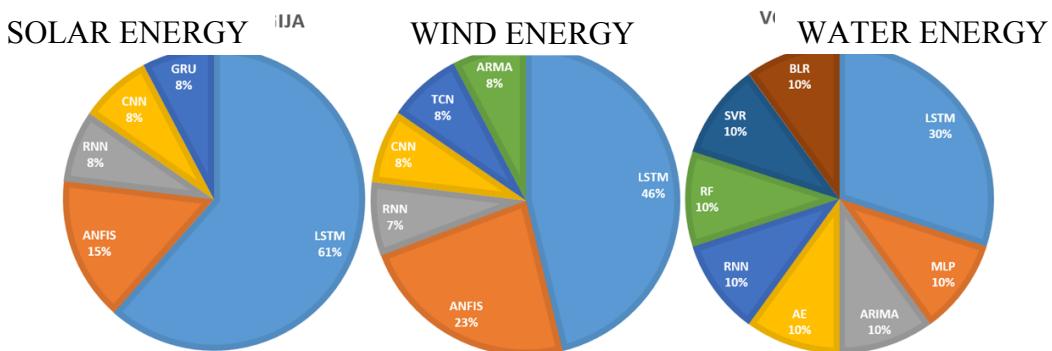


SOLAR ENERGY

WIND ENERGY

WATER ENERGY

Note: LSTM - long short-term memory, MLP - multilayer perceptron, GRU - gated recurrent unit, ANFIS - adaptive neuro fuzzy inference system, CNN - convolutional neural network, ARIMA - autoregressive integrated moving average, RNN - recurrent neural network, TCN - temporal convolutional network

*Figure 2: Distribution of forecasting methods used for renewable energy sources.*
*(Source: Author's own work)*

## 3. ANALYSIS OF THE IMPACTS OF AI IN THE ENERGY SECTOR

Based on the analysis, the following section presents findings on the impact of artificial intelligence in the energy sector, focusing on economic effects, environmental outcomes, user experience, the robustness of AI models, and future development trends:

- Economic effects

We found that the use of AI in the energy sector has a significant impact on economic outcomes. This is particularly evident in studies focused on energy price forecasting, where AI demonstrated strong effectiveness, particularly for liquid fuels. The economic impact of AI is also evident in the context of renewable energy use. As is well known, the storage of surplus energy from renewable sources remains technologically challenging and is the subject of ongoing research, particularly in terms of ensuring adequate capacity and storage efficiency. This limitation hampers the effective utilization of energy surpluses during peak production periods. More accurate forecasting of energy sources would therefore enable more optimal allocation, especially in cases of surplus or shortage in energy generation. By optimizing energy production and distribution through advanced AI algorithms, forecasting accuracy for renewable energy can be significantly improved, leading to higher productivity and, consequently, reduced costs. More precise forecasts enable better planning and allocation of resources, particularly during periods of energy surplus or shortage. This leads to economic benefits, as both providers and consumers can reduce energy losses and achieve a better balance between supply and demand, resulting in lower operational costs and improved productivity. The reliable integration of renewable energy sources can attract investment in new infrastructure aimed at supporting the sustainable transition. Considering the overarching goal of the green transition toward renewables, one of the key challenges lies in optimizing the forecasting of energy production, demand, and supply. Failing to do so can result in power grid instability.

- Environmental impacts

We found that advanced AI methods also have a significant environmental impact, as accurate energy consumption forecasting can contribute to more efficient resource allocation, resulting in a more stable and efficient energy grid and reduced energy waste. By accurately forecasting weather conditions, renewable energy sources can be utilized more effectively, thereby reducing reliance on non-renewable energy sources. This could enable a more effective transition from conventional to unconventional energy sources. Forecasting based on AI models can therefore facilitate the shift toward sustainable global energy systems. By providing insights into consumption trends and demand fluctuations, energy planners can strategically allocate resources and support the displacement of conventional energy sources. This transition to cleaner energy alternatives not only reduces greenhouse gas emissions but also enhances resilience to volatile market conditions and geopolitical factors associated with traditional energy sources.

- Consumer-related implications

We also identified important effects of AI on electricity users. More accurate forecasts allow for further optimization of the distribution network, making it easier to manage. With improved forecasting models, operators can more precisely predict fluctuations in energy consumption. This increases the reliability of the energy grid and reduces the need for surplus capacity, resulting in improved cost efficiency for both energy providers and consumers.

AI-based forecasting also enables smoother integration of renewable energy sources by predicting their generation levels, thereby supporting their incorporation into the grid and reducing dependence on traditional, non-renewable sources. Thus, the use of AI in energy consumption forecasting not only enhances operational efficiency but also contributes to sustainability goals by reducing carbon emissions and promoting environmentally friendly practices in the energy sector, ultimately having a positive impact on society. Forecasting also enables the implementation of dynamic pricing strategies and demand response mechanisms, which can encourage consumers to adjust their energy usage patterns in alignment with periods of lower demand or higher availability of renewable energy. By providing real-time insights into energy availability and pricing, predictive systems empower consumers to plan their energy usage more effectively, leading to more efficient utilization of energy resources and potential cost savings for end users.

- AI model robustness

The robustness of deep learning models heavily depends on the quality and diversity of the datasets used for training. These datasets must also include extreme events, as the model's response to unforeseen conditions cannot be expected to be adequate otherwise. One of the key advantages of deep learning models over traditional approaches is their potential to achieve better performance and adaptability to sudden changes—provided that appropriate training data are available. It is important that the outputs of current deep learning models serve as a complement to expert decision-making, especially in critical scenarios involving sudden changes. These models have not yet reached a sufficient level of accuracy to operate independently and reliably under abrupt external fluctuations. Based on the literature review, we found that current AI techniques still do not achieve sufficient accuracy in the presence of sudden changes. As a result, forecasting in the context of abrupt global events remains a relevant research challenge. In recent years, many researchers have turned to the use and development of hybrid models, aiming to leverage the advantages of both machine learning and deep learning approaches. Challenges related to variability, nonlinearity, and randomness in wind and solar energy are already being successfully addressed using deep learning techniques, as these methods are capable of capturing complex nonlinear relationships within data derived from renewable energy sources. However, sudden global impacts on forecasting continue to pose a significant challenge. By integrating various methods from the fields of machine learning and deep learning, hybrid models can enhance forecasting accuracy while mitigating the impact of abrupt environmental changes. Consequently, the development of hybrid models represents a promising direction in addressing robustness challenges faced in energy consumption forecasting under rapidly changing environmental conditions.

- Future use of AI in the energy sector

With continuous advancements in AI, improvements can be expected in deep learning methods, architectures, and algorithms that will provide the necessary robustness for widespread deployment of renewable energy systems. Furthermore, a certain degree of standardization in the preparation of datasets for deep learning models can be anticipated, aimed at ensuring higher data quality. Given the growing global trend toward renewable energy adoption, research related to energy forecasting is expected to intensify, with a strong focus on algorithmic improvement—particularly in the domain of deep learning. Due to the inherent characteristics of renewable sources, accurate forecasting is essential for the development of efficient and stable energy systems, and thus critical for a successful transition to renewables.

The effective application of deep learning can help balance supply and demand, facilitate the integration of renewable energy sources into energy systems, and reduce dependence on fossil fuels. In current forecasting research, one of the ongoing challenges is the selection of optimal model settings and parameters. This process still heavily relies on empirical experimentation with different parameter values among many researchers. Most studies collect their datasets from specific locations characterized by unique parameters such as population size, climate conditions, and the city's financial status. Due to the high variability in input datasets, comparing and evaluating models becomes more difficult, as they are tested under different conditions. The reviewed literature reveals that these datasets vary significantly, indicating a lack of standardization. As a result, individual datasets may be incomplete, leading to less accurate forecasting outcomes. To properly evaluate models, standardized datasets would be required. Establishing such standardized datasets would enable objective assessment of the developed forecasting models. As an increasing number of renewable energy sources are being implemented in the global energy system, one of the major future challenges for forecasting is the combined and simultaneous prediction of multiple renewable energy sources. AI allows for accurate forecasting and analysis of large datasets, with the ability to recognize patterns. In particular, deep learning models allow for real-time forecasting and can adapt to variability and fluctuations in energy sources through accurate predictions, thereby increasing system stability. Such systems enable more efficient planning of hybrid energy systems that combine multiple energy sources, ultimately resulting in lower energy costs. Therefore, machine learning and deep learning models hold great potential, as more accurate forecasting of renewable energy sources enables their successful integration into existing networks without compromising system stability.

## 4. CONCLUSION

The application of AI in the energy sector brings significant benefits on multiple levels. AI enables more accurate forecasting of energy production and consumption, leading to network optimization, cost reduction, and increased efficiency. It also enhances the utilization of renewable energy sources, thereby supporting the transition to a more sustainable energy system. From an environmental perspective, AI contributes to emission reductions through improved integration of renewables and decreased reliance on fossil fuels. For end-users, this translates into greater supply reliability and the ability to adapt consumption based on pricing and energy availability. Despite notable progress, challenges remain—particularly regarding the robustness of models in the face of sudden changes. This underscores the importance of high-quality and diverse datasets. There is a growing need for the standardization of datasets and the development of hybrid models that combine the strengths of various learning methods. The future development of AI will therefore be crucial for the effective integration of renewable energy into stable and flexible energy grids, which is essential for a sustainable energy future.

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# AI-GENERATED INFLUENCERS AND THE MATCH-UP HYPOTHESIS: EXPLORING THE IMPACT ON CONSUMER ATTITUDES AND PURCHASE INTENTIONS

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## *ABSTRACT*

*This study investigates the role and effectiveness of AI-generated influencers, focusing on their alignment with promoted products and the resulting impact on consumer attitudes and purchase intentions. The research emphasizes the UAE—a culturally diverse and technologically advanced market. A mixed-methods approach was employed, integrating quantitative survey data and qualitative insights from 62 respondents. The survey included comparative assessments of AI-generated and human influencers, focusing on their fit with specific products. Statistical analysis, including linear regressions, revealed significant correlations between perceived alignment, consumer attitudes, and purchase intentions, with R-values consistently above 0.7. Key findings indicate that while AI influencers are perceived as moderately aligned and can foster positive attitudes toward products, they lag behind human influencers in motivating purchase decisions. The study highlights the need for marketers to enhance the authenticity and cultural relevance of AI influencers while leveraging human influencers for trust and conversion. These findings offer actionable insights for designing balanced influencer marketing strategies in digitally advanced markets like the UAE.*
*Keywords: AI-generated influencers, Authenticity in advertising, Consumer attitudes, Cultural relevance, Digital marketing strategy, Human vs AI influencers, Influencer marketing, Perceived alignment, Purchase intentions, UAE market*

## 1. INTRODUCTION
The rapid evolution of digital marketing has witnessed transformative shifts, with artificial intelligence (AI) leading the charge. One of the most intriguing applications of AI in this space is the emergence of AI-generated influencers, also known as virtual influencers.

These digital entities, designed to engage audiences through social media platforms, are revolutionizing how brands interact with consumers. Unlike traditional influencers, virtual influencers offer consistency in brand representation, raising questions about their effectiveness and consumer perceptions. The integration of virtual influencers in marketing strategies reflects broader trends in technology adoption and consumer behavior. As consumers increasingly gravitate toward personalized and innovative experiences, virtual influencers provide a novel avenue for brand engagement. However, their emergence also introduces complexities—particularly in authenticity, trust, and cultural relevance. These factors are especially critical in culturally diverse regions like the UAE, where digital innovation intersects with unique socio-cultural dynamics.

**Research Problem**
Despite the growing prominence of AI-generated influencers, research on their effectiveness and consumer impact remains limited. Most existing studies focus on Western markets, offering little insight into regions such as the UAE. While short-term engagement metrics have been explored, the long-term implications on consumer trust and brand loyalty remain under-researched. Ethical concerns, such as transparency and potential consumer manipulation, further complicate this landscape.

**Research Questions and Hypotheses**
This study addresses the following research questions:
1. How effectively do AI-generated influencers match the products they promote in terms of perceived fit by consumers?
2. What is the impact of the perceived match on consumer attitudes toward the product?
3. How does perceived fit influence consumer purchase intentions?
4. Are attitudes and purchase intentions different when endorsed by AI versus human influencers?

**Hypotheses:**
- H1: Higher perceived match leads to more positive consumer attitudes.
- H2: Stronger perceived fit increases purchase intentions.
- H3: Strong product match generates more favorable attitudes.
- H4: Purchase intentions are higher for human-endorsed products even with equal match-up.

**Significance of the Study**
This research provides valuable insights for both academia and industry, especially for culturally diverse regions like the UAE. The findings contribute to digital marketing strategy development and offer guidelines for ethical influencer marketing practices.

**Objectives and Scope**
1. Analyze cultural factors shaping consumer interaction with virtual influencers.
2. Evaluate long-term brand trust and loyalty impacts.
3. Assess the role of transparency in influencing consumer trust.

**2. LITERATURE REVIEW**
AI has increasingly permeated marketing, with AI-generated influencers becoming a focal point in both academic and industry discourse. These influencers—also known as virtual influencers—are computer-generated characters designed to engage with audiences on social media platforms. Recent studies have explored various dimensions of this phenomenon.

One significant area of focus is the perception and trustworthiness of AI-generated influencers. For instance, Jin et al. (2022) analyzed consumer trust in virtual influencers compared to human influencers. Their findings revealed that while virtual influencers are perceived as less authentic, they excel in portraying consistent brand narratives, thereby fostering trust among younger, tech-savvy audiences. The Theory of Planned Behavior (Ajzen, 1991) has been applied to understand how consumers interact with AI influencers. Studies suggest that subjective norms and perceived behavioral control significantly influence consumers' willingness to engage with virtual influencers (Nguyen et al., 2023). Moreover, the novelty effect—the allure of new and unique technology—was identified as a critical factor driving consumer interest (Park & Kim, 2021). Other studies have investigated the effectiveness of virtual influencers in digital advertising. For example, Abidin (2020) examined the role of AI influencers in content marketing strategies, concluding that their ability to generate hyper-personalized content makes them valuable assets for brands targeting niche audiences. Additionally, insights from the field of consumer psychology indicate that anthropomorphism—the attribution of human-like qualities to non-human entities—plays a crucial role in how audiences relate to AI influencers (Li et al., 2019).

**Identifying Gaps**
Despite the growing body of research, several key gaps remain:
1. Geographic Scope: Most studies have focused on Western markets, neglecting culturally diverse regions such as the Middle East—particularly the UAE. Given the UAE's status as a hub for digital innovation and its unique socio-cultural dynamics, research tailored to this region is essential.
2. Long-Term Effects: There is limited understanding of the long-term impact of virtual influencers on consumer behavior. Existing studies tend to emphasize short-term engagement metrics, leaving questions about sustained consumer trust and brand loyalty largely unanswered (Jin et al., 2022).
3. Ethical Considerations: While the psychological foundations of consumer interactions with AI influencers have been explored, few studies address ethical issues such as transparency and disclosure. The lack of regulations governing AI-generated influencers raises concerns about potential consumer manipulation and data privacy (Nguyen et al., 2023).

**Linking to the Current Study**
This research aims to address the above gaps by exploring the adoption and effectiveness of AI-generated influencers in the UAE market. By focusing on this underrepresented region, the study will offer valuable insights into the cultural factors that shape consumer perceptions and behaviors. Furthermore, the study will evaluate the long-term implications of virtual influencer campaigns on brand trust and loyalty, as well as integrate a focused examination of ethical considerations. Specifically, it will assess how transparency and regulatory frameworks influence consumer trust in AI-generated influencers. By doing so, the research seeks to offer practical recommendations for brands operating in culturally diverse and digitally advanced markets like the UAE.

**3. METHODOLOGY**
**Research Design**
This study employs a mixed-methods approach, combining both quantitative and qualitative methodologies to provide a comprehensive understanding of the research topic:

- The quantitative component involves analyzing survey data to identify trends and patterns in consumer perceptions of AI-generated influencers.
- The qualitative component includes participant observations and open-ended responses to gain deeper insights into opinions and preferences.

This dual-method approach enhances the reliability and depth of the findings by capturing both measurable data and rich, contextual narratives.

**Sample Selection**

The target population consists of UAE residents and tourists, reflecting the region's diverse cultural and demographic characteristics. A purposive sampling method was used to ensure that participants were relevant to the study's objectives.

- The survey was distributed digitally via Google Forms, allowing for easy and broad participation.
- A total of 60 responses were collected, forming a dataset that, while limited, provides valuable insights into how individuals perceive and engage with AI-generated influencers.

**Data Collection**

Data were collected through an online survey designed to capture both quantitative and qualitative information.

- The survey presented images and posts from both AI-generated influencers and human influencers, allowing participants to make direct comparisons.
- Questions included a mix of multiple-choice items, rating scales, and open-ended prompts to allow for numerical analysis and deeper exploratory insights.

This format ensured that participants could express not only their attitudes and behaviors but also their thoughts and rationales.

**Ethical Considerations**

The study adhered strictly to established ethical guidelines throughout the research process.

- Participants were assured of confidentiality, with all identities and personal information kept anonymous.
- Informed consent was obtained digitally prior to participation.
- Participants were clearly informed that all collected data would be used solely for academic research purposes.

By upholding these standards, the study ensured privacy, transparency, and trust, in full compliance with research ethics protocols.

## 4. RESULTS

Demographics

- Over 40% of the survey respondents fall within the 25-34 age bracket, with the 16-24 and 35-44 age brackets make up a combined 48%
- The survey respondents were split almost equally across genders, with 52% being females
- The overwhelming majority of the survey respondents identified as Arabs, with 66%

Section 1
The sample audience were shown a promotional post by the AI-generated influencer, Miquela, in which she promotes the all-electric BMW iX2.

- As per figure 1 in the appendix, over 60% agreed that Miquela seemed well-suited to promote the BMW iX2
- As per figure 2 in the appendix, over 50% of the survey respondents agreed that Miquela was a good fit for the type of product that she was promoting, **the all-electric** BMW iX2
- However, as seen in figure 3 in the appendix, only 45% of the respondents felt that this endorsement from the AI-generated influencer was natural

Following upon the above, the respondents were asked about their attitude and impressions regarding the advertised BMW iX2, in which approximately 50% stated that they have both a positive attitude towards and impression of this vehicle, as can be seen in figures 4 and 5 in the appendix. However, when asked about their purchase intent, over 33% of the respondents took a neutral stance, only 27% expressed interest in purchasing the car following Miquela's promotion, while a significant 38% of the respondents showed no interest in this car (figure 6).

Section 2
The surveyed sample were shown two (2) promotional posts for the fashion brand Max & Co, one by a human influencer and the other by an AI-generated influencer.

- The large majority of the sample audience were able to identify which influencer was human and which was AI-generated (appendix figure 7)
- Over 57% of the respondents agreed that the human influencer matched Max & Co's brand persona more strongly, while 34% stated that both the human and theAI-Generated influencers equally matched the brand's persona (appendix figure 8)

- As seen in appendix figure 9, over 55% of the respondents stated that the human influencer motivated them more strongly towards purchasing products from Max & Co, while only 18% leaned towards theAI-generated influencer.

**SPSSResults**
After compiling the data collected from the survey, multiple linear regressions were conductedon the statistical analysis software, SPSS, in order to verify whether these results have any significance and if this data can be trusted and relied on. As seen in figures 10, 11, 12 and 13, the statistical models and linear regressions conducted on SPSS all resulted in an R value >0.70, indicating that a positive relationship between each pair of independent and dependent variables exists; for example, the more the AI-generated influencer seems well-suited to the brand or product being promoted, the more positive the attitude the consumer has towards said brand or product.

Moreover, the $R^2$ value for every model is >0.50, providing confidence that the data and models are a good fit and to be considered reliable. The results of the linear regressions models, also within the appendix figures 11 and 12, indicate that the relationship between each pair of independent and dependent variables tested is significant, with a confidence level of 99% for all models, and a minimum confidence level of 90% for each independent-dependent variable relationship. All in all, the statistical analysis provides proof that the survey data collected is reliable, and the analysis of the quantitative results of the survey will provide an indication of the the correlations identified based off of the study hypotheses.

## 5. DISCUSSION

**Interpretation of Findings**

The results from the survey and subsequent statistical analyses provide insight into how effectively AI-generated influencers align with the products they promote, and how this perceived fit influences consumer attitudes and purchase intentions. In the first scenario, where the AI-generated influencer Miquela promoted the BMW iX2, a majority of respondents viewed her as well-suited to the product, and more than half agreed that there wasastrongfit.However,lessthanhalffeltthather endorsementappeared entirelynatural. Eventhough the product attitudes were generally positive - with about 50% of respondents expressing a positive attitude toward the BMW iX2 - this did not translate strongly into purchase intentions. More than a third remained neutral about the idea of buying the car, and a significant portion indicated no interest in making a purchase. In the second scenario, comparing a human influencer and an AI-generated influencer for the fashion brand Max & Co, respondents could easily distinguish between the two influencer types. A majority indicated that the human influencer matched the brand persona more closely, and more than half found that the human influencer motivated them more strongly to consider purchasing. Only a small fraction reported stronger purchase motivation from the AI-generated influencer. The statistical analysis supports these observations. The correlations and regression models, which consistently yielded R values above 0.7, suggest strong relationships between perceived match, consumer attitudes, and purchase intentions. The results, with significance levels of 90% and above, reinforce the conclusion that an influencer's perceived alignment with a product or brand strongly influences how consumers feel about that product. However, the data also show that a favorable perception of an AI-generated influencer or alignment with a product does not consistently translate into heightened purchase intentions compared to a human influencer scenario.

**Limitations**

Although there is sufficient confidence that the findings are indicative, they are not without limitations. First and foremost, the surveyed sample audience was insufficient in size to reach any definitive conclusion. Secondly, the demographic distribution of the survey respondents, with its concentration of respondents from a 25-34 age range, and a majority identifying as Arabs, may limit the general applicability of the results. Attitudes and intentions might differ inotherculturalordemographiccontexts,in additiontothelackoftheless'tech-savvy' age groups that made up an insignificant percentage of the study's sample. Moreover, the survey setting does not capture the complexity of real-world purchasing decisions and might not fully represent how consumers behave outside a controlled environment. Finally, the survey focused on the electric car industry and the fashion industry; this meant that the survey lacked a specific focus, and should have been designed to revolve around one industry and dive deeper into said industry.

**Practical Implications**

From a practical standpoint, the findings suggest that while AI-generated influencers can be perceived as fitting and suitable for certain products, there remains a gap in how effectively they motivate consumers toward making a purchase. For marketers, this indicates that while efforts to ensure product and influencer alignment are important, authenticity and credibility remain key factors that drive purchase behavior. Focusing on increasing the sense of authenticity, whether through improved communication or more relatable content, could help narrow the gap in purchase motivation currently observed between AI-generated and human influencers. For brands working with human influencers, these results highlight the continued importance of human credibility and personal connection.

Marketers may find that humans still have an edge when it comes to instilling confidence and encouraging consumers to move beyond positive attitudes and into actual purchasing decisions. In the short term, businesses should consider a balanced approach—using AI influencers for certain branding or awareness objectives while relying on human influencers to reinforce trust and convert favorable perceptions into sales.

## 6. CONCLUSION

This study concludes that AI-generated influencers, while effective in fostering positive product perceptions, face challenges in translating these perceptions into purchase intentions, particularly when compared to human influencers. The findings emphasize the importance of authenticity, credibility and cultural alignment in influencer marketing. For brands operating in markets like the UAE, a dual strategy leveraging both AI and human influencers is recommended. AI influencers can be instrumental in generating awareness and maintaining consistent brand narratives, while human influencers are more effective in driving trust and converting consumerinterestintopurchases. Further researchis neededtoexplorelong-term impacts and refine strategies for integrating AI influencers into culturally diverse and dynamic marketing landscapes.

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# A.I. AND THE RULE OF LAW: OPPORTUNITIES AND RISKS IN THE DIGITAL AGE

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## ABSTRACT

*Artificial intelligence is transforming the way governments deliver services, ensure justice and engage citizens. The rule of law must continue to be ensured in a context of global change in the digital age. Governance and civil society are seriously affected by technology, in both good and bad ways. This research aims to explore the real applications of AI in the public sector, including the courts and alternative dispute resolution as a guarantee of timely access to justice, from the perspective of opportunities and risks in the judicial context. Research questions: (1) how AI can improve access, transparency and efficiency of justice; (2) how to avoid risks regarding data privacy protection, excessive and illegal surveillance or unequal access to law and legal protection; (3) what is driving the rule of law recession, and what can be done to reverse this trajectory in the context of a global society dominated by AI?*

*Findings: by focusing on institutional safeguards, regulatory frameworks and ethical standards, we will offer actionable insights for the responsible use of AI in favor of good governance and the rule of law. As a methodology, the relevant legal and juridical context will be analyzed, in particular, the importance of alternative dispute resolution (ADR) tools, in order to keep the rule of law safe and effective.*
**Keywords:** *AI - Artificial Intelligence; Alternative Dispute Resolution (ADR) tools; Governance; Rule of law.*

## 1. INTRODUCTION

Artificial intelligence (AI) is transforming the way governments deliver services, ensure justice and engage citizens. Governance and civil society are seriously affected by technology, in both good and bad ways.The rule of law must continue to be ensured in a context of global change in the digital age but technology can be a serious threat. This research aims to explore the real applications of AI in the public sector, it's opportunities and risks, in particular, in Justice. In this field we have several problems, but for now we're going to focus our research on access to a court decision in time and how AI can help to improve this. In the analysis, we also consider the application of AI in judicial and arbitral tribunals, taking into account the important role of alternative dispute resolution (ADR) as a guarantee of timely access to justice. Thus, the aim is to find out how AI can improve easy access, transparency and efficiency of justice and how to avoid risks related to data privacy protection, excessive and illegal surveillance or unequal access to law and legal protection. As we know, regulation is the most obvious answer, but can we actually regulate AI? What is causing the rule of law to recede and what can be done to reverse this trajectory in the context of a global society dominated by AI? Can AI improve access, transparency and the efficiency of justice?

How can risks relating to data privacy protection, excessive and illegal surveillance or unequal access to law and legal protection be avoided? What is causing the rule of law to recede and what can be done to reverse this trajectory in the context of a global society dominated by AI? By focusing the analysis on institutional safeguards, regulatory frameworks and ethical standards, we will offer some practical perspectives for the responsible use of AI in justice. In short, knowing the opportunities and risks in the judicial context, we try to put AI at the service of justice and the rule of law.

## 2.THE POTENTIAL OF AI IN PUBLIC SECTOR AND JUSTICE

AI is a fundamental tool for the modernisation of public administration. It is an evolutionary and unstoppable process. The digital transition of public administration offers countless opportunities, including the acceleration of procedures, increased efficiency and the democratisation of access to public services. However, it also presents significant risks, such as the exclusion of some of the most vulnerable social groups, who lack technological skills or the economic means to acquire them, failures in personal data protection, and cybersecurity issues. The same applies to the justice sector, with opportunities and risks that present some important particularities that we will highlight. As evidence of the potential of AI in justice, we can mention: (1) automated document processing, case forms, various applications, various records (e.g. tax returns, licence renewals); (2) Chatbots and virtual assistants as a public service response to requests; (3) Predictive analysis can anticipating public needs and allocate resources more efficiently; (4) AI legal assistants can allow speeding up case research, identifying relevant precedents and generating summaries of doctrine and case law; (5) document review allow an automate analysis of vast sets of documents with data relevant to litigation. All this tools are an importante judicial decision support. AI can also do sentencing recommendations, based on patterns from previous decisions or court costs estimates. In terms of access to justice, the use of AI chatbots for legal assistance can guide citizens in small claims, family law or immigration proceedings. Another very useful aspect is the real-time translation of statements, testimonies and multilingual documents. All this potential can be very useful for all courts (judicial ou arbitral) decide litigious in a short time, but cannot replace the human intervention of the judge in the intellectual operation of applying the legal morma to the facts of the concrete case. All this potential can be very useful for all courts (judicial or arbitral) to decide disputes quickly, but it cannot replace the human intervention of the judge in the intellectual operation of applying the legal norm to the facts in each specific case. One final important note to highlight is that  the potential of AI in the field of justice is easier to develop in a Judicial Law system than in a Civil Law system, but in both cases the advantages of its application are remarkable.

## 3. RISKS AND CHALLENGES OF AI IMPLEMENTATION

Despite the opportunities and advantages outlined above, the challenge of AI in the field of justice poses some considerable risks that we cannot ignore. The introduction of AI in the legal field poses significant regulatory and jurisprudential challenges that require critical analysis. Among these, issues of opacity, accountability, and regulatory compatibility with constitutional principles stand out. AI systems, particularly those employing machine learning algorithms, often function as "black boxes," rendering their decision-making processes inscrutable not only to laypersons but also to legal practitioners and public officials (Pasquale, 2015). This opacity poses a direct threat to the foundational precept of legal transparency, which undergirds the rule of law by ensuring that decisions can be explained, contested, and reviewed. Furthermore, the delegation of quasi-judicial or administrative functions to AI exacerbates concerns regarding accountability and due process.

As highlighted by Crawford and Paglen (2021), automated decision-making mechanisms can replicate and magnify preexisting societal biases embedded within data sets, thereby violating principles of equality and non-discrimination enshrined in international human rights instruments such as the ICCPR and ECHR. The inability to trace culpability in AI-generated decisions complicates both judicial review and remedies for wrongful actions, fundamentally disrupting the doctrine of legal responsibility (Yeung, 2018). Another substantial concern is the erosion of legal predictability. Unlike codified statutes or jurisprudential precedent, AI-driven legal analytics and decision tools lack normative grounding, potentially leading to outcomes that deviate from established legal reasoning. As Edwards (2018) observes, algorithmic governance may shift discretion from judges to engineers, thereby transforming normative adjudication into computational optimization devoid of legal proportionality or moral deliberation. Moreover, the extraterritorial operation of AI systems challenges national regulatory regimes, raising questions of jurisdiction, enforcement, and sovereignty in digital governance (Koops et al., 2017). The cross-border deployment of AI by multinational corporations may elude domestic legal safeguards, undermining democratic oversight and public accountability. In sum, the uncritical adoption of AI in legal systems threatens to displace core legal principles, including fairness, transparency, accountability, and equality before the law. These risks necessitate the formulation of robust regulatory frameworks, imbued with legal, ethical, and democratic legitimacy, to safeguard the rule of law in the algorithmic age. Another important issue is the guarantee of personal data protection. The General Data Protection Regulation (GDPR) to ensure that AI systems used in public administration respect citizens' privacy. The EU has one of the world's most comprehensive legal frameworks for data protection, primarily governed by the General Data Protection Regulation (GDPR), which came into force in May 2018. Its main goals are to give EU citizens more control over their personal data and to harmonize regulations across the EU member states. Finally, The AI Act is the first-ever legal framework on AI, which addresses the risks of AI and positions Europe to play a leading role globally.The AI Act (Regulation (EU) 2024/1689 laying down harmonised rules on artificial intelligence)is the first-ever comprehensive legal framework on AI worldwide. As European Commission highlit, the aim of the rules is to foster trustworthy AI in EU and sets out a clear set of risk-based rules for AI developers and deployers regarding specific uses of AI. It is part of a wider package of policy measures to support the development of trust and safe AI, which also includes the AI Innovation Package, the launch of AI Factories and the Coordinated Plan on AI. Together, these measures guarantee safety, fundamental rights and human-centric AI (Engelmann, et al,2021) and strengthen uptake, investment and innovation in AI across the EU.To facilitate the transition to the new regulatory framework, the Commission has launched the AI Pact to support the future implementation, engage with stakeholders and invite AI providers and deployers from Europe and beyond to comply with the key obligations of the AI Act ahead of time. All propositions are focused in human rights protectoion and respect for fundamental principles of rule of law.

## 4. THE RULE OF LAW: INSTITUTIONAL AND REGULATORY SAFEGUARDS

Digital public administration and the use of new technologies is an important evolutionary process, in respect by the rule of law. The digital transition offers numerous opportunities, for public administration, however it also poses significant risks, such as the exclusion of some vulnerable groups and failures in the protection of personal data and cybersecurity problems. In some EU countries, with older populations, and poor digital literacy, guarantee a good governance in digital public administration is not an easy task. We can say, therefore, that the first challenge of digital public administration is to guarantee universal access to all citizens, protecting the most vulnerable (Anjos & Mimoso, 2018). In Portugal the digital transition in public administration has made progress but still faces several challenges.

Regarding the digital transition in justice is remarkable the  dematerialisation of processes, implementation of digital platforms and access to statistical information, introduction of virtual assistants (e.g. in social security), among other innovations. However, the following obstacles remain. The first is the interoperability of systems due the lack of integration between different platforms and information systems hinders efficient data exchange between institutions. Creating a unified digital infrastructure is essential to improve collaboration and efficiency. Secondly, Cybersecurity failures, because with the digitization of public services the risk of cyberattacks and data breaches increases. For example, the services of the public prosecutor's office, which has jurisdiction over criminal investigations, are not integrated into the digital access platform that works for all other proceedings, for fear of violating judicial secrecy. Ensuring the security of criminal investigation, citizens' information and protection against cyber threats is a constant challenge. The human resources capacity in a context of digitalization requires a workforce with adequate technological skills. Training and capacity-building for public employees are crucial for the effective implementation of digital initiatives. Another importante limitation is, as said, the accessibility and digital inclusion (Anjos, et al. 2024), because although many digital services are available, there are still citizens without access to technology or digital skills. It is important to ensure that everyone can benefit from digital public services, regardless of their socioeconomic situation. In this point, arbitral courts has an important advantage to judicial one's disposing support to help the most vulnerable persons to put a request or process. In this regard, arbitration tribunals have an important advantage over judicial courts, which is the availability of support to help the most vulnerable people file a claim or initiate proceedings (e.g. consumer arbitration tribunals). At last, there are yet a large resistance to innovation. Implementing digital solutions often faces resistance from employees and citizens accustomed to traditional processes (Ferrari, 2019). Promoting a culture of innovation and adaptation is essential for the success of digital transformation. To overcome these difficulties, it is important to regulate effectively without bureaucratising or blocking the functioning of the systems. The key word is 'Keep it simple and secure.' The most important regulatory safeguards should focus on privacy and data protection, as well as change management. Digitalization raises questions about the privacy of citizens' data, so complying with regulations, such as the General Data Protection Regulation (GDPR), is a significant challenge. In other and, the transition to digital public administration requires careful change management. Strategic planning and effective communication of the benefits of digitalization are necessary to ensure acceptance and success of initiatives. Implementing digital technologies often requires significant investments (Coutinho, et al, 2029) Ensuring adequate funding and the long-term sustainability of digital initiatives is an ongoing challenge. At the end, measuring the effectiveness of digital services and making continuous improvements based on citizen feedback can be complicated. Establishing clear metrics and conducting regular evaluations is crucial for the evolution of digital public administration. Overcoming these challenges is essential for Portugal and other European countries to continue progressing in the digitalization of public administration and to offer more efficient and accessible services to its citizens.

## 5. METHODOLOGY AND LEGAL ANALYSIS

It follows from the above that the methodology followed in this analysis was based on the study of the relevant legal and regulatory context, such as: AI regulation, data protection and digital tools, and compliance with the rule of law. This work focus on institutional safeguards, regulatory frameworks and ethical standards, we will offer actionable insights for the responsible use of AI  as a tool of justice eficiency, good governance and the rule of law. As mentioned, the efficient implementation of digital technology in public administration, and in particular in the justice system, requires the commitment of various stakeholders to ensure the process is successful.

The enormous diversity of processes requires a diverse range of means to ensure the process is successful. In this topic, we analysed the importance of alternative dispute resolution (ADR) tools in order to enable access to justice for all and maintain a secure and effective rule of law. The proposals presented below were designed based on this methodological assumption. The design followed is based on the separation of processes by type, complexity, and economic and social impact. The goal is to achive a more easier and fast decision-making.

## 6. DISCUSSION AND MITIGATION PROPOSAL

Although the integration of AI into legal and governance systems poses significant risks, it also opens up new avenues for legal innovation, administrative efficiency, and improved access to justice. To reap these benefits while containing potential threats to the rule of law, a differentiated approach is needed that prioritises ethical design, institutional oversight, and transnational cooperation. First, a shift to context-sensitive algorithmic design is imperative. Rather than applying uniform AI solutions across disparate legal systems or jurisdictions, developers and regulators must tailor systems to reflect local legal traditions, socio-political realities, and constitutional values (Binns, 2018). For example, automated decision-making tools used in immigration law or criminal sentencing must be aligned with human rights safeguards and procedural fairness guarantees specific to the jurisdiction. Second, participatory governance models should be instituted to incorporate stakeholder perspectives at every stage of the AI lifecycle. This includes public consultations, civil society involvement in algorithmic impact assessments (AIA's), and meaningful channels for redress and contestation. Mechanisms such as citizen panels or algorithmic ombuds institutions can provide democratic legitimacy and reinforce the accountability of both public and private AI actors (Veale et al., 2018). Third, while previous sections have highlighted the importance of legal oversight, there is also a pressing need for interdisciplinary regulatory frameworks (Rodriguez-Araña, 2017). Lawyers, ethicists, computer scientists, and data protection authorities must collaborate to establish standards for explainability, non-discrimination, and auditability in AI systems. Crucially, these standards must evolve alongside technological advancements to remain effective. Fourth, international cooperation must be strengthened to prevent regulatory fragmentation. Given that AI technologies often transcend borders, the absence of coordinated global norms risks regulatory arbitrage and uneven rights protection. Initiatives like the OECD AI Principles and UNESCO's Recommendation on the Ethics of Artificial Intelligence offer promising blueprints for multilateral engagement (UNESCO, 2021; OECD, 2019). Finally, capacity-building within judicial and administrative institutions is essential. Training judges, prosecutors, and civil servants in AI literacy will ensure informed scrutiny and appropriate application of AI systems in the public sector. Such efforts should also extend to fostering a culture of digital constitutionalism, where the deployment of AI is consistently framed in terms of fundamental rights and democratic values (Cohen-Eliya & Porat, 2021). Mitigating the risks of AI in legal contexts is not merely a technical task, but a profoundly political and normative one. It requires institutional courage, public engagement, and a steadfast commitment to preserving the foundational principles of the rule of law in the face of rapid technological transformation.

## 7. CONCLUSION

As conclusion we go back to research questions to propose a constructive answer.

(1) How can AI improve access, transparency, and efficiency in the judicial system? Yes, it can be an important tool for achieving these goals, if implemented properly, wisely, and safely. Therefore, it is advisable to separate cases by speciality, complexity and nature of the subject under discussion (for example, cases involving sensitive data require different precautions than purely economic proceedings) in order to ensure adequate protection of confidentiality and the

principles of the rule of law. One area where AI can be a very important tool is public procurement, if the requirements are defined objectively. It can even substantially reduce the corruption associated with these processes. No confidentiality or data protection issues can justify any difficulties.

(2) How can we avoid risks related to data privacy protection, excessive and illegal surveillance, or unequal access to the law and legal protection? By regulating data protection, access to information, the functioning of AI, and, above all, separating AI systems according to the nature of the processes involved, based on the greater or lesser objectivity of the problems to be solved.

(3) What is driving the decline of the rule of law, and what can be done to reverse this trend in the context of a global society dominated by AI? Lack of effective regulatory and compliance tools. The law is not enough. It is absolutely essential to change institutional culture, management and compliance. We need to strengthen legal and institutional structures for AI, develop binding international regulations on ethics, transparency and accountability in AI. But all this requires algorithmic explainability in the use of AI in the public sector (e.g. predictive policing, judicial risk assessments). We must be aware that the speed of AI evolution is not compatible with the time it takes to draft legislation, which tends to quickly become outdated. An example of this is the AI Act (Regulation (EU) 2024/1689), which became outdated even before it came into force. In adicion, is important to support global agreements on AI governance, akin to climate treaties, even because of the enormous problem of sustainability that AI is generating due to the high consumption of water, energy and rare metal. Reinforce judicial independence abd oversight, to promote constitutional safeguards. Another importante issue is education and digital literacy and ethics, in irder to achive a good governance in all fields of public administration, where justice is one of the most relevant issue. Critical thinking and media literacy skills to resist disinformation is essential, promoting civic tech platforms that increase transparency and allow for citizen participation in legal reform processes.The rule of law recession is not just a political crisis, it's a techno-legal crisis. In the brave new world of AI (Anjos, et al, 2024) maintaining the rule of law requires redefining legal principles for a digital age, rebuilding public trust, and ensuring accountability for both human and machine decisions. It requires coordinated action by governments, technology companies, civil society and international organisations, based on transparency, ethics and global solidarity. Let us imagine that this is possible. Otherwise, the end of the story could be something like 'The Strange Case of Dr Jekyll and Mr Hyde'.

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# PRELIMINARY STUDY ON MICROPLASTIC CONTAMINATION IN RICE USING FLUORESCENCE MICROSCOPY

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## ABSTRACT

*Microplastics (MPs) have become widespread in the environment, infiltrating ecosystems and entering the food chain. They have been found in various food and beverage products, raising concerns about their potential health impacts. Rice, a dietary staple consumed globally and particularly in Portugal, where per capita consumption is the highest in Europe, may act as a pathway for MP exposure. The aim of this study is to present a method for extracting and detecting MP contamination in rice using fluorescence microscopy. While digesting whole grains has proven challenging, the most effective results for extracting surface-bound MPs were achieved using a 10% (w/v) potassium hydroxide digestion, followed by filtration through 1.0 μm pore polycarbonate filters. Detection was performed with Nile red staining and fluorescence microscopy. To validate the method, a range of synthetic polymers and organic matter analogs were analyzed. Numerous microparticles were identified in the analyzed rice samples, particularly in highly processed, ready-to-eat rice; however, not all were confirmed to be microparticles by Nile red staining. This suggests that rice can be a direct pathway for human exposure to environmental plastic pollution. Further research is needed to develop more effective digestion strategies for whole grains, ensuring the complete recovery of MPs while minimizing interference from organic residues.*

*Keywords: Fluorescence microscopy, KOH digestion, microplastics, Nile red, rice contamination*

## 1. INTRODUCTION

Plastic litter of small dimensions, microplastics (MPs), is of significant importance as an environmental contaminant, and as a consequence of their small size and ubiquity, MPs have negative impacts at all levels of biological organization (SAPEA, 2018). Microplastics are defined as plastic particles measuring less than 5 millimeters in diameter, originating either from the breakdown of larger plastic debris, secondary MPs, or being manufactured at a small size, primary MPs, such as in cosmetic microbeads or industrial abrasives (Boucher & Friot, 2017; Frias & Nash, 2019). Microplastics have been accumulating in the oceans since the 1960s (Thompson et al., 2004).

They have now been detected in nearly every environmental compartment, including oceans, rivers, soils, air, and even remote locations such as Arctic ice and mountain peaks (Allen et al., 2019; Bergmann et al., 2019). The global production of plastics has surpassed 460 million tons annually, with a significant portion mismanaged, resulting in environmental harm (Ritchie et al., n.d.). While there are numerous types of plastic materials, the most common ones include polyethylene terephthalate (PET), high-density polyethylene (HDPE), low-density polyethylene (LDPE), polypropylene (PP), polystyrene (PS), and polyvinyl chloride (PVC) (Andrady & Neal, 2009). Estimates suggest that approximately $82-358$ trillion plastic particles weighing $1.1-4.9$ million tonnes circulate in surface waters (Eriksen et al., 2023), and atmospheric transport has further facilitated their deposition on terrestrial surfaces and into food systems (Allen et al., 2019). The presence of MPs in food has been confirmed in seafood (Unuofin & Igwaran, 2023), table salt (Peixoto et al., 2019), honey (Mühlschlegel et al., 2017), milk (Kutralam-Muniasamy et al., 2020), sugar (Liebezeit & Liebezeit, 2013) and drinking water (Almaiman et al., 2021). Rice, in particular, is gaining attention due to its processing, packaging in plastic materials, and high global consumption (Dessì et al., 2021). So far, the presence of MPs in rice grains has been less studied compared to aquatic foods; however, emerging studies indicate that they can become contaminated during cultivation, harvesting, processing, and packaging (Liang et al., 2023).

A recent study has shown that instant rice contains significantly higher levels of MPs than uncooked rice, highlighting the influence of industrial processing (Dessì et al., 2021). Rice is one of the most important staple crops globally, accounting for 21% of the world's population's calorific intake and up to 76% of the intake in South East Asia (Fitzgerald et al., 2009). Portugal has the highest per capita rice consumption in Europe, with an average of over 15 kilograms per person annually (INE, 2024; *Rice Production in Portugal*, 2024). Microplastics can disturb critical intestinal functions, potentially promoting the development of chronic immune disorders (Hirt & Body-Malapel, 2020), disrupt reproductive health (Wang et al., 2024) and might ultimately contribute to the onset of diseases such as cancer, metabolic disorders, and neurodevelopmental conditions (Molina & Benedé, 2022). The combination of cultural significance and high intake underscores the potential public health implications of MP contamination in rice. To study MPs in food matrices, such as rice, researchers employ a multi-step analytical workflow that typically includes sample digestion, filtration, staining, and microscopic or spectroscopic identification. Digestion methods aim to remove organic matter without degrading MPs and include the use of alkaline solutions such as potassium hydroxide (KOH), oxidizing agents like hydrogen peroxide ($H_2O_2$) (Prata et al., 2019), or enzymatic cocktails for more delicate matrices (Catarino et al., 2017; Courtene-Jones et al., 2017). Identifying MPs is technically challenging due to their small size, diverse polymer types, and the presence of interfering organic materials. Common difficulties include incomplete digestion of organic matter, particle loss during handling, and interference from natural materials (Adhikari et al., 2022). Staining with fluorescent dyes, such as Nile red, has gained popularity for the rapid screening of MPs (Erni-Cassola et al., 2017). Nile red is a lipophilic dye that preferentially binds to hydrophobic polymers and fluoresces under specific wavelengths of light (Maes et al., 2017). This technique has been validated across various food matrices and is considered effective for distinguishing synthetic particles from organic debris, particularly when controls and proper imaging conditions are applied (Erni-Cassola et al., 2017). Given the increasing concern about MP ingestion and rice's central role in the global diet, further research is necessary to develop standardized methods for detecting MPs in rice grains and to evaluate contamination levels in real-world conditions. This study aimed to explore practical techniques for extracting and visualizing MPs in rice with different levels of industrial processing.

## 2. METHODOLOGY
### 2.1. Sampling strategy
Three types of commercially available rice varieties were selected based on their processing levels: organic whole grain rice, white rice, and microwavable (ready-to-eat) rice. These correspond to low, medium, and high processing levels, respectively, and are designated as R1, R2, and R3 (Figure 1). Rice sample R1 is packaged in an unidentified plastic material, R2 is packaged in paper, and R3 is packaged in polypropylene (PP). For analysis, three 10 g samples of each rice variety were weighed.
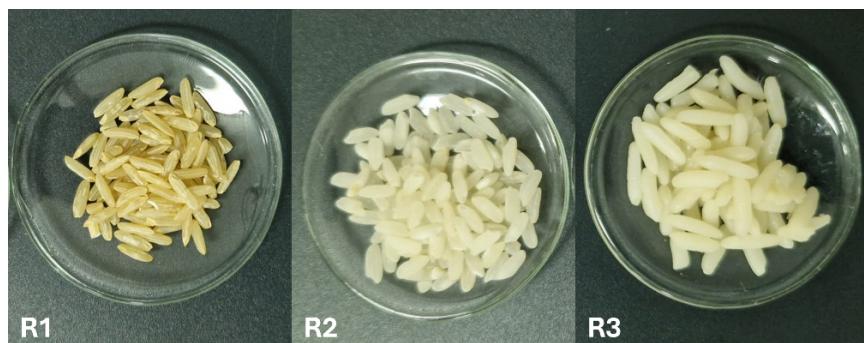


*Figure 1: Representative images of the three rice samples analyzed for MP contamination: organic whole-grain rice, R1; white rice, R2; microwavable, ready-to-eat rice, R3.*

### 2.2. Preparation of plastic sample array
Plastic samples were collected from common consumer items and included polyethylene terephthalate (PET), high-density polyethylene (HDPE), low-density polyethylene (LDPE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), and cellulose acetate. Additionally, non-plastic materials such as cellulose, wood, and charcoal were included as controls to assess potential interference in staining and detection protocols. A Nile red stock solution was prepared by dissolving the dye in filtered acetone at a concentration of 1.0 mg/mL (Maes et al., 2017) and stored at 4 °C. A working solution was freshly prepared by diluting the stock with methanol to a final concentration of 2.0 µg/mL (Erni-Cassola et al., 2017). Small fragments of each material were stained with Nile red on concave glass slides and incubated for 20 minutes at room temperature. The fragments were then rinsed with 70% ethanol in deionized water. Replicas of each material were also prepared and left unstained. All samples were mounted in glycerol and examined under brightfield and fluorescence microscopy (Excitation 560 nm / Emission 630 nm).

### 2.3. Micoplastics extraction from rice samples
Multiple extraction protocols were assessed for their effectiveness in digesting whole rice grain samples to isolate MPs. The methods tested included: oxidative digestion with 30% hydrogen peroxide ($H_2O_2$) at room temperature (Prata et al., 2019); alkaline digestion using 10% potassium hydroxide (KOH) (Amelba A. B. T. et al., 2022) at room temperature and 50°C; and enzymatic digestion with α-amylase at 0.5 to 5.0 mg/mL, at 37°C (Pautong et al., 2022; Toutounji et al., 2019). As an alternative to whole-sample digestion, surface-bound MPs were extracted by washing the rice samples with five sequential portions of deionized, 0.45 µm-filtered water. In parallel, for the enzymatic treatment, filtered acetate buffer (pH 5.7) was used instead of water. The resulting wash fractions were pooled by treatment type. To the pooled water extracts, 20% (w/v) KOH was added at a 1:1 volume ratio to achieve a final concentration of 10% KOH.

The pooled acetate buffer extracts were treated with α-amylase at a concentration of 5.0 mg/mL. The KOH-treated samples were incubated at 50°C, while the enzymatically treated samples were incubated at 37°C. All treatments were conducted over incubation periods lasting up to five days, and then the samples were filtered through 1.0 μm pore glass fiber or polycarbonate filters to collect the MPs.

## 2.4. Nile red staining

Two filter materials, glass fiber and polycarbonate, with a 1 μm pore size, were evaluated for their suitability in digestate filtration and Nile red staining. Based on reduced background fluorescence and better particle visibility, polycarbonate filters were selected for subsequent analyses. After filtering the digested samples, the filters were thoroughly rinsed with deionized water to remove any residual digestate. The working Nile red staining solution was then applied directly to the filter surface and incubated for 20 minutes at room temperature. Following incubation, the filters were sequentially rinsed with 70% ethanol in deionized water to reduce nonspecific background staining, then rinsed again with deionized water. Stained filters were observed under brightfield and fluorescence microscopy (Excitation 560 nm / Emission 630 nm).

## 2.5. Quality assurance and quality control

Special care was taken to minimize sample contamination with environmental MPs during the analysis (Brander et al., 2020). The reagents and solutions used were filtered through a 0.45 μm pore filter before use. Whenever possible, glass and metal materials were preferred over plastic. These materials were rinsed with filtered deionized water and kept closed or covered with aluminum foil. Laboratory personnel wore cotton lab coats at all times. Additionally, procedural blank filters were included and processed in the same manner as the sample filters.

## 3. DATA ANALYSIS AND RESULTS
### 3.1. Digestion and extraction protocol

The extraction of MPs from organic samples and other complex matrices is challenging (Rani et al., 2023). To evaluate the feasibility of extracting MPs from entire rice samples, we tested various digestion protocols, including oxidative, alkaline, and enzymatic methods. The goal of these methods was to break down organic materials while maintaining the integrity of the MPs for later filtration and detection (Rani et al., 2023). However, in each trial, the resulting digestate was either too viscous or heavily loaded with particles, preventing it from passing through filters with a pore size of 1.0 μm. Consequently, none of the initial protocols produced satisfactory results for extracting MPs from whole samples under the tested conditions. Results were significantly improved by transitioning from whole-sample digestion to a surface-washing method. However, previous studies have reported that rinsing rice with water may not completely remove the MPs (Dessì et al., 2021; Espiritu et al., 2024), indicating a possible limitation of this methodology. After 72 hours of treatment with KOH, we successfully obtained digestates that could be filtered using 1.0 μm pore-size polycarbonate membrane filters.

In contrast, samples treated with amylase remained incompletely digested and could not be filtered under the same conditions, indicating that amylase alone demonstrated limited effectiveness in degrading the matrix. Enzymatic digestion of rice is commonly preceded, and could be improved, by pre-boiling the samples (Pautong et al., 2022; Toutounji et al., 2019), however, digestion methods with temperatures higher than 60°C should be avoided as this may cause the loss of MPs (Munno et al., 2018).

### 3.2. Plastic sample array and quality control

The Nile red staining protocol for MPs and the visualization conditions were tested using samples of common plastics, including PET, HDPE, LDPE, PP, PS, PVC, and cellulose acetate (Figure 2). The sample set also included non-plastic materials such as cellulose, wood, and charcoal (Figure 2). All plastic samples exhibited fluorescence when stained with Nile red, as shown in Figure 2. However, higher intensities were observed for PET, LDPE, PS, PVC, and cellulose acetate compared to HDPE and PP. Other authors have also reported differences in the fluorescence intensity of different plastics and attributed these differences to plastic type and sample thickness (Erni-Cassola et al., 2017). No fluorescence was observed for cellulose and charcoal using Nile red. However, intense emission was observed from stained wood fragments, as has previously been reported by other authors (Erni-Cassola et al., 2017). No autofluorescence was observed in any of the tested samples (data not shown).
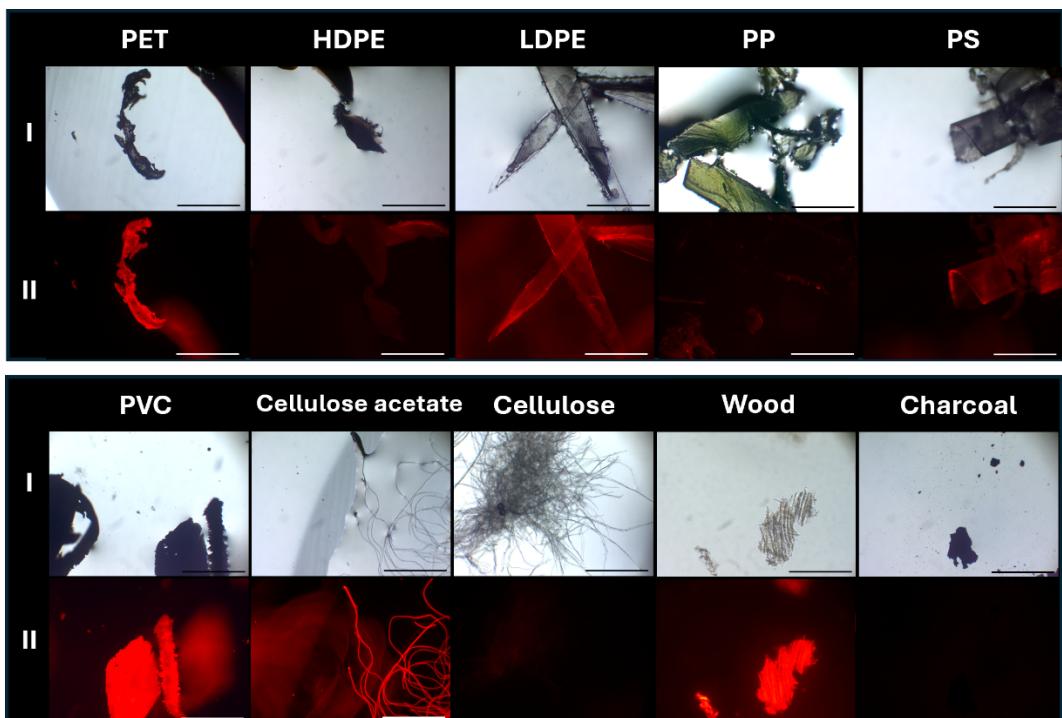


*Figure 2: Brightfield (I) and fluorescence (II) microscopy images of common plastic polymers and natural materials stained with Nile red. The bar represents 1000 μm.*

Control samples are essential for verifying the quality and effectiveness of the extraction and staining methods (Brander et al., 2020). Alongside other quality control measures, filters treated with and without Nile red staining were prepared using the same procedure employed for the rice extracts. These control samples help to identify potential contamination from the materials, solutions, and manipulation techniques employed. As expected, despite implementing quality control measures, some contamination was observed (Figure 3). A small number of fibers and fragments were noted in both control samples, with and without Nile red staining (Figure 3). However, most of these did not exhibit fluorescence (Figure 3D), indicating that significant MP environmental contamination of the samples is unlikely.
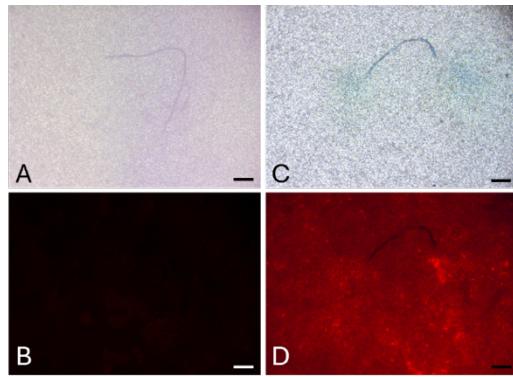
*Figure 3: Brightfield and fluorescence microscopy images of control polycarbonate filters.*
*Filters A and B are unstained, while filters C and D are stained with Nile red.*
*The bar represents 100 μm.*

### 3.3. Microplastics in rice samples

The presence of MPs in rice samples has been previously reported in a limited number of studies (Amelba A. B. T. et al., 2022; Bhavsar et al., 2024; Dessì et al., 2021; Dmitrowicz et al., 2025; Espiritu et al., 2024). However, to our knowledge, this is the first report to use Nile red for detection. Three types of commercially available rice were selected for analysis based on their processing levels: organic whole-grain rice (R1), white rice (R2), and microwavable, ready-to-eat rice (R3). It is expected that the processing level will follow the pattern R1 < R2 < R3, and that the likelihood of MP contamination will increase accordingly (Dessì et al., 2021). Stained fibers and fragments were commonly observed in R1, as shown in Figures 4A-D. This rice sample was the most difficult to analyze due to background staining from undigested material (Figure 4D). Notably, fibers and fragments were significantly less abundant in R2 (Figures 4E-H), despite the expectation that processing levels would be higher for this rice variety.
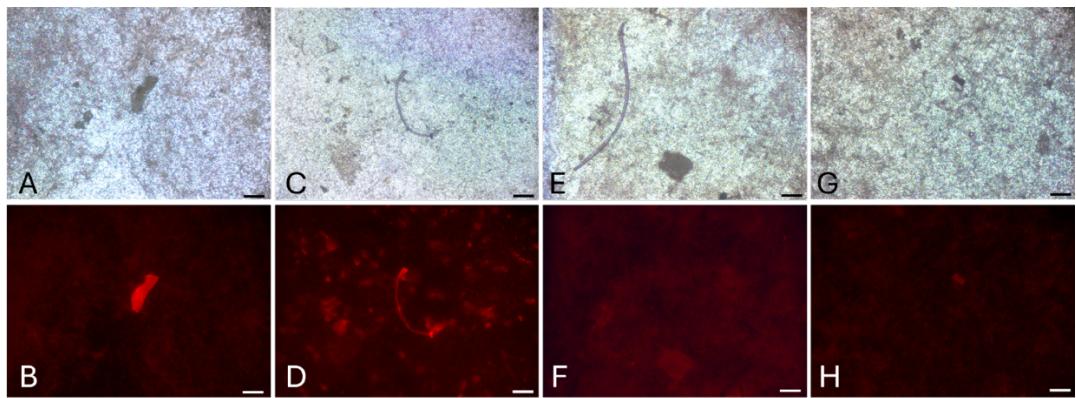


*Figure 4: Brightfield and fluorescence microscopy images of microparticles stained with Nile*
*red and extracted from: A - D Organic whole-grain rice sample (R1);*
*E - H White rice sample (R2). The bar represents 100 μm.*

Fibers and fragments stained with Nile red were most abundant in the samples prepared from R3, as shown in Figure 5. A recent study on MP concentration in rice found that pre-cooked rice contained four times higher levels of MP than uncooked rice (Dessì et al., 2021). Additionally, all the rice samples contained non-fluorescent particles, indicating that some of the microparticle contamination is not plastic, a finding also reported in previous studies on rice (Dmitrowicz et al., 2025). Definitive confirmation and MP identification are frequently conducted using FTIR or Raman microscopy, although these methods are time-consuming and costly (Erni-Cassola et al., 2017).
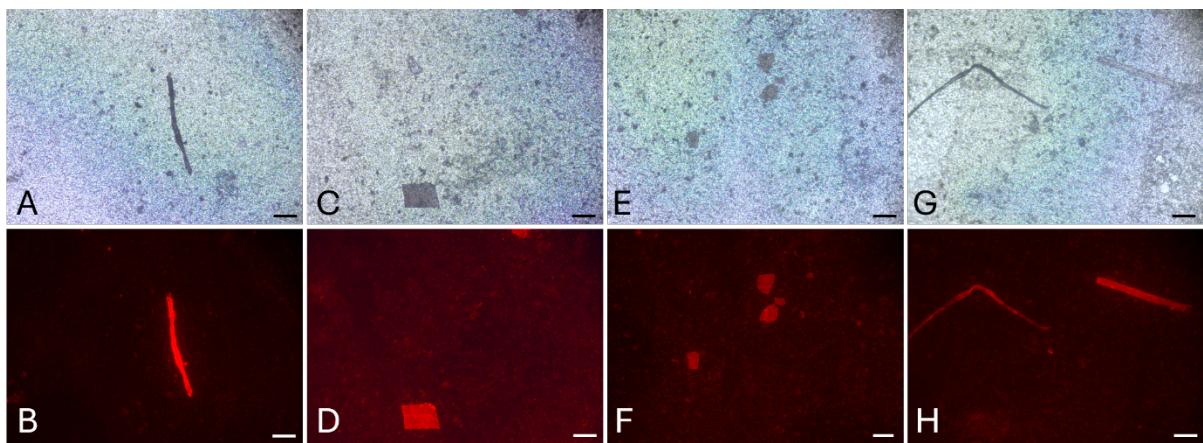
*Figure 5: Brightfield and fluorescence microscopy images of microparticles stained with Nile red and extracted from microwavable, ready-to-eat rice. The bar represents 100 μm.*

## 4. CONCLUSION

This study examines the extraction and detection of MPs in commercially available rice that has undergone various levels of processing. Numerous microparticles identified as plastic through Nile red staining were present in all rice samples, demonstrating that rice can serve as a direct pathway for human exposure to environmental plastic pollution. This preliminary research sets the stage for more detailed and comprehensive studies of MPs in rice and other staple grains. Additionally, it shows that Nile red staining is an effective method for identifying MPs within these foods. Although this study is qualitative and does not include quantitative data on MP levels, it suggests a correlation between the extent of food processing and the degree of MP contamination. This connection, supported by other researchers, deserves further investigation. Future research should focus on developing more effective digestion methods that ensure the complete recovery of MPs from whole grains.

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# FINANCIAL FLOWS AND THEIR SUSTAINABILITY IN SERBIA IN TODAY'S CONTEXT

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***ABSTRACT***
*Strong geopolitical shifts on the global level in the latest period have significantly affected both developed and developing countries. In this paper, we analyze relevant cash and capital flow dynamics, in particular, the FDIs, remittances and primary income flows for the Serbian economy. The results indicate slowdown of FDI and remittances inflows followed by increased net outflows of capital-related forms of income, affecting the balance of payment structure and net position while indicating the need for refocusing in financing process and stronger orientation on sustainable growth and development.*
***Keywords:*** *Foreign direct investment, Primary income, Remittances, Serbia, Sustainability*

## 1. INTRODUCTION
In the case of Serbia, latest developments open the question of countries' future financing schemes and put in focus possibilities for reorientation from external to internal financing sources. Shifts in foreign flows point to the exhaustion of the current growth model which has been primarily based on foreign and public capital investments. A more resilient framework would require strengthening of export capacities, stimulating domestic private investments, and fostering of human capital development. It should be supported by improvements in institutional quality, a more favorable business climate, enhancement of the educational system, and a transition towards higher value-added production.

## 2. REMITTANCE INFLOWS TO SERBIA: TRENDS AND COMPARATIVE ANALYSIS
Global migration flows and diaspora growth have made personal transfers (remittances)[1]one of the key sources of external financing, especially in developing countries and those with large emigrant populations. In regions with pronounced regional differences and a high migration rate, such as the Western Balkans (WB), they contribute to macroeconomic stability and preservation of the standard of living.

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[1]We will use the terms *Personal transfers* and *Remittances* interchangeably throughout the text, although a clear methodological distinction and differences in values exist between the categories of *Workers' remittances*, *Personal transfers*, and *Secondary income*. For detailed definitions of these items, see the Balance of Payments and International Investment Position Manual, Sixth Edition (BPM6) by the International Monetary Fund (IMF, 2009). For differences in values in Serbia, see Figure 2 in this paper.
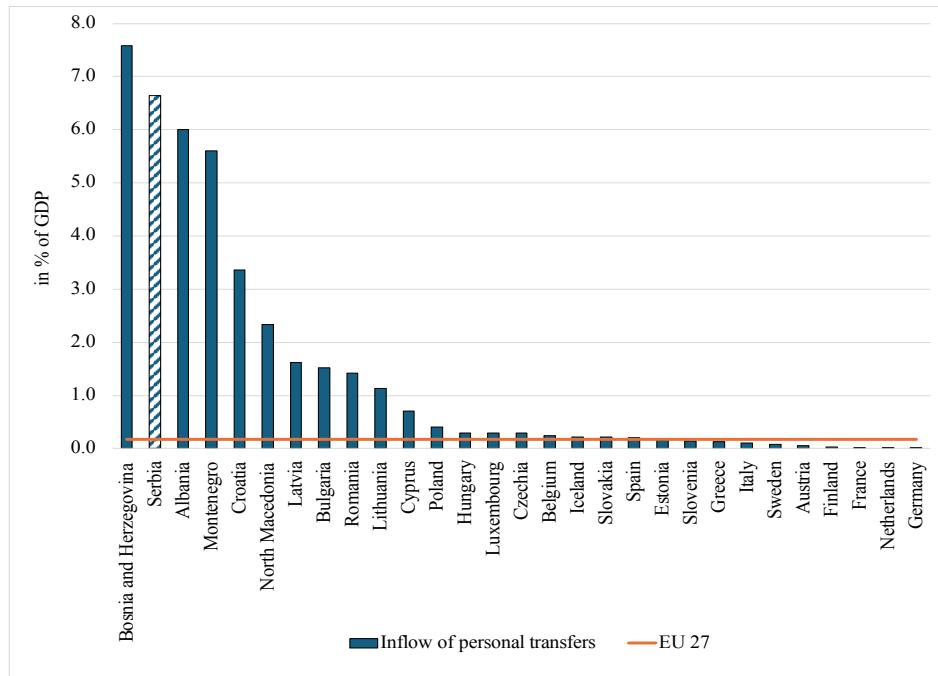
*Figure 1: Inflow of personal transfers in European countries, 2023*
*(Source: Authors' calculation based on Eurostat database)*

According to Eurostat data (Figure 1), the inflow of personal transfers varies significantly among European countries. The highest share of personal transfers in GDP was recorded in the countries of the Western Balkans, with Bosnia and Herzegovina and Serbia leading with over 7% and 6.5%, respectively. High relative levels were also registered in Albania, Montenegro, Croatia and North Macedonia. On the contrary, most of the European Union members record this share below 0.5% of GDP. The average for the EU-27 is only 0.17% of GDP, which is many times lower than the level in the Western Balkans countries.

This distribution indicates that the inflows of personal transfers represent an important source of external financing in the countries of the WB and part of the EU – primarily the CEE countries. In contrast, in a large number of EU member states, these inflows have a relatively small importance. Serbia is one of the biggest recipients of remittances among European countries. The data for Serbia (Figure 2) show that in the period from 2012 to 2024, the net inflow based on remittances was on average about EUR 2.5 billions, i.e. 5.2% of the annual GDP value. If we look at the broader current account category – personal transfers, the average annual net inflow was EUR 3.2 billion, i.e. 6.6% of GDP.

Thus, an average net inflow of EUR 4 billion was recorded on the secondary income account, which on average amounts to 8.2% of the annual value of the GDP of Serbia. The maximum amounts in the observed period (Figure 2), expressed as a percentage of GDP, in these current account positions of the balance of payments were reached in 2022. At that time, the surplus on the secondary income account amounted to EUR 6 billion, i.e. 9.4% of GDP. Of that amount, the net inflow from personal transfers was EUR 4.63 billion (7.4% of GDP), which was mostly the result of net inflows from remittances (EUR 3.8 billion, net, i.e. 6% of GDP).

| | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ▢ Secondary income | 8.4 | 8.3 | 8.1 | 9.0 | 8.3 | 8.6 | 9.4 | 8.2 | 7.3 | 7.9 | 9.3 | 7.5 | 6.4 |
| ▦ Of which: Personal transfers | 7.0 | 7.1 | 6.6 | 7.2 | 6.6 | 6.8 | 7.4 | 6.8 | 5.8 | 5.9 | 7.3 | 6.1 | 5.4 |
| ■ Of which: Workers' remittances | 5.5 | 5.7 | 5.0 | 5.6 | 4.9 | 5.0 | 5.9 | 5.3 | 4.3 | 4.5 | 5.9 | 4.9 | 4.3 |
| ▤ Direct investment | 2.1 | 3.4 | 3.3 | 4.8 | 5.0 | 5.9 | 7.1 | 7.4 | 6.0 | 6.5 | 6.8 | 5.7 | 5.6 |
| ▯ Primary income | -3.1 | -3.7 | -3.6 | -4.5 | -5.3 | -6.2 | -4.9 | -5.2 | -2.9 | -3.7 | -4.7 | -5.2 | -6.3 |
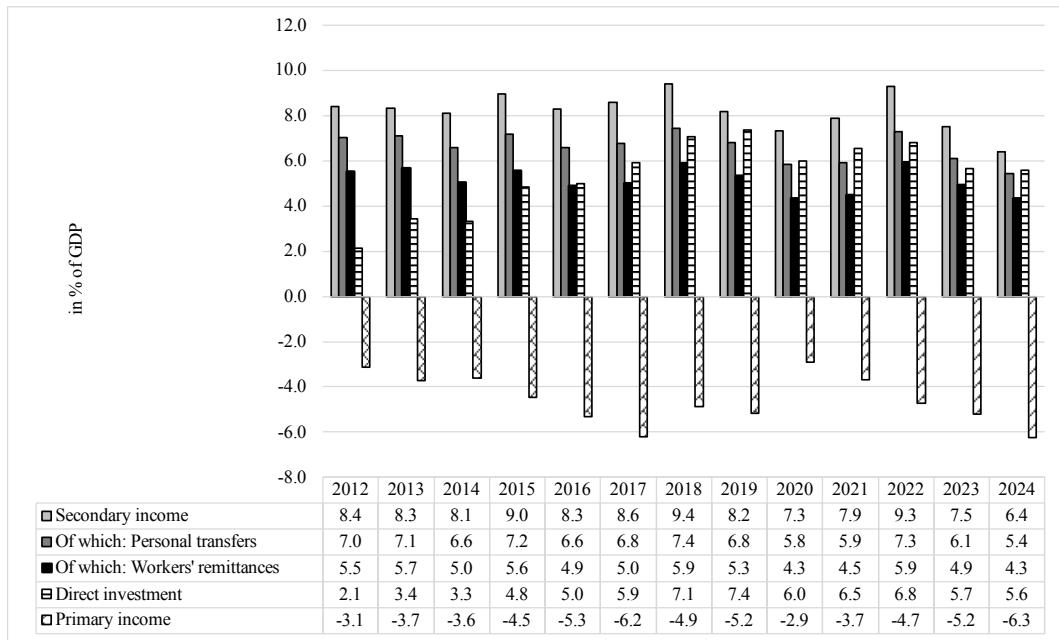
*Figure 2: Net flows from secondary and primary income accounts and foreign direct investment, 2012-2024*
*(Source: Authors' calculation and representation based on NBS and Statistical Office of the Republic of Serbia)*

The series of data given in Figure 2 confirms the stable high inflow of these funds to Serbia in the observed period, with a certain growth in the last few years. According to the data from the National Bank of Serbia (NBS), the inflow of personal transfers amounted to approximately EUR 2-3 billions until 2017, then EUR 3-4 billion from 2018 to 2021, and EUR 5 billion in 2022, 2023 and 2024. As a share of GDP, these amounts remained relatively stable until 2020, while during the COVID-19 pandemic years, 2020 and 2021, they recorded a slight decline. After a recovery in 2022 and 2023, a renewed decline is observed in 2024 and early 2025, in the context of persistent instability across Europe and the world, including armed conflicts, trade tensions, and labor market disruptions in Germany and other developed EU countries.[2]

In Figure 2, where the data is given in net amount, it can be seen that the average inflow of personal transfers in Serbia on average exceeds the net inflow based on FDI, although in recent years they have been fairly even. On the other hand, there is an increase in net outflow based on primary income, reflecting the increase in income payments to foreign actors, primarily through interest, dividends and earnings of foreign investors.

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[2] Remittances have shown high level of stability and resilience during crises and disasters, though literature presents opposing views on their cyclical behavior (e.g. Neagu and Schiff, 2009).
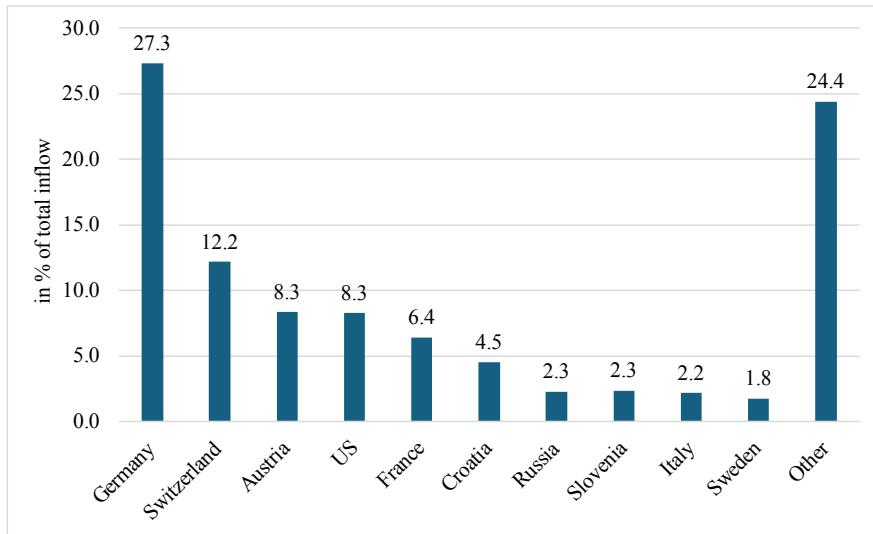
*Figure 3: Inflow of personal transfers to Serbia, by sending countries, 2021*
*(Source: Authors' calculation based on Cakajac et al. (2023),*
*Table 1, p. 38, based on NBS data)*

Figure 3 shows the inflow of personal transfers to Serbia by country of origin in 2021, expressed as a percentage of the total amount of inflow of personal transfers. The largest amount of these funds came from Germany, with a share of over a quarter of the total inflows (27.3%). Switzerland (12.2%), Austria (8.3%), the USA (8.3%) and France (6.4%) follow, which indicates a strong presence of the Serbian diaspora in economically developed countries of Western Europe and North America. Smaller, but still significant shares come from the countries of the region (e.g. Croatia - 4.5% and Slovenia - 2.3%) and Russia (2.3%). About a quarter of the total inflows are from other countries of the world, which speaks for Serbia's geographically widespread diaspora. For 2022, 2023 and 2024, the same countries from which the largest part of personal transfers (remittances) traditionally arrives in Serbia are selected. Personal transfers (remittances) are one of several sources of foreign currency inflows from abroad, and they have a particularly important place in Serbia's balance of payments. For decades, they have been a stable and reliable source of income for households, and their share ranks Serbia among the European countries where they have a distinct macroeconomic importance. According to NBS, the largest part of remittances is used by households in Serbia for current consumption, where they have accounted for about 10% of total personal consumption in the previous ten years. At the same time, a smaller part is directed to investments and savings, which additionally has the potential to stimulate economic growth and preserve the standard of living of the population (Gligoric and Jankovic, 2016; Ratha, 2016). If most of these funds were directed towards productive investments in human and physical capital, small and medium-sized enterprises or development infrastructure, and innovative solutions (e.g. green remittances), they could make a significant contribution to sustainable development.

## 3. FOREIGN DIRECT INVESTMENTS AS THE SOURCE OF FINANCING – EVIDENCE FROM SERBIA

After a few different crises that the world economy was faced with at the beginning of the new century, the importance and even the necessity of capital inflows from other countries became obvious. These situations are similar to the eighties, during the last century, when the debt crisis in numerous developing countries further strengthened the role of capital inflows in the form of foreign direct investments.

If the country does not have enough domestic sources of capital, turning to foreign direct investment becomes a perfectly acceptable solution. When they arrive, no one should automatically expect only positive effects, although it is evident that an increase in FDI is associated with an increase in welfare (Blomström, Kokko and Zejan, 2000, p. 5). That specific sort of necessary support for further development is only one of many financial sources. The host economies are facing two main challenges: the first is dilemma whether the level of FDI is going to be enough and the other is strategic orientation and implementation to get maximum benefits with minimum losses. The effects of FDI are viewed from the aspect of contribution to productivity growth and exports of the host countries. That contribution has been proven, but to a different extent, because, the net benefits of the FDI varies, depending on the host country's industry and policy environment (Blomström and Kokko, 1997, p. 34). There is a research pointing to only a weak correlation between the inflow of FDI and GDP growth, according to data 2007-2018 (Vasa and Angeloska, 2020, p. 170).
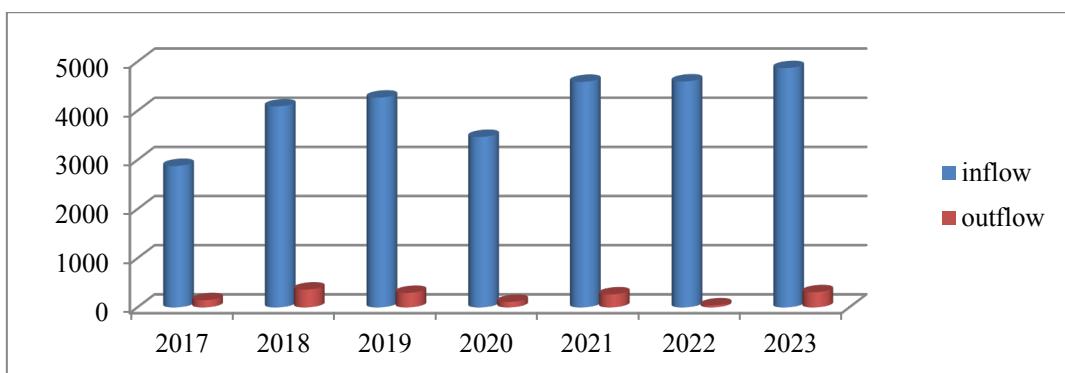


*Figure 4: Republic of Serbia – FDI inflows and outflows, 2017-2023, in USD millions (Source: Authors presentation based on World Investment Report 2022 – International Tax Reforms and Sustainable Investment data, Geneva 2022, p. 210, (data for 2017, 2018) and World Investment Report 2024 – Investment Facilitation and Digital Government data, Geneva 2024, p. 156, (data 2019-2023))*

Since 2010, FDI inflows in Serbia have recovered, although this was a gradual growth, slower than during the period before the 2008 crisis. The more representative period started from 2017, when the inflow of FDI was more intensive, compared to the period immediately after the crisis. Serbia achieved its maximum FDI inflow precisely during the last observed year, 2024. It is the value of more than EUR 5 billion.

The regional structure of liabilities points out to the dominant role of European Union countries as sources of FDI in Serbia according to the data during the period 2016-2024. They are followed by other countries and some off-shore activities. Concerning individually the EU member countries, as the main sources, we can indicate the following countries: Netherlands, Austria, Luxembourg, Germany, Italy, Slovenia and France. In the group of countries outside the EU important are Russian Federation, Switzerland, UAE and the rising role of China at the end of the observed period. In 2016, China appeared on the list of top five origin countries of FDI in Serbia and maintains at these high positions during the following years.

| Year/Rang | 1 | 2 | 3 | 4 | 5 | Total |
|---|---|---|---|---|---|---|
| **2016** | Netherlands 341.8 | Switzerland 234.6 | Luxembourg 232.9 | Austria 232.4 | China 219.4 | **2126.9** |
| **2017** | Netherlands 542.8 | Austria 248.6 | Italy 195.6 | Germany 185.4 | China 179.2 | **2548.1** |
| **2018** | France 716.3 | China 690.0 | Netherlands 350.7 | Germany 263.3 | Russia 263.0 | **3464.5** |
| **2019** | Netherlands 803.7 | Russia 576.8 | Hungary 520.9 | Switzerland 405.5 | China 344.9 | 3815.3 |
| **2020** | Netherlands 590.6 | China 529.5 | Slovenia 466.1 | Germany 353.4 | Gr. Brit. 175.4 | 3038.9 |
| **2021** | Switzerland 663.8 | China 630.4 | Netherlands 532.4 | Germany 409.5 | Gr. Britain 333.0 | 3886.0 |
| **2022** | China 1378.5 | Russia 463.7 | Gr. Britain 329.6 | Germany 282.3 | Austria 245.4 | 4432.5 |
| **2023** | China 1374.3 | Netherlands 770.4 | Gr. Britain 341.6 | Austria 307.7 | Germany 223.0 | 4564.4 |
| **2024** | China 1630.9 | Netherlands 1010.5 | Gr. Britain 552.7 | Luxembourg 407.7 | Switzerland 204.4 | 5211.1 |

*Table 1: Republic of Serbia – Top five foreign direct investments origin countries, 2016-2024, in EUR millions*
*(Source: National Bank of Serbia data)*

The most recent past has lightened the inflow from China which has become the leading source of FDI, especially starting from 2022, with amounts of EUR 1.5 billion approximately, per year. The role of Great Britain is also emphasized, especially during the last three years. That brought Britain at the third place on the list of the FDI top five origin countries. The Foreign Affiliates Statistics (Inward FATS) observes, registers and describes activities of the business entities, residents in a specific country, controlled by the enterprises which are based in another country. It refers to business entities with at least 50% of foreign capital. The main aim is getting the data for the analysis of the foreign affiliate`s presence impact on every national economy. The role of these business entities in the national economy could be observed from a few aspects: the share in total number of business entities, the share in total number of employed persons in a country and the share in total value added. Observing last decade data, we can see an increase of the foreign direct investment in Serbia, expressed, among other indicators, by the increase in the transnational companies` affiliates opened in Serbia in last decade, with the tendency of further rise. With the increase in the value of FDI, there has also been an increase in the number of active foreign affiliates in the economy. In 2011 there were 2478 foreign affiliates in Serbia and that number reached 2942 until 2023. They participate in the total number of business entities with 1.4% (Statistical Office of the Republic of Serbia).

They have a positive impact by employing over 300,000 people and this number is continuously increasing. In 2023, they had the share of 21.2% in the total number of persons employed. Starting from 174605 employed persons, their number until 2023 has more than doubled (Statistical Office of the Republic of Serbia).

| | Number of affiliates | Number of persons employed | Turnover | Value of output | Value added at factor costs | Personnel costs |
|---|---|---|---|---|---|---|
| | | | | | | In RSD millions |
| 2011 | 2478 | 174 605 | 2 178 829 | 1 384 486 | 397 445 | 195 312 |
| 2012 | 2708 | 181 953 | 2 523 346 | 1 547 017 | 479 329 | 214 637 |
| 2013 | 2642 | 189 414 | 2 725 001 | 1 789 085 | 504 724 | 233 905 |
| 2014 | 2624 | 198 797 | 2 813 511 | 1 855 490 | 520 461 | 250 675 |
| 2015 | 2615 | 198 732 | 2 875 772 | 1 908 835 | 530 611 | 262 597 |
| 2016 | 2713 | 223 125 | 3 163 174 | 2 076 645 | 597 734 | 294 229 |
| 2017 | 2740 | 245 573 | 3 498 493 | 2 355 815 | 668 147 | 337 993 |
| 2018 | 2789 | 275 511 | 3 862 673 | 2 633 489 | 757 065 | 391 981 |
| 2019 | 2785 | 292 483 | 4 101 038 | 2 784 425 | 824 844 | 441 045 |
| 2020 | 2744 | 312 055 | 4 006 635 | 2 833 998 | 901 575 | 493 806 |
| 2021 | 2862 | 337 484 | 4 734 749 | 3 366 856 | 1 195 502 | 576 578 |
| 2022 | 2890 | 352 789 | 6 026 004 | 4 249 317 | 1 514 322 | 700 460 |
| 2023 | 2942 | 369 918 | 6 260 738 | 4 454 605 | 1 624 410 | 860 986 |

*Table 2: Foreign affiliates in Serbia, 2011-2023*
*(Source: Statistical Office of the Republic of Serbia)*

The value of production in foreign affiliates is also constantly increasing, indicating potential large contribution. However, it can also be said that this contribution is more modest because of the fact that new value added data show that the share of embedded domestic value production of affiliates is reaching only between one third and one quarter of the total. In 2023, the share of foreign affiliates in total value added was 34.1% (Statistical Office of the Republic of Serbia).

## 4. PRIMARY INCOME FLOWS
Primary income flows in the balance of payments are composed of earnings coming from the factors of production – labor, financial assets, land, and natural resources. It includes the following: Income from interest, profits, and dividends (generated from foreign investment); Compensation of employees; Taxes and subsidies on products and production. The following, Figure 5, represents current account financial services (FS) data for Serbia (credit vs debit data).
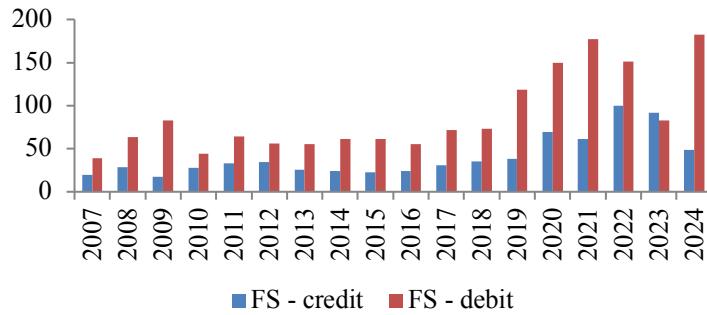
*Figure 5: Financial services in the period 2007-2024, in EUR millions*
*(Source: Authors' presentation based on the National Bank of Serbia data, www.nbs.rs)*

Current account financial services flows indicate the more profound increase of debit flows reaching the level of EUR 182 millions in 2024. The net investment income as the component of the primary income is facing sharp decrease in the lates five years reaching EUR -5,070 millions in 2024 (Figure 6).
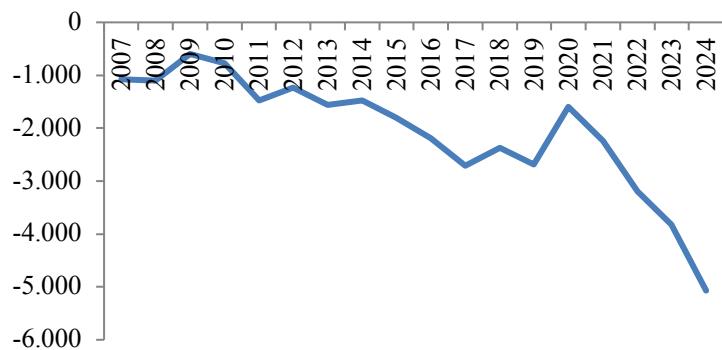


*Figure 6: Investment income in the period 2007-2024, net in EUR millions*
*(Source: Authors' presentation based on the National Bank of Serbia data, www.nbs.rs)*

While foreign direct and portfolio investments as the most significant source of foreign financial flows in Serbia are reaching record high in 2024 the net income generated indicates increasing withdrawals (Figure 7).
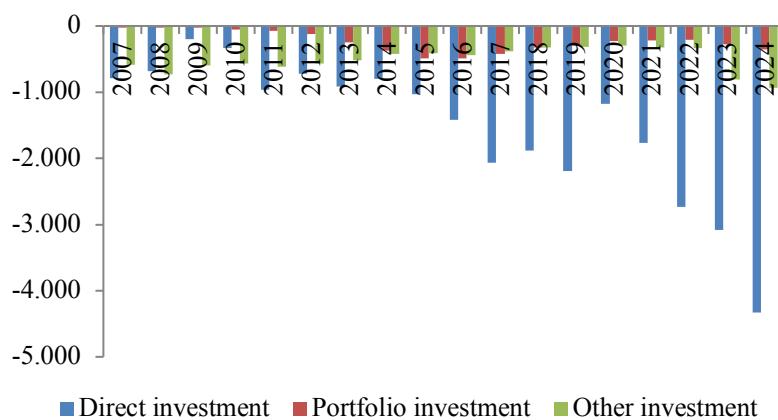


*Figure 7: Direct, portfolio and other investment income*
*in the period 2007-2024, net in EUR millions*
*(Source: Authors' presentation based on the National Bank of Serbia data, www.nbs.rs)*

To see it in more detail for direct investment income, the net income generated on equity and debt indicates increasing withdrawals especially from 2022 onwards (Figure 8).
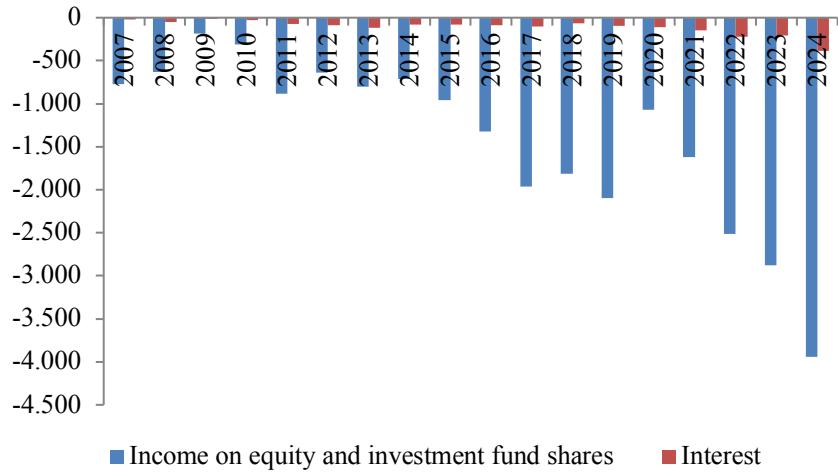


*Figure 8: Direct investment income in the period 2007-2024, net in EUR millions*
*(Source: Authors' presentation based on the National Bank of Serbia data, www.nbs.rs)*

Te income generated based on direct investments in the form of dividends and return on investment funds shares had more or less stable dynamic while net withdrawals show increase from 2022 onwards reaching EUR -2,401 million in 2024 (Figure 9).
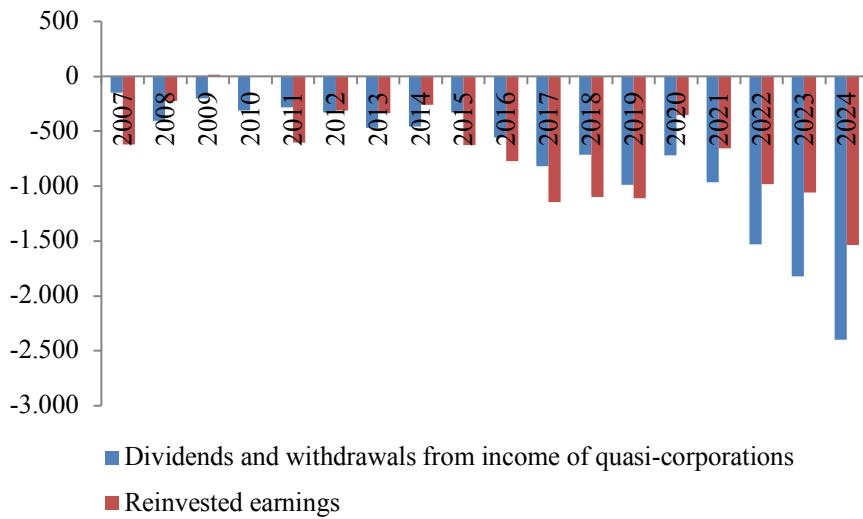


*Figure 9: Direct investment – income on equity and investment funds shares and retained earnings in the period 2007-2024, net in EUR millions*
*(Source: Authors' presentation based on the National Bank of Serbia data, www.nbs.rs)*

Portfolio investment net income flows indicate the dominant withdrawal of funds in the form of interest income, reaching EUR 368 million in 2024 (Figure 10).
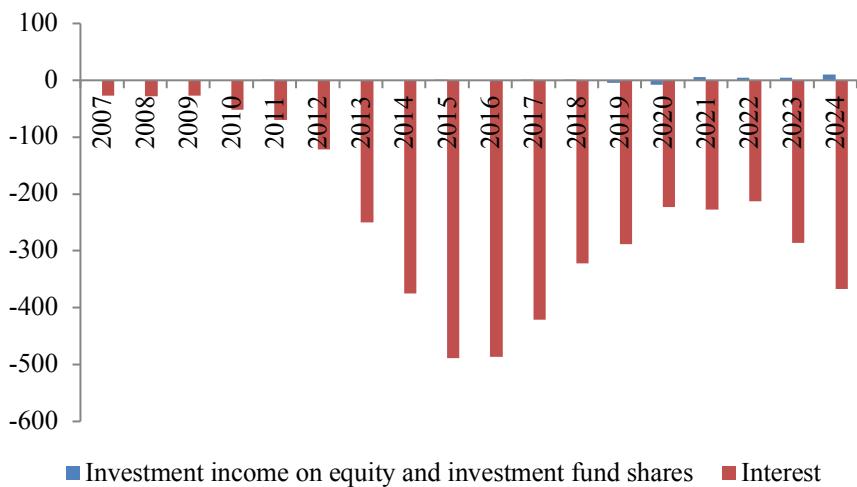
*Figure 10: Portfolio investment – investment income on equity and investment funds shares and interest income in the period 2007-2024, net in EUR millions*
*(Source: Authors' presentation based on the National Bank of Serbia data, www.nbs.rs)*

Significant primary income outflows in the latest period, observed in parallel with remittance and FDI flows dynamics, especially from 2022 onwards, signal the importance of rethinking the strategic focus and financing sources structures that would provide resilient basis for country's sustainable economic growth in the future period.

## 5. CONCLUSION

Remittances are an important and stable source of foreign exchange inflows in Serbia and are primarily used for household consumption. Redirecting a larger portion of remittances towards productive investments – for example in human and physical capital, small and medium-sized enterprises, and infrastructure development – as well as investments in the sustainable energy sector and climate change resilience and adaptation, could make a significant contribution to sustainable development. Apart from obvious increase in FDI value in Serbia during the last decade, we should point out the role and impact of foreign affiliates of transnational companies. Their number increased, as well as the number of employed persons, which is more than doubled, during the observed period. We are also witnessing the increase of value added, although with almost no change in its share of domestic value production. Finaly, the primary income flows indicate the increasing withdrawals of funds generated on invested foreign capital in Serbia. All stated stress the importance of financing strategies refocusing on internal growth generators that represent the solid basis for stable growth and sustainable development in the future.

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# SYSTEMATIC ANALYSIS OF TRANSFORMATION IN DECARBONIZATION POLICY: DIMENSIONS AND SECTORS

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*ABSTRACT*

*Unless the climate emergency is properly addressed, it will trigger an economic, social, and human crisis. To prevent this, we need to accelerate energy system decarbonization, which requires innovation policies to speed up and redirect the pace of innovation. This research addresses this gap by identifying the characteristics that define a policy as having transformative potential, determining if these characteristics are present in current decarbonization policies, and exploring regional and sectoral differences in their incidence and implementation. The methodology involved a systematic analysis of decarbonization policies from four global regions. Data was gathered from publicly available sources like the IEA's country energy policy database. The analysis first sought evidence of the five transformative dimensions within these policies, assessing their regional incidence. Subsequently, the research identified sectors (e.g., Energy, Transport) with a higher frequency of policies exhibiting transformative potential. Results suggest that policies with transformative characteristics are still rare globally and, in most sectors, indicate limited transformative potential in current policies. However, there are regional and sectoral differences. For instance, the Energy and Buildings sectors combined showed a high incidence of transformative dimensions across all regions. Japan displayed more dynamic experimentation than China and Europe. These research results add to the growing literature in order to better understand the transformative potential of energy and environmental policies.*

*Keywords: Decarbonization, Policy assessment, Transformative policies*

## 1. INTRODUCTION

At present, human activities constitute an open cycle that moves from an initial state of environmental equilibrium to one of imbalance, meaning consumed resources cannot be regenerated [1]. The energy sector, largely driven by fossil fuel production and combustion, is a primary cause of these adverse environmental effects. Because users view energy, and particularly electricity, as an indispensable commodity for the modern economy, energy policies need to assess both economic performance and environmental considerations to ensure sustainable development and economic growth [2, 3]. Anthropogenic emissions are on the rise, consistently setting undesirable records each year due to human activities and production processes, despite clear scientific evidence that global emissions must be drastically cut. Climate destabilisation is a global public welfare issue [2]. If left unaddressed, the climate emergency will escalate into an economic, social, and human crisis [4]. Accelerating energy system decarbonization demands crucial innovation policies to speed up and redirect the pace of innovation, development, and dissemination of desired technologies. This will require radical shifts in business strategies, significant public and private investments, and workforce reskilling [2, 5, 6]. The research aims to identify the characteristics that define a policy as having transformative potential, determine if these characteristics are present in current decarbonization policies, and explore regional and sectoral differences in their incidence and implementation.

To achieve this, a literature review across innovation policy and sustainable transition studies was conducted. This led to the identification of five key transformative policy dimensions: Continuous learning & adaptation, Multi-scalar coordination, Dynamic experimentation, Stakeholder engagement, and Cross-sectoral integration. These five dimensions supported a meta-analysis of energy and environmental policies to assess whether and to what extent the literature's transformative characteristics are present in energy and environmental policies, giving directions towards its transformative potential. This paper is organised as follows: after this introduction, Section II presents the methodology that comprises the two major parts involving this research – the definition of transformative policy characteristics and the analysis of the energy and environmental policies on EEA and IEA databases' policy content concerning defined categories. Section III demonstrates the main results of the survey carried out and the discussion. Finally, in Section IV, the conclusions and how this research may improve the debate are mentioned.

## 2. METHODOLOGY

This research methodology has two primary components. The first involved defining transformative policy characteristics based on innovation policy, and sustainable transitions literature. The second assessed these characteristics' presence in energy and environmental policies by analysing the EEA and IEA database content [7, 8]. Using the five transformative dimensions identified in the literature review as a framework, it was systematically analysed 3387 energy and environmental policies. These policies, sourced from publicly available IEA country reviews and the EEA database, represent Europe, Japan, China, and the USA. This systematic analysis first involved identifying and assessing the regional incidence of the five transformative dimensions within the policies. Then pinpointed sectors (e.g., Energy, Transport) with high transformative potential, globally and by region. Finally, it was examined how transformative dimensions combine within these sectors to understand their organisation and content. This methodology enabled an assessment of whether policies with transformative potential are effectively being formulated. It also helped identify any regional differences in their formulation, considering the sectors they target. Figure 1 provides an illustration of the study design and the methodology implemented.
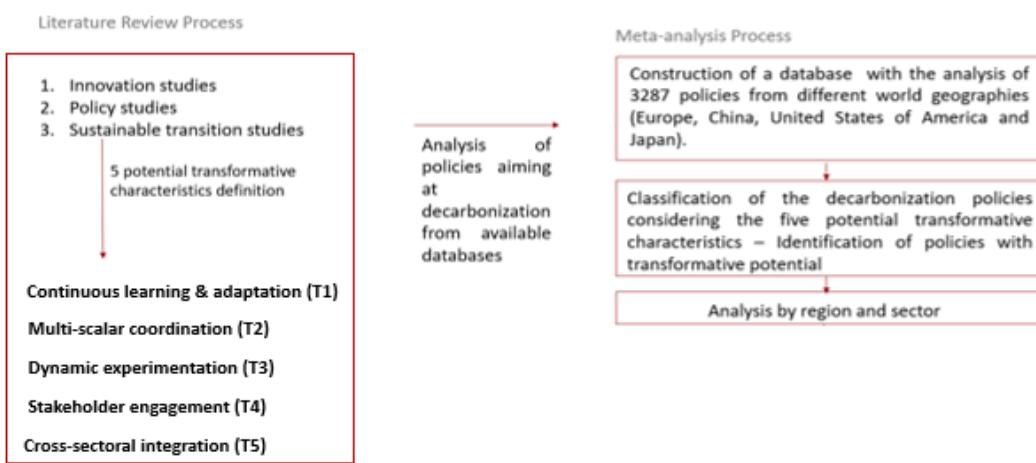


*Figure 1: Study design and methodology.*
*(Source: From the author)*

## 2.1. Key aspects of transformative policy

### 2.1.1. Continuous learning & adaptation

Effectively setting policy direction is complex, demanding clear goal definitions and new monitoring indicators [9]. Missions or challenge-oriented approaches [10] are increasingly seen as enhancing the directionality of innovation policy, fostering socio-technical transitions [4]. Missions strategically choose and focus on specific societal transformations, requiring strategic thinking about desired pathways, public sector capacity, policy execution and incentive structures for both public and private sectors [9, 11]. While missions increase directionality, some argue they offer too narrow a perspective for complex societal transformation, suggesting that Transformative Innovation Systems (TIS) might yield more effective results. However, both missions and TIS can inform directionality and strategy, potentially benefiting from a "policy inosculation" where their strengths combine [12]. Missions, being more focused, may be better for short-term or specific challenges, preventing conflicts from broad actor involvement [13]. Conversely, TIS's focus on policy coordination and reflexivity can improve mission design, ensuring that diverse actors interact and co-construct knowledge. While TIS's broad, multi-actor discussion enriches perspectives, it can also complicate setting a clear direction and strategy. Implementing directionality requires designing, evaluating, and monitoring policies for systemic change, emphasising policy coherence and articulation through appropriate policy mixes to prevent transformation failures [5, 14]. Despite its importance, the role of policy mixes in driving systemic directionality has received limited explicit attention [14]. Governments play a crucial role in setting direction, system-building, and accelerating transformation, potentially through infrastructure investments that influence future expectations [15, 16].

### 2.1.2. Multi-scalar coordination

To foster low-carbon transitions, the literature emphasises the critical need for instrument mixes characterised by strong governance, coherence, consistency, and complementarity, which are vital for maximising the socio-economic benefits of innovations [5, 9, 16, 17, 18]. Effective policy coordination and alignment are crucial to ensure activities are synergistic rather than counteracting [2, 16]. However, achieving policy consistency is challenging due to differing national interests based on economic development and resource levels, and it requires the ability to integrate diverse factors like knowledge, skills, finance, institutions, and demand [2, 16]. Difficulties often stem from coordination and governance issues rather than technical ones, making it unrealistic to identify universally "good" policy mixes, as optimal mixes are highly context-dependent and evolve within specific institutional dynamics [19, 20]. Therefore, the focus should be on the actors, instruments, institutions, and interactions that shape public policy [20]. An effective policy mix must be holistically embedded within complementary policies, spanning areas like education, environment, research, health, employment, and territorial cohesion [9]. Rapid sustainable energy system transformations demand policy mixes that account for hierarchical government levels (urban, regional, municipal) to influence land-use, building codes, and infrastructure investments [2]. For instance, community energy management requires integrating various policy interventions from building codes to infrastructure. The embeddedness and inclusiveness of policy mixes need continuous evaluation of transformative practices with clear responsibilities for coordination and monitoring, assessing the systemic impacts of policy portfolios rather than isolated interventions [11, 21]. Policy mixes should better connect economic and political agendas, moving beyond single-minded efficient pricing to simultaneously orchestrate creation and destruction, actively encouraging industries that accelerate environmental protection while potentially implementing "degrowth policies" for those that do not align with transformative goals [22, 23, 24].

While societal learning and innovation are crucial, embedding policy design can lead to social contestation [25]. Consequently, if traditional and transformative policy mixes weaken directionality, innovation may only contribute to economic growth, potentially compromising broader societal challenges [13].

### 2.1.3. Dynamic experimentation

Present policies evaluation and monitoring fail to recognise factors that can cause policy impairment and policy failure, in the design of strategies, transitions, feedback loops and serendipity, transparency for failures and successes must be considered [2]. The willingness to explore new approaches, with broad consultation processes to discuss rationales and perspectives to broaden the scope of policy inputs, may change the outcome of *"conflicts, power struggles, contestations, lobbying, coalition building, and bargaining"* [25]. According to Borrás and Schwaag Serger (2022), the higher the contestation, complexity, and uncertainty of the problem underlying a particular challenge, the more difficult it might be for policy to derive legitimate, clear, and well-informed missions from it. Different learning levels may arise, the first, government learning, relates to learning and coordination within and across public government organisations. The second, network learning, refers to collective learning taking place in the support structure of an innovation system through broadening of the competence base and new combinations of experiences and practices, including stakeholders such as firms, universities and non-governmental organisations. The third dimension, governance learning, encompasses state–economy–civil society relations broadly understood. If institutional structures hinder collective action, if learning processes constrain recursive actor rationality, and if consultative and deliberation mechanisms are not inclusive, then the systemic capacity to design appropriate industrial policy strategies for societal goals would be significantly hampered. Furthermore, this could even lead to conflicting dynamics that result in further horizontal inequalities, polarisation of power and social unrest for the reclaim of policy space.

### 2.1.4. Stakeholder engagement

Innovation policy has evolved significantly, moving beyond simply optimising the innovation "*ecosystem*" for economic competitiveness towards a "*third generation*" approach that actively steers transformative change to achieve societal goals, particularly in sustainability [16, 18, 26]. This directionality necessitates demand-side actor participation, requiring a deep understanding of who drives change, how power relations shift, and how to navigate the complex, multi-actor networks inherent in socio-technical regimes [13, 27, 28]. Direction can be driven by both top-down state projects and bottom-up public-private partnerships supporting new technologies, though multi-actor complexity introduces challenges like contestation, uncertainty, and the need for policy trade-offs [13, 16]. The long-term nature of transitions, especially in energy, demands evolving capacities at actor and system levels, fostering new relationships between the state, market, and civil society [2, 24, 29]. This will lead to proactive, entrepreneurial state action and new forms of public-private collaboration based on interaction, communication, and long-term commitment [11, 16, 24, 27, 30]. Transformative policies must shift focus from single actors to diverse actor networks (business, civil society, supranational structures), emphasizing combined knowledge for collective learning, coalition building, and mitigating negative impacts [2, 9, 11, 16, 21, 24, 31, 32, 33, 34, 35]. This approach empowers stakeholders across fields and policy levels to coordinate solutions, leveraging cooperativism for knowledge dissemination and resource access [32]. This broader perspective replaces the narrow concept of "*market failures*" with a focus on "*system failures*" including poor networks and institutional or infrastructure shortcomings [24, 31, 36]. Finally, new actors emerging from niche existence are crucial for providing directionality and fostering regime shifts [27]. Investment in socio-technical system changes requires long-term planning and commitment, recognising that actors' intentions evolve [16, 27].

Institutional flexibility and the de-institutionalisation of existing structures are vital for niche innovations to succeed [11, 37, 38]. Institutional alignment is key to promoting sustained interactions between emerging technologies and challenging dominant practices [21, 32]. Reshaping institutions necessitates exploring innovation agencies that consolidate organisational patterns through responsive, evolving policies aligned with problem-solution structures [11, 36, 37, 39].

### 2.1.5. Cross-sectoral integration

Economic reconfiguration driven by creation and destruction processes will induce structural changes in manufacturing, technology, and organisational structures across entire value chains [9, 16]. This will lead to widespread societal structural change, impacting interconnected systems and reconfiguring actor networks, social networks, and communities at various geographic levels. A successful policy mix will result in mainstreamed niches, upscaling, replication, circulation, and institutionalisation of these changes. Strong contextual complementarities can accelerate technological development, boosting labour productivity and driving systemic change [40]. Technological innovation is a primary driver for sustainable development within these transformation processes [9, 30, 39, 41, 42]. While innovation can facilitate policy shifts, it also presents significant economic and social challenges. Therefore, policies should adopt a broader systemic failure rationale instead of a narrow market failure perspective [25, 40, 43].

## 3. RESULTS AND DISCUSSION

Policies demonstrating transformative characteristics are currently rare, with their overall transformative potential proving largely unexpressed across various regions and sectors. While the degree of transformative potential varies by region and sector, some consistent patterns emerge. Notably, the Energy and Buildings sectors combined consistently showed one of the highest occurrences of transformative dimensions across all regions analysed.

### 3.1. General Results by Economic Sector

#### 3.1.1. Japan

Continuous learning & adaptation (T1) and Dynamic experimentation (T3) are the most relevant dimensions in the overall analysis of the sectors. However, the results show that Continuous learning & adaptation (T1) is primarily relevant in the Energy and Buildings sector. Meanwhile, Dynamic experimentation (T3) is primarily relevant in cross-sectoral policies, which cover a multiplicity of sectors and none in particular. Multi-scalar coordination (T2), which was not the least relevant overall, holds no weight in three distinct sectors: Transport, Cross-sectoral, and Energy and Buildings.
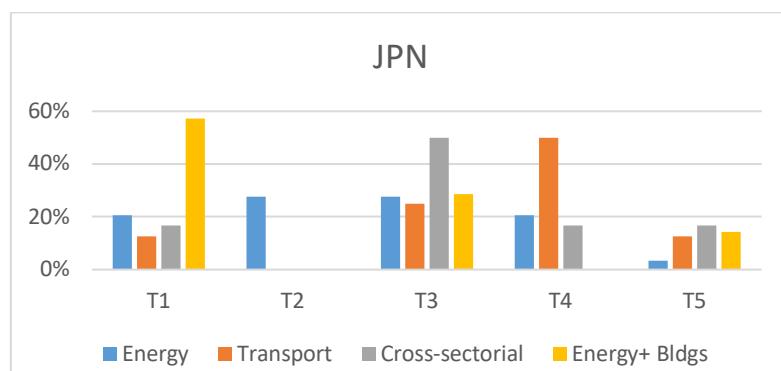


*Figure 2: Japan's transformative potential by sector considering the five dimensions. (Source: From the author)*

| | Continuous learning & adaptation (T1) | Multi-scalar coordination (T2) | Dynamic experimentation (T3) | Stakeholder engagement (T4) | Cross-sectoral integration (T5) |
|---|---|---|---|---|---|
| Energy | 21% | 28% | 28% | 21% | 3% |
| Transport | 13% | 0% | 25% | 50% | 13% |
| Cross-sectorial | 17% | 0% | 50% | 17% | 17% |
| Energy & Bldgs | 57% | 0% | 29% | 0% | 14% |

*Table 1: Japan's transformative potential by sector, considering the five dimensions in %. (Source: From the author)*

Table 1 illustrates the percentage relevance of five transformative dimensions across four different sectors in Japan: Energy, Transport, Cross-sectoral, and Energy & Buildings. Each percentage signifies the weight or importance of a particular dimension within a given sector. There is a dominance of Continuous learning & adaptation (T1) in the Energy & Buildings sector, overwhelmingly with a significant 57%. This suggests that for this combined sector, the ability to learn, adapt, and innovate on an ongoing basis is paramount. This is a much higher percentage than any other dimension in any other sector, making it a standout observation. Multi-scalar coordination (T2) shows a notable absence (0%) in the Transport, Cross-sectoral, and Energy & Buildings sectors. This indicates that for these specific areas, coordination across different scales or levels is not considered a significant factor in the context of the analysed data. Conversely, it holds a relatively higher relevance in the Energy sector (29%), suggesting its importance in managing complex energy systems. Dynamic experimentation (T3) is crucial for cross-sectoral initiatives, with the highest value at 50%. This highlights that for policies or initiatives that span multiple sectors, an iterative and experimental approach is deemed most effective. Stakeholder engagement (T4) is paramount in transport, the Transport sector heavily relies on Stakeholder engagement (T4), with a 50% relevance. Interestingly, Stakeholder engagement (T4) has no relevance (0%) in the Energy & Buildings sector, contrasting sharply with its importance in Transport. Compared to other dimensions, Cross-sectoral integration (T5) generally has lower percentages across all sectors, ranging from a mere 3% in Energy to 18% in Cross-sectoral. This might suggest that while integration across sectors is present, it's not the primary transformative driver in the same way as, for instance, learning or experimentation, or it might be implicitly covered by other dimensions in certain contexts. Considering a sector-specific analysis, Energy shows a more balanced distribution, with Multi-scalar coordination (T2), Dynamic experimentation (T3), Continuous learning & adaptation (T1) and Stakeholder engagement (T4) all hovering around 22-29%, indicating a multifaceted approach. Cross-sectoral integration (T5) is least important here. The Transport sector highly emphasises Stakeholder engagement (T4). The complete absence of "Multi-scalar coordination (T2) is a key characteristic. Cross-sectoral sector strongly prioritises Dynamic experimentation (T3). Similar to Transport, Multi-scalar coordination (T2) plays no role. In the combined energy & Buildings sectors, rely heavily on Continuous learning & adaptation (T1). The lack of Multi-scalar coordination (T2) and Stakeholder engagement (T4) is a distinguishing feature of this sector's approach to transformation. In conclusion, the data clearly illustrate that the importance of different transformative dimensions varies significantly across sectors.

This suggests that effective strategies for transformation need to be tailored to the specific characteristics and priorities of each sector, rather than adopting a one-size-fits-all approach.

### 3.1.2. China

Regarding the overall results, Continuous learning & adaptation (T1) and Stakeholder engagement (T4) were the most relevant dimensions. However, the results show that the sector where Continuous learning & adaptation (T1) has the most weight is Energy and Buildings. In contrast, the Energy sector alone is where Continuous learning & adaptation (T1) has the least weight. The opposite is true for Stakeholder engagement (T4), where its greatest weight is attributed to the Energy sector, and its least weight is attributed to the Energy and Buildings and Cross-sectoral sectors. Contrary to what was observed in Japan, all sectors in China have a certain weight from all transformative dimensions.
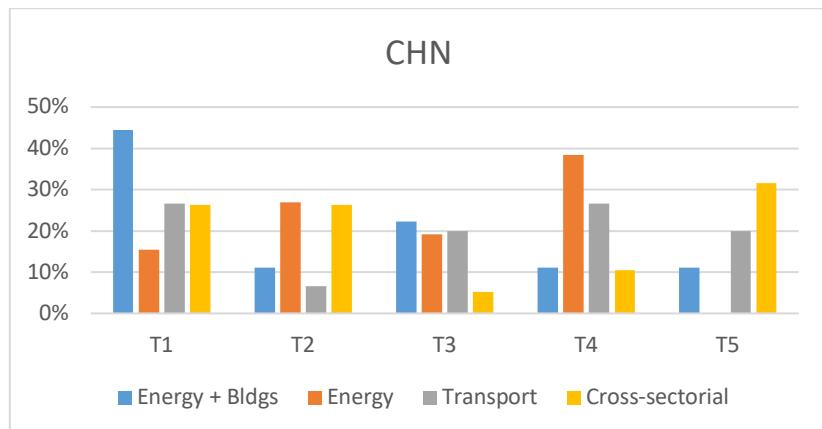


*Figure 3: China's transformative potential by sector considering the five dimensions.*
*(Source: From the author)*

| | Continuous learning & adaptation (T1) | Multi-scalar coordination (T2) | Dynamic experimentation (T3) | Stakeholder engagement (T4) | Cross-sectoral integration (T5) |
|---|---|---|---|---|---|
| Energy | 15% | 27% | 19% | 38% | 0% |
| Transport | 27% | 7% | 20% | 27% | 20% |
| Cross-sectorial | 26% | 26% | 5% | 11% | 32% |
| Energy & Bldgs | 44% | 11% | 22% | 11% | 11% |

*Table 2: China's transformative potential by sector, considering the five dimensions in %.*
*(Source: From the author)*

Table 2 presents China's transformative potential by sector, considering five key dimensions in percentage. The analysis reveals distinct patterns of relevance for each dimension across different sectors, offering insight into the country's strategic priorities and focuses. Beginning with the Continuous learning & adaptation (T1) dimension, it is observed to be the most prominent in the Energy & Buildings sector, with 44% relevance, underscoring the importance of continuous learning and adaptation for this combined sector. However, it is considerably less relevant in the Energy sector in isolation, with only 16%.

The Multi-scalar coordination (T2) dimension shows significant weight in the Energy (28%) and Cross-sectoral (27%) sectors, indicating the importance of multi-scalar coordination in these areas. In contrast, its transformative potential is notably low in the Transport sector, at only 7%. Regarding Dynamic experimentation (T3), the values are generally lower compared to other dimensions, suggesting that dynamic experimentation may not be the primary transformative lever in many sectors in China. Its peak is in the Energy & Buildings sector (23%), but it reaches its lowest point in the Cross-sectoral sector (5%), which is a notable finding and may indicate a lesser emphasis on pure experimentation in inter-sectoral initiatives in China. The Stakeholder engagement (T4) dimension is the most relevant for the Energy sector, with 39%, highlighting the importance of involving stakeholders for transformations in this domain. On the other hand, it shows significantly less weight in the Cross-sectoral and Energy & Buildings sectors, both at 11%. Finally, Cross-sectoral integration (T5) demonstrates its greatest potential in the Cross-sectoral sector (33%), which is logical given the nature of the sector. A critical observation, however, is the complete absence of relevance (0%) for this dimension in the Energy sector, suggesting a lack of focus on cross-sectoral integration for energy transformations in China, at least in the analysed data. Continuous learning & adaptation is fundamental for the Energy & Buildings sector, while Stakeholder engagement is crucial for Energy. Multi-scalar coordination is important in Energy and Cross-sectoral, and although Dynamic experimentation is not universally dominant, Cross-sectoral integration is vital for inter-sectoral initiatives. The absence of certain dimensions in specific sectors (such as T5 in Energy or T2 in Transport) points towards highly segmented transformation approaches in China.

### 3.1.3. USA

Regarding the overall results, Continuous learning & adaptation (T1) was the most relevant transformative dimension for the USA. The sector where Continuous learning & adaptation (T1) has the most weight is Energy and Buildings. For Multi-scalar coordination (T2) alone, there is no weight for the transport sector.
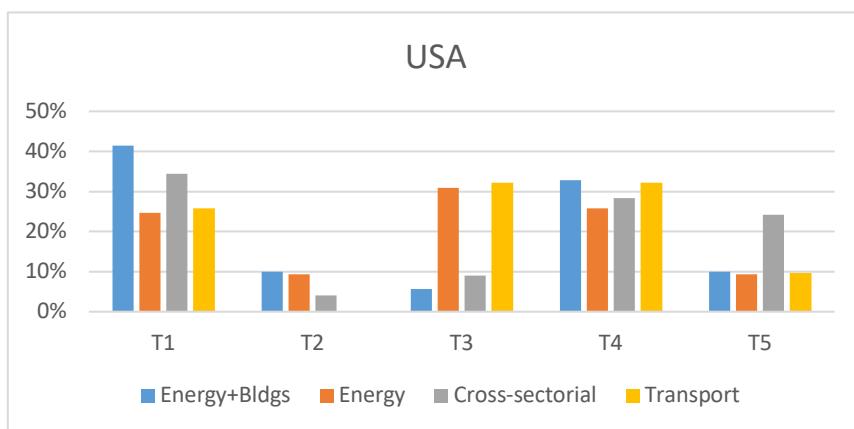


*Figure 4: USA transformative potential by sector considering the five dimensions.*
*(Source: From the author)*

|  | Continuous learning & adaptation (T1) | Multi-scalar coordination (T2) | Dynamic experimentation (T3) | Stakeholder engagement (T4) | Cross-sectoral integration (T5) |
|---|---|---|---|---|---|
| Energy | 25% | 9% | 31% | 26% | 9% |
| Cross-sectorial | 34% | 4% | 9% | 28% | 24% |
| Transport | 26% | 0% | 32% | 32% | 10% |
| Energy & Bldgs | 41% | 10% | 6% | 33% | 10% |

*Table 3: USA transformative potential by sector, considering the five dimensions in %.*
*(Source: From the author)*

Table 3 outlines the transformative potential by sector in the USA, considering five key dimensions in percentages. The data reveals distinct patterns in how different transformative dimensions contribute to sector potential across the United States. Continuous learning & adaptation (T1) emerges as a consistently strong dimension across all sectors, with its highest relevance in Energy & Buildings at 42%, indicating a significant emphasis on ongoing learning and adaptability within this combined sector. It remains a substantial factor in "ross-sectorial (35%) and Transport (27%) as well, though it's relatively lowest in Energy"(26%) among the sectors. Multi-scalar coordination (T2) appears to be a less dominant transformative dimension in the USA context. Its relevance is generally low across all sectors, with a notable absence (0%) in the Transport sector, suggesting it plays no role there. While it has some presence in Energy (9%), Energy & Buildings (10%), and Cross-sectoral (4%), its overall lower percentages indicate it is not a primary driver of transformation compared to other dimensions. Dynamic experimentation (T3) shows a bimodal distribution. It is highly relevant in the Transport (33%) and Energy (32%) sectors, pointing to an active embrace of experimental approaches in these areas. However, its importance drastically drops in Energy & Buildings (6%) and Cross-sectorial (9%), where it holds very little transformative potential. Stakeholder engagement (T4) demonstrates broad relevance across all sectors, with strong percentages. It is particularly prominent in Energy & Buildings (34%) and Transport (33%), highlighting the crucial role of involving diverse stakeholders in these sectors' transformations. Its lowest, yet still substantial, percentage is in Cross-sectorial (29%). Finally, Cross-sectoral integration (T5) registers its highest potential within the Cross-sectorial category itself (25%), which logically aligns with the nature of cross-sectoral initiatives. However, its relevance is considerably lower across the other sectors, with similar percentages in Energy (9%), Transport (10%), and Energy & Buildings (10%), suggesting that explicit cross-sectoral integration is a more specialized transformative lever rather than a universal one in the USA. In summary, the USA's transformative potential is characterized by a strong emphasis on Continuous learning & adaptation and Stakeholder engagement across most sectors. Dynamic experimentation is critical in Energy and Transport but less so in Energy & Buildings and Cross-sectorial. Multi-scalar coordination consistently plays a minor role, notably absent in Transport, while Cross-sectoral integration is primarily a driver within cross-sectoral contexts. This nuanced distribution underscores that transformative strategies in the USA are tailored to specific sectoral needs and priorities.

Regarding the overall results, Continuous learning & adaptation (T1) was the most relevant transformative dimension for Europe. Similar to the United States, China, and Japan, the findings indicate that Continuous learning & adaptation (T1) is particularly relevant in the Energy and Buildings sector. For Cross-sectoral integration (T5), there's no weight for the transport sector, and the same applies to Multi-scalar coordination (T2) for the Energy and Buildings sector.
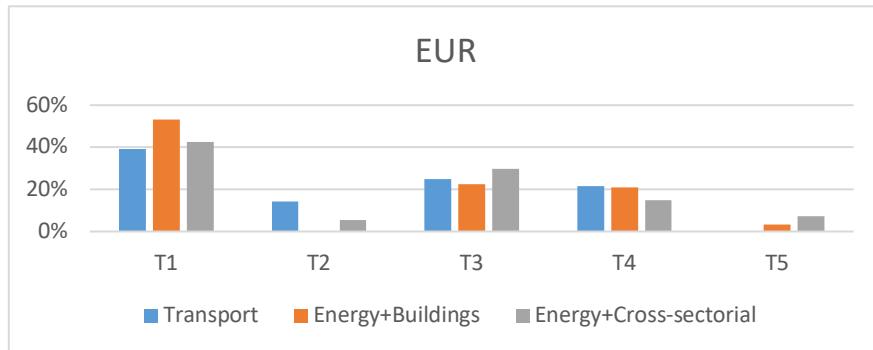


*Figure 5: Europe transformative potential by sector considering the five dimensions.*
*(Source: From the author)*

| | Continuous learning & adaptation (T1) | Multi-scalar coordination (T2) | Dynamic experimentation (T3) | Stakeholder engagement (T4) | Cross-sectoral integration (T5) |
|---|---|---|---|---|---|
| Transport | 39% | 14% | 25% | 21% | 0% |
| Energy & Cross-sectorial | 43% | 6% | 30% | 15% | 7% |
| Energy & Buildings | 53% | 0% | 23% | 21% | 3% |

*Table 4: Europe transformative potential by sector, considering the five dimensions in %.*
*(Source: From the author)*

Table 4 presents Europe's transformative potential by sector, showcasing how different dimensions contribute to transformation across specific areas. The data reveals distinct priorities and varying levels of emphasis on each dimension within the European context. Continuous learning & adaptation (T1) emerges as the most prominent transformative dimension across all listed sectors in Europe. It reaches its peak in Energy & Buildings with a significant 53% relevance, highlighting the critical role of ongoing learning and adaptability in this combined sector. It also holds strong positions in Energy & Cross-sectoral (43%) and Transport (40%), indicating a widespread strategic focus on continuous improvement and responsiveness to change across European transformative efforts. In stark contrast, Multi-scalar coordination (T2) generally displays very low transformative potential. It registers a complete absence (0%) in Energy & Buildings, suggesting that coordination across different scales is not considered a key driver in this sector.

Its relevance is also minimal in Energy & Cross-sectorial (6%) and relatively low in Transport (15%), pointing to a general de-emphasis on this dimension as a primary transformative factor in the analysed European sectors. Dynamic experimentation (T3) holds a moderate, yet consistent, importance across the sectors. It is highest in Energy & Cross-sectorial (31%) and Transport (26%), suggesting that experimental approaches play a supporting role in driving change in these areas. It is somewhat less emphasised in Energy & Buildings (24%). Similarly, Stakeholder engagement (T4) maintains a moderate level of relevance. It shows equal weight in Transport (22%) and Energy & Buildings (22%), indicating its consistent importance in involving various parties in these sectors. It is slightly less emphasized in Energy & Cross-sectorial (16%). Finally, Cross-sectoral integration (T5) registers as the dimension with the lowest overall relevance across the European sectors, with a complete absence (0%) in Transport. It shows only minor contributions in Energy &Cross-sectorial (7%) and Energy & Buildings (3%), suggesting that explicit cross-sectoral integration, while potentially present, is not seen as a major direct transformative force in the same way as other dimensions in Europe. In summary, Europe's transformative potential is largely driven by a strong emphasis on Continuous learning & adaptation across all analysed sectors. While Dynamic experimentation and Stakeholder engagement play supportive roles, Multi-scalar coordination and Cross-sectoral integration exhibit notably lower, and often absent, direct transformative potential in these European sectors. This indicates a strategic inclination towards internal learning and adaptation as primary engines of change, with less overt reliance on broader coordination or explicit cross-sectoral integration, particularly in transport and building-related energy sectors.

*3.1.5. Geographic zone results comparison*
The comparative analysis of transformative potential across Japan, China, the USA, and Europe reveals both common global trends and distinct regional priorities for driving change within various sectors. Continuous learning & adaptation (T1) stands out as a universally high-priority dimension across all regions. Japan leads this emphasis, particularly in Energy & Buildings with an impressive 57%, followed closely by Europe (53%), China (44%), and the USA (42%) in the same sector. This strong, consistent emphasis underscores a global recognition of adaptability and continuous improvement as fundamental for effective transformations. In contrast, Multi-scalar coordination (T2) is generally a less emphasised dimension across all regions. Japan, similar to Europe and the USA, shows a complete absence (0%) of T2's relevance in key sectors such as Transport, Cross-sectoral, and Energy & Buildings. While China presents a slightly higher emphasis on T2 in its Energy (28%) and Cross-sectoral (27%) sectors, indicating a relatively stronger focus on coordination there, it remains a less dominant transformative driver compared to T1 across the board. Dynamic experimentation (T3) exhibits notable regional differences in its perceived importance. Japan assigns a very high value to T3 in cross-sectoral initiatives (50%), a peak not matched by other regions in this category. The USA prioritises T3 significantly in Transport (33%) and Energy (32%). Europe shows a more moderate, consistent emphasis on T3 across its sectors (ranging from 24-31%). China, however, generally places less emphasis on T3, with a maximum of 23% in Energy & Buildings and a remarkably low 5% in its Cross-sectoral sector, suggesting a more cautious approach to pure experimentation. Stakeholder engagement (T4) is broadly recognised as an important dimension, but its dominance varies by region and sector. Japan strongly emphasizes T4 in Transport (50%) but shows no relevance (0%) in Energy & Buildings. The USA demonstrates a consistently high relevance for T4 across all its sectors (29-34%), indicating a pervasive focus on involving stakeholders. China prioritizes T4 significantly in Energy (39%) but less so in its Cross-sectoral and Energy & Buildings sectors. Europe maintains a moderate importance for T4 across its sectors (16-22%). Finally, Cross-sectoral integration (T5) is generally a dimension with lower overall relevance or even zero in certain sectors across all regions.

It tends to be most prominent within dedicated Cross-sectorial categories (e.g., Japan 18%, China 33%, USA 25%). However, T5 registers zero relevance for the Energy sector in China and the Transport sector in Europe, and is very low across other sectors in Japan, USA, and Europe. This indicates that while integration is present, it's often a more specialized or indirect transformative lever, not a primary driving force across most sectors. In essence, while Continuous learning & adaptation forms a common bedrock for transformative potential globally, regions diverge significantly in their reliance on other dimensions. Japan and the USA show stronger peaks in Dynamic experimentation and Stakeholder engagement in specific sectors, while China's approach to Dynamic experimentation appears more subdued. The less universal adoption of Multi-scalar coordination and Cross-sectoral integration across all regions highlights their context-specific application in driving transformations.

## 4. CONCLUSION

Results suggest that policies with transformative characteristics are still rare globally and, in most sectors, indicating limited transformative potential in current policies. However, there are regional and sectoral differences. For instance, the Energy and Buildings sectors combined showed a high incidence of transformative dimensions across all regions. Japan displayed more dynamic experimentation than China and Europe. Cross-sectoral integration was the least common transformative dimension across all regions. The study anticipates that Continuous learning & adaptation and Dynamic experimentation will often be combined, as will Cross-sectoral integration and Stakeholder engagement. In conclusion, the analysis of transformative potentials across Japan, China, the USA, and Europe reveals that Continuous learning & adaptation is a consistently paramount dimension, universally underpinning sectoral transformations. Conversely, Multi-scalar coordination and Cross-sectoral integration generally exhibit lower, and often absent, direct influence. The emphasis on Dynamic experimentation and Stakeholder engagement, however, varies significantly by region, indicating diverse strategic priorities and highlighting that effective transformation strategies are highly tailored to specific geographic and sectoral contexts rather than following a uniform global approach.

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# ARTIFICIAL INTELLIGENCE AND FINTECH IN MOROCCO: COMPARATIVE INSIGHTS AND EMERGING CHALLENGES IN THE MENA REGION

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## ABSTRACT

*The digital transformation of the Moroccan financial sector is accelerating under the combined effect of the rise of FinTech and the gradual integration of artificial intelligence (AI). This study aims to provide an overview of the FinTech ecosystem in Morocco, focusing on the emerging role of AI in the optimization of financial services. A qualitative methodology was adopted, based on a review of recent literature and institutional data. It highlights the progress made in Fintech, while placing the Moroccan dynamic in a regional perspective, through a comparison with key countries in the MENA region. The study presents two main research constributions. First, it draws up a regional comparison between Morocco, Egypt, the United Arab Emirates, Saudi Arabia and Tunisia, highlighting the level of maturity of the sector, regulatory initiatives and the opportunities and challenges specific to each country. Second, it provides a detailed overview of the Moroccan situation, highlighting the progress made by the Central Bank, the testing of AI solutions in the fight against fraud or credit scoring, but also the obstacles encountered, notably the lack of talent, limited access to data or regulatory delays. The findings confirms that Morocco has real potential to become a regional player in financial innovation. If coordination between stakeholders is strengthened, the adoption of appropriate regulatory frameworks is accelerated and training in advanced digital skills is supported. The article concludes with the need for further empirical work and proposes courses of action to encourage the inclusive and sustainable development of FinTech and AI in the Moroccan context.*
*Keywords: FinTech, Financial sectro, Artificial Intelligence, Morocco, MENA Region*

## 1. INTRODUCTION

The rapid rise of digital technologies is profoundly transforming the global financial industry, giving rise to a dynamic FinTech ecosystem where artificial intelligence (AI) is playing a key role in reshaping banking, payments and financial inclusion. In the MENA region, this transformation is accelerating, with increasing competition between countries to establish themselves as regional hubs for financial innovation (World Bank, 2023; Findexable, 2022). Morocco, with its banking sector renowned for its stability, is part of this movement; it aims to catch up technologically while capitalising on the rise of digitalisation and the growing power of FinTech. However, despite promising initiatives in digital payments, regulatory sandboxes and the gradual adoption of AI in some institutions, the Moroccan ecosystem is still facing several structural challenges: sector concentration, lack of specialised talent, weak venture capital, and persistent regulatory uncertainties (El Amrani & Rowe, 2022; PwC, 2023).

Faced with the growing power of regional players such as the United Arab Emirates, Egypt and Saudi Arabia, it is essential to draw up a critical assessment of Morocco's positioning, to identify the levers for catching up and to propose courses of action to strengthen the country's attractiveness and competitiveness in the in the MENA FinTech arena. To address these issues, this article adopts a comparative methodology based on:
- A review of recent academic and institutional literature (2020-2024) on FinTech and AI in Morocco and the MENA region;
- Analysis of secondary data from international reports (World Bank, Oxford Business Group, Findexable, WEF, PwC, etc.), enabling a comparison of the FinTech ecosystems of five key countries: Morocco, Egypt, United Arab Emirates, Saudi Arabia and Tunisia;
- The synthesis of results from Moroccan scientific articles identifying local solutions, obstacles and best practices in the adoption of FinTech and AI.

In accordance with the scientific requirements expected of research in economics and management, the approach adopted mobilises verifiable sources, favours a critical and nuanced analysis, and endeavours to put national specificities into perspective with regional trends. The aim is to make an original contribution to understanding FinTech/IA dynamics in Morocco, while formulating informed recommendations for public policy and sector strategy.

## 2. LITERATURE BACKGROUND

The researchs on financial technologies (FinTechs), artificial intelligence (AI) and banking regulation has grown considerably over the past decade. Several seminal works help to structure this thinking around three main axes: the evolution of FinTechs, the impact of AI on financial services, and the associated regulatory issues. Arner, Barberis and Buckley (2015), in their study "FinTech and RegTech: Impact on Regulators and Banks", offer a literature review that highlights the speed of innovation in the financial sector. They point out that this technological dynamic poses major challenges for regulators, who must adapt their frameworks to keep pace with technologies such as blockchain or artificial intelligence. In another publication, the same authors (2015) stress the need for flexible regulation, focused on consumer protection while supporting innovation. On the technological front, Brynjolfsson and McAfee (2014), in The Second Machine Age, show that AI makes it possible to automate complex tasks, thereby improving productivity. However, this automation can also lead to job losses, particularly in those sectors most exposed to digitalization. This duality is also explored by Gomber, Koch and Siering (2017), who, through conceptual analysis and case studies, demonstrate that FinTechs are profoundly transforming traditional banking services, bringing greater flexibility and efficiency, but also new risks related to security and regulation. The very definition of FinTech has been clarified by Schueffel (2016), who offers a systematic review aimed at scientifically framing this constantly evolving concept. This clarification is essential to better grasp the economic and regulatory implications of these innovations. Artificial intelligence, in particular, is receiving increasing attention. Kissell and Mack (2020) show, through an empirical study, that AI improves risk management and portfolio optimization. Similarly, Narula et al. (2020) point out that machine learning enables better prediction of financial trends, although it requires robust infrastructures. Lu, Sun and Shi (2019) offer a comprehensive review of AI applications in financial services, ranging from fraud detection to process automation. In emerging markets, Bessière and Lebeau (2017) demonstrate that FinTechs and blockchain can foster financial inclusion and reduce transaction costs. This perspective is complemented by Chuen et al (2017), who analyze the future impact of FinTechs on traditional banking relationships, with a focus on reducing costs and improving the customer experience. Ethical and regulatory issues are also at the heart of the debate. Zohar (2021) warns of the risks associated with the protection of personal data and the transparency of automated decisions.

Lamberti and Bonacina (2020) discuss the challenges of integrating AI into banks, particularly in terms of ethics and data governance. Finally, Markou et al. (2020) explore the synergies between blockchain and AI, highlighting their potential to reduce costs and improve data management. Philippon (2016), from an economic perspective, sees FinTechs as a catalyst for innovation and cost reduction, while highlighting regulatory and trust challenges.

This vision is shared by Lee and Shin (2018), who analyze the impact of blockchain on the banking industry, highlighting its contributions in terms of transparency and security, despite persistent technical and regulatory obstacles. Finally, Binns and Smith (2019) show that AI is revolutionizing financial decision-making, from risk management to process automation, confirming the growing importance of these technologies in transforming the financial sector.

## 3. FOUNDATIONS AND PRINCIPLES OF FINTECH

Table 1 tracing the evolution of FinTech technologies highlights a linear and relatively structured progression of the sector, but this periodisation needs to be read critically. Indeed, although the division into four phases helps to clarify the major technological breaks, it tends to simplify the complex and often non-linear history of financial digitalisation (Gomber et al., 2017). For example, the emergence of digital banking or bankcards did not immediately lead to mass adoption, which was conditioned by the maturity of infrastructures and the level of banking coverage in each region (Bunea et al., 2016).

Furthermore, the chronology proposed in the table gives the impression of a systematic transition from one phase to another on a global scale, whereas in reality, the dynamics of adoption are heterogeneous between developed and emerging countries (Zetzsche et al., 2020). For example, some African and Asian economies are still experimenting with FinTech 2.0 models, while other markets, driven by technological investment or competitive pressure, have jumped straight to adopting fourth-generation technologies (Philippon, 2016).

The table also highlights the rise of BigTechs and the "platformisation" of finance, but does not sufficiently address the associated risks in terms of data sovereignty, market fragmentation and unfair competition (Arner, 2021; Zetzsche et al., 2020). The trend towards concentration and the dominance of a few major players pose new regulatory challenges which, for the time being, remain largely unresolved.

Finally, while there is an emphasis on innovation and financial inclusion in the latest phase, it is important to remember that these promises are not being systematically realised on the ground. Several recent studies point to the persistence of digital divides and inequalities in access, particularly in the countries of the South, where financial inclusion through digital means still depends largely on the institutional context, the level of education and confidence in the new tools (FSB, 2020; Gomber et al., 2023).

| Phase | Period | Main features | References |
|---|---|---|---|
| Fintech 1.0 | 1866 – 1987 | -Transition from analog to digital<br><br>- Transatlantic telegraph (1866): reduced financial communication times<br><br>- Telex network (1930s)<br><br>- First credit cards (1950s) | Arner et al., 2015 |
| Fintech 2.0 | 1987 – 2008 | - Digital banking<br><br>- Automated banking<br><br>- ATMs, bank cards, online banking<br><br>- Traditional banks still dominant | (Arner et al., 2015); (Zavolokina et al., 2016); (Gomber et al., 2017) |
| Fintech 3.0 | 2009 – 2019 | - Emergence of FinTech start-ups<br><br>- Blockchain, cryptocurrencies (Bitcoin, 2009)<br><br>- Mobile applications, contactless payments<br><br>- Acceleration with the COVID-19 pandemic | (Philippon, 2016); (Nakamoto, 2008); (Gomber et al., 2017); (FSB, 2020) |
| Fintech 4.0 | 2019 - today | - Platformization of finance<br><br>- Entry of BigTechs (Amazon, Google, Alibaba)<br><br>- Economies of scale, network effects<br><br>- Regulatory challenges<br><br>- Financial inclusion and sustainability | (Arner, 2021) |

*Table 1: Evolution of FinTech technologies*
*(Source: Compiled by authors)*

## 4. OVERVIEW OF FINTECH IN MOROCCO

It is important to discuss the real depth of this dynamic and examining the systemic factors that are limiting the sector's growth, although the table 2 below effectively summarises the current state of FinTech and AI in Morocco. Firstly, the relatively small number of start-ups (50-60 in 2023) and their concentration in the payments segment reveals a structural weakness: the Moroccan ecosystem remains predominantly transactional, with no real diversification into high value-added segments such as insurtech, wealth management or advanced RegTech (World Bank, 2023; Findexable, 2022).

This phenomenon reflects not only a lack of innovation, but also an orientation of the sector strongly dictated by the traditional banking offering, which tends to slow down the emergence of new disruptive models (PwC, 2023). The adoption of AI in FinTech, although promising on paper, remains embryonic: most of the initiatives identified are limited to pilots in credit scoring or the fight against fraud, without yet translating into fully operational solutions on a large scale (PwC, 2023; Oxford Business Group, 2023). This situation is symptomatic of a twofold impediment: the lack of local skills specialising in AI, exacerbated by a talent drain and a training offer that is still limited, and the difficulty of accessing quality data, in a context where data governance remains largely unresolved (WEF, 2023).

On the regulatory front, the introduction of a regulatory sandbox by Bank Al-Maghrib in 2019 is often cited as a factor opening the door to innovation. However, the reality on the ground reveals that access is still restrictive: few local fintechs have actually benefited from structured support, and most AI guidelines are still at the draft stage (Bank Al-Maghrib, 2023). This situation fuels uncertainty that limits risk-taking and discourages venture capital, which is already not very active in Morocco (Findexable, 2022). Furthermore, Moroccan regulation, in seeking to protect financial stability, sometimes tends to slow down the adoption of new business models that could nevertheless meet local needs, particularly in terms of financial inclusion (El Amrani & Rowe, 2022).

As far as opportunities are concerned, the table rightly highlights the expansion of digital payment and open banking, but underestimates the difficulty of realising these promises in a context marked by the low interoperability of solutions and a reluctance to open up banking data (World Bank, 2023; PwC, 2023). Moreover, digitalisation alone is not enough to guarantee financial inclusion: rural populations, women and small businesses often remain on the sidelines of the movement, due to limited access to technology and low digital literacy (WEF, 2023; Oxford Business Group, 2023). This digital divide tends to reproduce and even accentuate existing inequalities, even though FinTech is regularly presented as a means of democratising access to financial services.

Finally, the weakness of the venture capital ecosystem, the scarcity of local success stories and the absence of a national "champion" capable of taking innovation to the international stage are all signs that the sector is lagging behind in terms of systemic structuring (Findexable, 2022). Added to this are the cross-cutting challenges of cybersecurity, compliance with international standards (AML/CFT), and adapting human resources to the needs of the sector, which for the time being remain insufficiently addressed by public policy (World Bank, 2023).

Overall, the table should be read as a snapshot of a sector that is changing but still under construction, where the potential is real but where structural barriers and public policy choices will determine Morocco's ability to align itself with regional and international standards. In addition to technological innovation, the success of an AI-enhanced Moroccan FinTech depends on cross-functional mobilisation: reform of higher education, greater regulatory flexibility, active support for venture capital and, above all, a coherent national digital inclusion strategy (World Bank, 2023; WEF, 2023).

| Dimension | Current Status (Morocco) | Illustrative Examples / Data | Source |
|---|---|---|---|
| **FinTech Market Size / Maturity** | Emerging sector; approx. 50–60 active FinTech startups (2023), mainly in payments and digital banking | Inwi Money, CIH Bank digital platforms, Payit, Wafacash | World Bank (2023); Findexable (2022); StartUp Maroc (2023) |
| **AI Adoption in FinTech** | Early-stage adoption; pilot projects in credit scoring, e-KYC, fraud detection, RegTech | Bank of Africa using AI for anti-fraud; Finéa (Groupe CDG) experimenting with digital credit scoring | PwC (2023); El Amrani & Rowe (2022); Oxford Business Group (2023) |
| **Regulatory Framework** | Regulatory sandbox launched by Bank Al-Maghrib in 2019; AI guidelines under development | Participation of fintechs in sandbox (e.g., CIH Bank, M2T) | Bank Al-Maghrib (2023); World Bank (2023) |
| **Key Opportunities** | Financial inclusion, digital payments expansion, open banking potential, efficiency gains | Maroc Pay, HPS Switch, interoperability of mobile payments | World Bank (2023); El Amrani & Rowe (2022) |
| **Key Challenges** | Lack of AI/FinTech talent, limited access to data, regulatory delays, cybersecurity gaps | Less than 5% of startups are AI-focused; weak venture capital ecosystem | PwC (2023); Findexable (2022); WEF (2023) |

*Table 2: AI and FinTech Landscape in Morocco: Key Dimensions*
*(Source: Compiled by authors)*

## 5. OVERVIEW OF MOROCCAN ACADEMIC RESEARCH ON FINTECH SOLUTIONS

The literature reveals that Moroccan researchers have explored a wide range of topics, from cybersecurity and blockchain integration to credit scoring, digital payments, and the adoption of innovative financial technologies in various sectors, including health and mobile banking. Most studies emphasize both the technological and organizational aspects of FinTech adoption, while also considering the regulatory and socio-economic environment unique to Morocco.

Table 3 highlights the methodological and thematic diversity of Moroccan academic publications on FinTech, but it also reveals several structural limitations of the national research field. Firstly, the variety of methodologies (technological integration, Delphi, data mining, acceptance models) shows a willingness to adopt both qualitative and quantitative approaches, which is a positive point for the robustness of the analyses. However, most of the work remains at an exploratory or experimental stage, often based on case studies or theoretical frameworks without large-scale operational deployment.

For example, Chouraik's (2024) contribution to cybersecurity remains focused on the proposal of a strategic framework, without empirical validation or evaluation of the actual impact on the reduction of cyber-risks in the Moroccan banking sector. This finding reflects a lack of linkage between research and practice, which limits the direct usefulness for economic players (El Amrani & Rowe, 2022). In addition, we note that the issue of technological adoption, although present (Berrado et al., 2013; Niya et al., 2022), is mainly studied from the angle of individual perception (usefulness, risk, etc.) and rarely from the point of view of systemic or institutional constraints: payment infrastructures, regulatory framework, organisational culture, or financial education. Consequently, the role of the user may be overestimated, to the detriment of the other major obstacles to FinTech innovation in Morocco (World Bank, 2023). Another critical point is the lack of attention paid to impact assessment and the generalisation of results. The articles focus on technical feasibility (e.g. automated scoring systems in Bazzi et al., 2019) or the identification of challenges (Nach, 2024), but few of them propose longitudinal analyses, post-adoption performance measurements, or international benchmarks to situate Morocco in the MENA region or at global level (Findexable, 2022). This methodological shortcoming weakens the comparative scope and limits the transferability of the proposed solutions. Finally, although some studies address the collaborative dimension between banks and start-ups (Nach, 2024), institutional support, regulation and ecosystem integration often remain recommendations rather than empirical analyses based on robust data or the observation of real success stories. This reflects an incomplete maturation of the Moroccan academic sector in FinTech, which would benefit from comparative methodologies, partnerships with sector players and field studies to support the rapid evolution of the ecosystem.

| Authors | Title | Methodology | Key contribution |
|---|---|---|---|
| Chouraik (2024) | Enhancing cybersecurity in Moroccan banking: A strategic integration of AI, blockchain, and business intelligence | Technology integration framework<br><br>Based on AI, Blockchain technology and Business intelligence | -Identification of cyber security threats<br><br>-Proposition of integrated cyber security strategy |
| Bazzi et al. (2019) | Intelligent credit scoring system using knowledge management | develop an intelligent credit scoring system aimed at automating the credit granting process | Increased efficiency in credit processing |
| Nach (2024) | Navigating the FinTech Frontier in Morocco: A Delphi Study of Expert Perspectives | Delphi method<br><br>To recongnise challenges for an econosystem integrating fintech in Morocco | Highlight the need for a regulatory and collaborative environment between traditional banks and fintech startups, with a support for these stuturps |

| Niya et al. (2022) | Adoption of technological solution on fintechs using training engineering: case of health sector | Analyzes fintech useing M-wallet methods<br><br>Applied into Health sector. | Analyzes FinTech, InsurTech and Blockchain by specifyingthe M-wallet technology, applying it in the health sector, as a solution that will mainly be based on training engineering. |
|---|---|---|---|
| Berrado et al. ( 2013) | Using data mining techniques to investigate the factors influencing mobile payment adoption in Morocco | Technology Acceptance model (TAM)<br><br>Survey design | The ease of use, usefulness, risk perception and transaction fees affect Moroccans' intention to adopt mobile payment but with different degrees of impact. |

*Table 3: Key Moroccan Scientific Contributions to FinTech Solutions*
*(Source: Compiled by authors)*

## 6. MOROCCAN FINTECH: REGIONAL STANDING AND COMPARATIVE ANALYSIS WITHIN MENA

The Moroccan FinTech ecosystem, while demonstrating notable progress in recent years, occupies a distinctive yet evolving position within the broader MENA region. This section critically examines Morocco's achievements, comparative advantages, and remaining challenges in FinTech development relative to leading regional peers such as the UAE, Egypt, and Saudi Arabia. Table 4 highlights the diversity of national trajectories in FinTech and the adoption of artificial intelligence in the MENA region, and invites a critical reading of the factors that explain the relative positioning of each country. The first major difference concerns the level of maturity of the ecosystems. The United Arab Emirates (UAE) and Egypt appear to be major hubs, attracting talent, international capital and massive technological investment (DIFC, 2022; WEF, 2023). In contrast, Morocco and Tunisia are still in an emerging or nascent phase, with a limited number of start-ups, a concentration of sectors (payments, digital banking) and low international visibility (World Bank, 2023; Findexable, 2022). Saudi Arabia, on the other hand, is rapidly catching up, supported by ambitious public policies (Vision 2030). The adoption of AI varies greatly. The Emirates and Egypt are already developing advanced applications (wealth management, insurtech, robo-advisory, RegTech), while Morocco, Tunisia and Saudi Arabia are mostly at the pilot or sector-specific use stage. Morocco, for example, is still focusing on credit scoring, the fight against fraud and regulatory compliance, while other countries are beginning to tackle more complex issues such as mass customisation and advanced automation (El Amrani & Rowe, 2022 ; PwC, 2023). The table also shows that regulation and national strategy are decisive factors.

Countries that introduced robust regulatory sandboxes early on (UAE, Saudi Arabia) or legislation dedicated to FinTech (Egypt) are the ones where innovation is accelerating. In Morocco, although Bank Al-Maghrib's sandbox was a sign of openness, the AI guidelines are still under development and the ecosystem is waiting for greater clarification of standards (World Bank, 2023). Although Tunisia has launched its national AI strategy, it still suffers from low levels of investment and fragmentation of the sector. In terms of opportunities, all the countries are emphasising financial inclusion and the digitalisation of payments. However, Morocco and Tunisia still face major challenges: lack of venture capital, limited access to data, low digital maturity and digital divide (Findexable, 2022). In contrast, the UAE is capitalising on attracting international talent, massive investment in R&D and openness to global partnerships. Each country faces its own challenges: cyber security and consumer confidence in Saudi Arabia, informality and regulatory fragmentation in Egypt, privacy and ethics in the UAE, and, for Morocco, mainly the lack of talent, regulatory slowness and access to quality data. Tunisia, on the other hand, needs to catch up in terms of financing and developing its entrepreneurial ecosystem. Table 4 shows that although Morocco is making progress, it is still in the middle of the pack: better structured than Tunisia, but still a long way from the dynamism of the UAE or Egypt.

The ambition to accelerate will depend on the capacity to diversify applications, to strengthen training and the attractiveness of talent, to structure the financing ecosystem, and to adopt agile and incentive-based regulation. In short, convergence towards regional leadership means going beyond the logic of catching up to embrace a dynamic of proactive innovation, inspired by the best practices of MENA leaders but adapted to Morocco's specific characteristics.

| Country | FinTech Market Size / Maturity | AI Adoption in FinTech | Regulatory Framework | Key Opportunities | Key Challenges | Main References |
|---|---|---|---|---|---|---|
| **Morocco** | Emerging, ~50 active startups(as of 2023) | Early-stage pilots in payments, credit scoring, RegTech | Regulatory sandbox launched in 2019; AI guidelines under study | Financial inclusion, digitization of payments | Lack of talent, limited data access, regulatory delays | World Bank (2023); El Amrani & Rowe (2022) |
| **Egypt** | Leading MENA fintech hub; >150 startups | AI use in digital lending, anti-fraud, insurtech | FinTech Law (2022); AI strategy in progress | Young population, high mobile penetration | Informal economy, regulatory fragmentation | Startup Genome (2023); IMF (2023) |
| **UAE** | Mature, global hub (Dubai, Abu Dhabi); >200 firms | AI in wealth management, payments, RegTech | Proactive AI strategy (UAE 2031); strong regulatory sandboxes | FDI, international talent, tech investment | Cybersecurity, ethical concerns, data privacy | DIFC (2022); PwC (2023); WEF (2023) |

| Saudi Arabia | Rapidly growing; >80 fintechs (2023) | AI in Sharia-compliant finance, robo-advisory | Saudi Central Bank regulatory sandbox; National AI Strategy | Vision 2030 digitalization, government support | Consumer trust, data localization requirements | SAMA (2023); KPMG (2022); WEF (2023) |
|---|---|---|---|---|---|---|
| Tunisia | Nascent, <20 startups | Early exploration (e-KYC, microcredit) | Regulatory sandbox launched in 2020 | Financial inclusion, diaspora remittances | Limited VC funding, digital divide | Findexable (2022); World Bank (2022) |

*Table 4: Comparative Table: AI and FinTech Development in Selected MENA Countries*
*(Source: Compiled by authors)*

## 7. CONCLUSION

Over the past few years, Morocco has gradually established itself as an emerging player in the FinTech sector in the MENA region, but its positioning remains contrasted with the dynamics observed in regional hubs such as the United Arab Emirates, Egypt and Bahrain. While the Moroccan ecosystem stands out for the steady growth in the number of FinTech start-ups - mainly active in digital payment services, mobile banking and financial inclusion - it is still characterised by sector concentration and limited innovation compared with its regional peers (World Bank, 2023; Findexable, 2022). Compared with regional centres of excellence such as Dubai or Abu Dhabi, which have set up free zones dedicated to FinTech and attracted significant international investment, Morocco is lagging behind in terms of attractiveness, diversity of applications and development of high value-added solutions (Oxford Business Group, 2023). Whereas countries such as Egypt and the Emirates are capitalising on a large pool of data science talent and incentive-based public policies, the Moroccan ecosystem remains hampered by a lack of venture capital, limited AI capabilities and regulation that is still under construction (PwC, 2023). However, Morocco stands out positively for the rise of financial inclusion services (such as Inwi Money, CIH Bank digital platforms and Wafacash), which meet local needs in terms of bank penetration and access to payments for unbanked or underbanked populations. This is in line with the regional trend towards the digitalisation of payments, but falls short of the breakthroughs seen in the fields of insurtech, wealth management and RegTech in Saudi Arabia and the Emirates (Findexable, 2022).

From the point of view of the adoption of artificial intelligence, Moroccan initiatives remain mainly at the pilot stage: use of AI for credit scoring, the fight against fraud or the automation of KYC (PwC, 2023; Oxford Business Group, 2023). While these projects are promising, their generalisation and impact remain limited by the challenges of skills, access to data and funding. From a regulatory point of view, even if the introduction of a regulatory sandbox by Bank Al-Maghrib is a positive sign, the ecosystem suffers from a regulatory framework that is still under construction, sometimes perceived as unclear or too cautious by start-ups and foreign investors (World Bank, 2023). While this caution helps to limit certain systemic risks, it also has the effect of slowing down the implementation of innovative solutions and international collaboration, which are nevertheless decisive success factors in the regional competition. In short, Morocco currently occupies an intermediate position in MENA FinTech: it stands out for its dynamic financial inclusion and its efforts to experiment with AI, but it needs to speed up the diversification of its applications, strengthen the entrepreneurial ecosystem and develop more ambitious public policies if it is to compete with the regional leaders in the sector.

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# EXPLORING USER BEHAVIOR IN TIKTOK USAGE FOR EDUCATIONAL PURPOSES

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***ABSTRACT***

*Social media has become an integral part of modern life, with its user base growing significantly each year. TikTok, in particular, has dominated the digital landscape as the most downloaded app in 2024. Moreover, users spend a significant amount of time on social media, with teenagers being the most engaged users online. Despite concerns about the negative effects of excessive social media use, its presence in everyday life is undeniable. Efforts should focus on maximizing its positive impact—particularly in education—if its use in educational settings is feasible. TikTok has emerged as a potential tool for enhancing the learning experience by delivering course content in an engaging and effective manner. This study examines the habits, attitudes, and satisfaction of young users with TikTok as an educational platform. By analysing user perceptions, the research assesses the feasibility of integrating TikTok into formal learning environments. The findings offer valuable insights for educators and institutions, facilitating a better understanding of how students engage with social media for learning purposes. Moreover, this study contributes to the relatively underexplored field of social media's role in education, offering guidance for future academic and pedagogical strategies.*
***Keywords****: social media users, TikTok, education*

## 1. INTRODUCTION

Social media plays an important role in lots of people`s lives. Namely, social media as a contemporary phenomenon has many users and most of them spend many hours online. Moreover, the number of users constantly rise. In accordance to Statista (2025) the number of users increased year by year, such as for example there were 2.73 billion in 2017 and 5.17 billion in 2024 year. The trend is expected to remain the same, namely in accordance to Statista (2025) the number of users will reach 6.05 billion in 2028. Moreover, the number of social media users (5.22 billion) almost reach the number of internet users worldwide (5.52 billion) (Statista, 2025). Among many social media platforms, the most popular are Facebook (3.065 million users), Youtube (2,504), Instagram (2,000), Whatsapp (2,000) and TikTok (1,582) (Statista, 2025). It is also important to note that TikTok was the most downloaded application in 2024 year with 825.48 million of downloads, while Instagram (817.49), Facebook (597.87) and Whatsapp (564.33) stood behind it (Statista, 2025). Moreover, the role of social media in people`s lives can be realized if known that in 2024 on average, people spend about 143 minutes on social media every day (Soax, 2025) and teenagers spend even 4.8 hours per day on various social media (Gallup, 2025). And despite many recognized negative outcomes of social media and its heavy use, it should be accepted as a fact of modern life and efforts should be made to use it in a ways that achieve and maximize positive outcomes. One among positive outcomes of social media usage can be the improvement of the educational process and it was highlighted that TikTok can be seen as a potentially helpful tool in conveying course content in an impactful and engaging way for students (Ružić, 2024).

Beside this potential it is important to research how young TikTok users really use this media and what are their attitudes about the possibilities of use TikTok as a helpful educational tool. In accordance with the above, the main aim of this paper is to investigate users` attitudes, habits and satisfaction regarding the educational aspects of TikTok as a social media platform. The research results can be helpful for educational institutions and professors in better understanding pupils` and students` use of TikTok and potentially serve as a stimulus for its inclusion in the educational process. The study findings could also provide new insights in this still underexplored field of social media use for educational purposes.

## 2. THE USE OF TIKTOK FOR EDUCATIONAL PURPOSES: LITERATURE REVIEW

### 2.1. Applications of TikTok for educational purposes

TikTok is a social media platform launched in the Chinese market in 2016 (as Douyin) by the startup ByteDance, and internationally in 2017, following its acquisition of Musical.ly (under the name TikTok) (Ma & Hu, 2021; Meola, 2020). Despite facing numerous controversies and challenges, TikTok remains one of the most popular social media platforms today, with the highest viewership share among users aged 18 to 24 (41.7%) (Ružić, 2023). TikTok offers tools that are well-suited for creating educational videos, and the platform promotes the dissemination of such content. In May 2020, TikTok launched the LearnOnTikTok program, which featured educational videos intended to support learning during the COVID-19 lockdown (Fiallos, Fiallos, & Figueroa, 2021). The platform allows users to create and share short videos (15 to 180 seconds) that can be quickly and easily edited using a variety of effects and sounds from TikTok's media library (Kusumastuti & Ningtyas Ningrum, 2022; Hutchinson, 2020). Educational challenges and trends on TikTok have also gained popularity. Teachers design challenges that encourage students to engage creatively with educational content.

These challenges can cover a wide range of topics, including scientific experiments, mathematical puzzles, historical reenactments, and artistic projects. By participating in such challenges, students actively learn and apply knowledge in a dynamic and enjoyable way (Fardouly et al., 2018). Ružić (2024) emphasized in his paper that the impact of social media on education can be significant, and previous studies have demonstrated numerous successful examples of its use in educational settings across various disciplines. TikTok has shown positive effects in both dissemination and content creation in areas such as medicine, language teaching, literacy engagement, chemistry, mathematics, physics, drawing, cooking, crafting, science, origami-making, sports science (body movement), dance instruction, STEM fields, social sciences (law and education), the dissemination of scientific knowledge, biology (often featuring animals and plant life), psychology, and communication courses. Furthermore, Ružić (2024) highlighted several positive outcomes of using TikTok in education, including enhanced student learning experiences, greater commitment, involvement, and contribution, a more learner-centered approach, increased creativity, improved communication, and overall academic performance. In addition, both Ružić (2024) and Fiallos, Fiallos, & Figueroa (2021) noted that using TikTok for educational purposes positively affects students' motivation, satisfaction, engagement, and curiosity. The platform can also support the development of high-quality e-learning content that enhances the pedagogical process through nano-learning principles (Khlaif & Salha, 2021). Yelamos-Guerra, Garcia-Gamez, and Moreno-Ortiz (2022), in their study conducted among students, concluded that TikTok is perceived as an innovative educational tool. It is highly integrated with new technologies and regarded as an effective way to promote active learning, thereby improving understanding in an engaging and motivating environment.

**2.2. Most popular hashtags used for the goal of learning**

As previously mentioned, in May 2020, TikTok launched the LearnOnTikTok program, consisting of educational videos aimed at facilitating learning during the COVID-19 pandemic (Fiallos, Fiallos, & Figueroa, 2021). The creators of these videos include experts from various disciplines, students, and other users who shared their knowledge with the platform's audience. Videos tagged with the hashtag #learnontiktok cover a wide range of topics—from chemistry experiments, cooking recipes, and health advice to language learning and origami making—all created by users themselves (Fiallos et al., 2021). Previous studies have confirmed that the use of short video lectures increases participant satisfaction (Hsin, 2013). The hashtag #learnontiktok reflects a growing trend of educational content on the platform. Users create short videos that deliver informative and educational content on diverse topics. From science and history to language learning and practical skills, TikTok serves as a medium for sharing bite-sized educational content in an engaging and accessible format. The hashtag enables users to easily discover and access educational resources, expanding their knowledge in a fun and enjoyable way. An analysis of the hashtags #booktok, #learnontiktok, and #studytok reveals the significant use of TikTok for educational purposes. These hashtags act as markers for content related to learning, studying, and books on the platform. The hashtag #booktok points to a successful community of TikTok users interested in literature, with 70.7 billion views as of August 2022. It is commonly used to share book recommendations, reviews, reading lists, and literary discussions. Users employ this hashtag to express their love for reading, promote reading culture, engage with fellow book enthusiasts, and discover new titles and authors. By using this hashtag, TikTok users not only promote reading and literature but also help reshape the perception of reading as a "cool" activity, ultimately influencing book sales as well (Ružić, 2023). Similarly, the hashtag #studytok emphasizes TikTok's role as a platform for sharing learning tips, study techniques, and academic motivation. Users post study routines, organizational strategies, note-taking methods, and productivity hacks to inspire and support fellow students. This hashtag fosters a sense of community among TikTok users who are actively engaged in their educational pursuits and striving to improve their learning skills and academic success. The prevalence of these educational hashtags highlights TikTok's potential as a supplementary educational tool. By leveraging the platform's visual and interactive features, both creators and users can transfer knowledge, spark intellectual curiosity, and promote an environment of collaborative learning. The widespread use of hashtags such as #booktok, #learnontiktok, and #studytok underscores TikTok's emergence as a platform for educational content and discourse. TikTok's unique format and user-driven content creation offer opportunities for learning, knowledge-sharing, and the growth of education-focused communities. As educational content on TikTok continues to expand, it is essential that users approach it with a critical mindset and actively seek reliable sources to ensure a well-rounded learning experience.

**3. Investigation of usage habits and user satisfaction with educational content on TikTok**
**3.1. Methodology**

The aim of the conducted research was to identify the specific characteristics of using the social media platform TikTok for educational purposes. Specifically, the study sought to determine the attitudes, habits, and satisfaction levels of Croatian users regarding the educational aspects of this social media platform. To achieve the research objectives, the authors developed a survey questionnaire consisting of a total of 17 questions. The research sample comprised TikTok users to whom the survey was distributed electronically. The study was conducted from June 24 to June 30, 2023, using a Google Forms online questionnaire. A total of 92 responses were collected.

The sample consisted of 77.2% female and 22.8% male respondents. The majority of participants had completed secondary education (36.7%), followed by 34.4% with a university degree, 27.8% with a college degree, and 1.1% holding a doctoral degree. Most respondents were between the ages of 21 and 30 (81.1%), followed by 13.3% aged 20 or younger, 3.3% aged between 31 and 40, and 2.2% aged between 41 and 50.

## 2.4. Research results analysis

In the observed sample, the majority of respondents use the TikTok application (90.2%) (Figure 1).
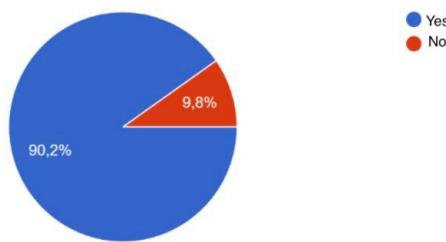


*Figure 1. Use of the TikTok Application*
*(Source: authors)*

Furthermore, the largest number of respondents use the application daily (63%). Several times a week, 16.3% of respondents use the application, while 10.9% use it rarely. 1% of respondents use it once a week, and 8.7% never use it (Figure 2).
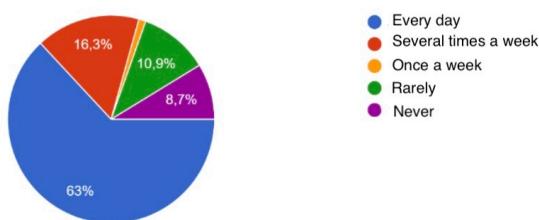


*Figure 2. Frequency of Application Use*
*(Source: authors)*

The research showed that 47.5% of respondents are satisfied or extremely satisfied with the user experience on TikTok. Furthermore, 40.3% of respondents are neither satisfied nor dissatisfied, while 5.3% of respondents are dissatisfied or extremely dissatisfied (Figure 3).
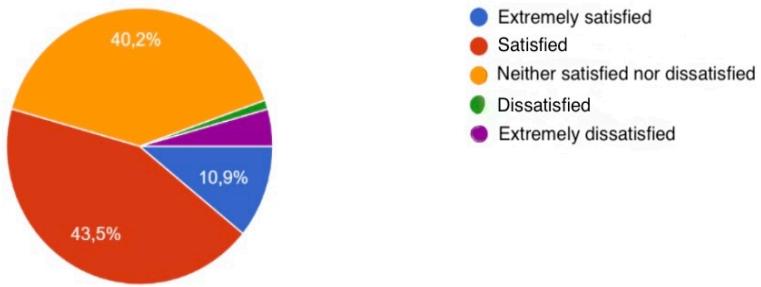
*Figure 3. Overall User Satisfaction with the TikTok Experience*
*(Source: authors)*

Among the offered functionalities on TikTok, the majority of respondents watch videos (93.5%), 55.4% share videos with friends, 12% create their own videos, and 9.8% like and comment on videos posted by other users (Figure 4).
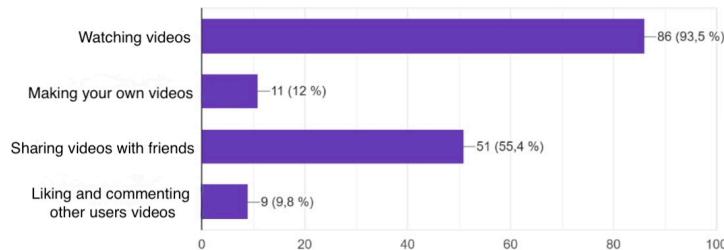


*Figure 4. Most Frequently Used TikTok Features*
*(Source: authors)*

In response to the question about the types of educational content TikTok users engage with (participants were allowed to select two options), the largest number of respondents indicated that they use study and productivity tips (42.4%), creative project tutorials (40.2%), follow scientific experiments (22.8%), and language lessons (15.25%) via TikTok (Figure 5).

*Figure following on the next page*

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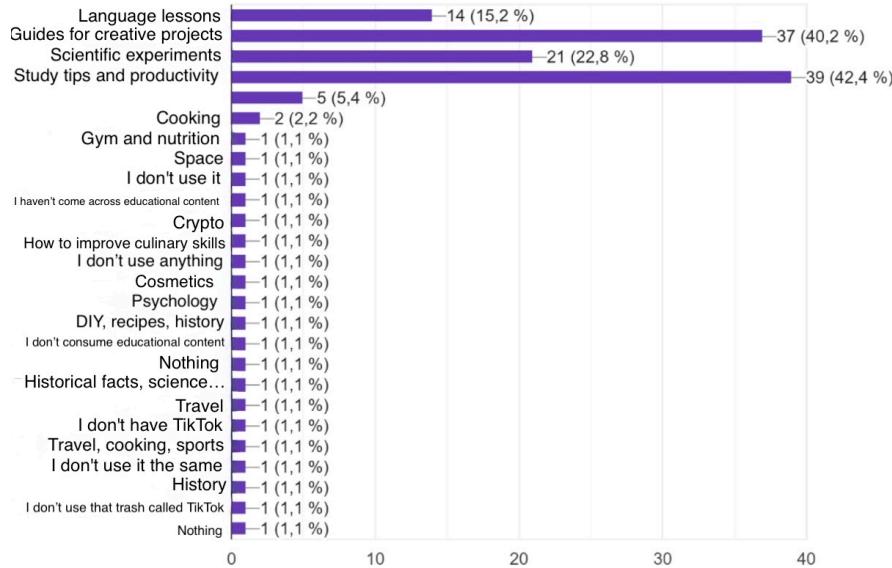
*Figure 5. Types of Educational Content Consumed by Respondents*
*(Source: authors)*

In response to the question about the frequency of consuming educational content on TikTok (educational content is understood as content that can be applied in daily life, with general knowledge as an example), the majority of respondents indicated occasionally (42.4%), while 18.5% of respondents indicated very frequently. Furthermore, 17.4% of respondents rarely watch educational content, and 16.3% never watch it. 5.4% of respondents are not aware of the possibility of using TikTok for educational purposes (Figure 6).



*Figure 6. How Often Do You Use TikTok for Educational Purposes*
*(Source: authors)*

In response to the question about their own perception of TikTok's usefulness as a learning tool, 52.2% of respondents stated that they don't know or are unsure whether it is a useful tool for learning. Furthermore, 33.7% of respondents believe TikTok is a useful learning tool, while 14.1% of respondents believe it is not useful (Figure 7).
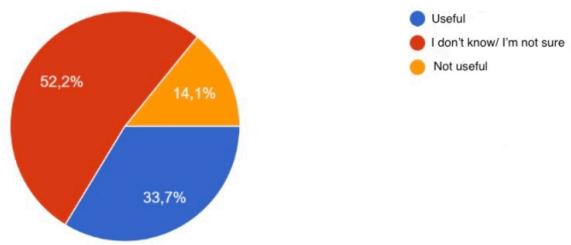
*Figure 7. Do You Consider TikTok a Useful Tool for Learning*
*(Source: authors)*

In response to the question about the advantages of using the TikTok app for educational purposes, respondents were allowed to select up to two options. The majority of responses highlighted the availability of diverse educational content (54.3%) and inspiration for creativity and expression (53.3%). 35.9% of respondents cited the quick and easy acquisition of information, while 39.1% selected the visual representation of material and interactivity and communication (Figure 8).
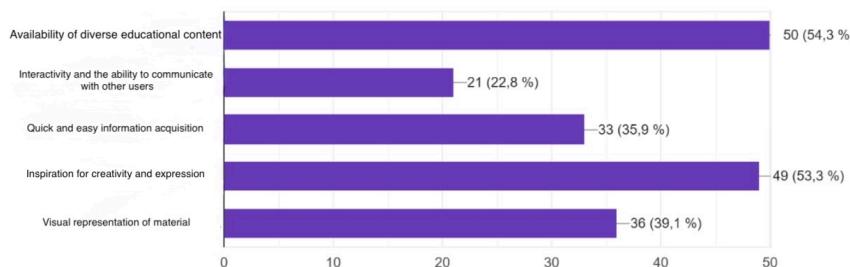


*Figure 8. What Are the Advantages of Using TikTok for Educational Purposes*
*(Source: authors)*

Regarding the disadvantages of using the TikTok app for educational purposes, respondents were allowed to choose two options. The majority of respondents believe that unreliable information and lack of fact-checking are the biggest drawbacks (67.4% of responses), followed by distractions and the possibility of losing focus on non-educational content (63%). Additionally, 34.8% of responses cited difficulties in finding high-quality educational content, and the short duration of videos, which limits deeper understanding of the topic (Figure 9).

*Figure following on the next page*
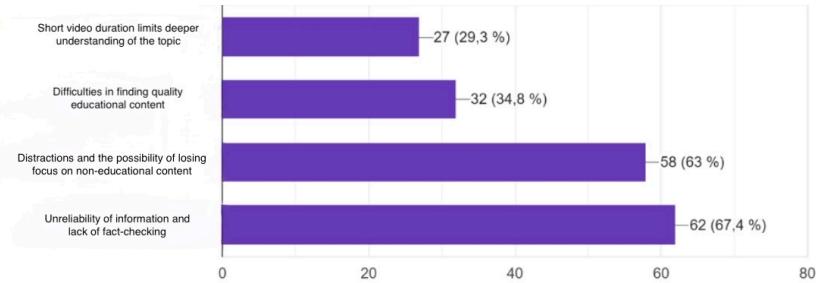
*Figure 9. Disadvantages of Using TikTok for Educational Purposes*
*(Source: authors)*

In the following question regarding respondents' opinions on the need for TikTok to offer more tools or features for educational purposes, the majority (59.8%) stated that they believe TikTok should offer more tools and features, but that these should be well-verified and developed. Furthermore, 21.7% of respondents agreed with this, while 10.7% were unsure. 8% of respondents believe the current features are sufficient (Figure 10).
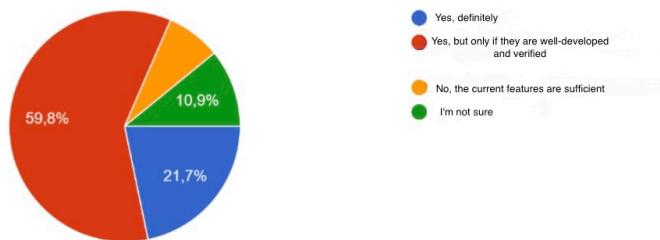


*Figure 10. Opinions about tools and features offered on TikTok*
*(Source: authors)*

In the following question, respondents were asked to rate the quality of educational content on TikTok. The majority of respondents, 47.8%, answered that they would give an average rating, while 35.9% would give a good rating, and 13% would rate the quality of educational content as poor. Only 3.3% of respondents would give an excellent rating (Figure 11).
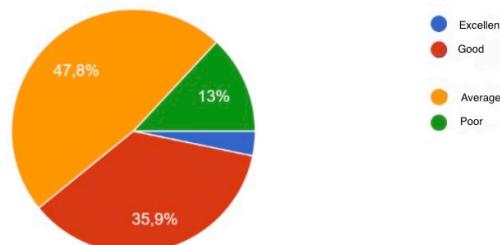


*Figure 11. Ratings of the quality of content on TikTok*
*(Source: authors)*

In response to the question of whether they have ever participated in challenges or trends on TikTok with an educational character, the majority of respondents answered that they have never participated (75%). Furthermore, 9.8% of respondents are not aware of such challenges or trends, and 9.8% have rarely participated in challenges or trends, 4% have occasionally participated, and only 1% of respondents frequently participate (Figure 12).
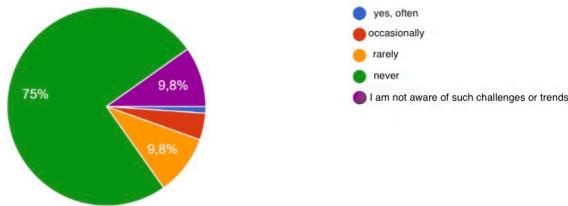


*Figure 12. Participation in Challenges or Trends on TikTok with an Educational Character (Source: authors)*

In response to the question about the frequency of using TikTok as a source of information for school, studies, or work, the majority of respondents stated that they never use it for these purposes (41.3%). Additionally, 37% of respondents rarely use TikTok as a source of information for education. However, 8.5% of respondents use TikTok occasionally as a source of information, and 4% use it very frequently as a source of information for studies, work, or school (Figure 13).
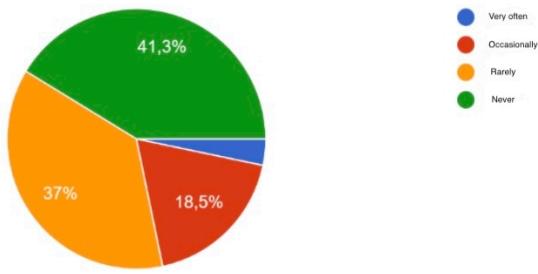


*Figure 13. Frequency of Using TikTok as a Source of Information for School/Studies/Work (Source: authors)*

In response to the very specific question of whether respondents would recommend TikTok for use in the education system, particularly for visually presenting material or capturing students' attention, the majority of respondents (47.8%) believe that there are better tools for education and would not use TikTok for educational purposes. Furthermore, 38% of respondents answered that they might recommend its use depending on the needs and interests of users. Only 9.8% of respondents were unsure whether they would recommend TikTok for use in the education system, while 4% would definitely recommend using the TikTok app (Figure 14).
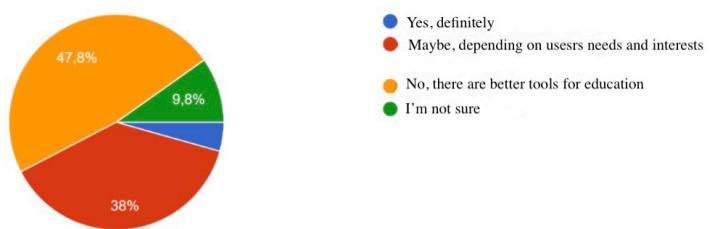
*Figure 14. Recommendations of TikTok use in education*
*(Source: authors)*

## 3. DISCUSSION

The results of the research on both the usage and the potential of using TikTok for educational purposes reveal several interesting insights. Among the surveyed participants, the majority use TikTok regularly—most often on a daily basis—and report satisfaction with their user experience. This is expected, considering that TikTok ranks fourth among social media platforms in terms of the number of users. However, this data actually highlights the platform's relevance and widespread adoption, indicating its potential to be used for positive purposes, including as a supplementary tool for disseminating knowledge to a broad audience. There is also potential to deliver knowledge in a way that is appropriate and preferred by a large number of users. The official user demographics indicate that younger age groups dominate TikTok's user base—a finding confirmed by this study. This further points to the platform's potential for educational use among individuals in school or university, even though they often perceive it mainly as a platform for entertainment and creative expression. When it comes to using the platform specifically for educational purposes, most respondents recognize TikTok as a source of educational content. However, a significant number of users rarely or never use it for educational purposes—possibly due to a lack of available content, or because some respondents are not currently engaged in any formal education process. In terms of educational topics, users most often search for videos that offer study tips and productivity advice. The short video format appears to offer certain advantages for knowledge transfer. Users appreciate the diversity of educational content, the inspiration it provides for creativity and self-expression, and the benefits of visually presented materials. Additionally, quick absorption of information—enabled by the short video format—is seen as a major advantage. Unfortunately, social media platforms are often associated with several drawbacks. The respondents highlighted the following key disadvantages of using TikTok for education: unreliable information, distraction from non-educational content, and difficulties in finding quality educational materials. Opinions on the usefulness of TikTok for education were mixed. Some respondents were uncertain or believed there was insufficient data to form a firm opinion, while a considerable number thought TikTok could serve as a useful learning tool. A smaller portion of respondents held a contrary view. Currently, users rate the quality of educational content on TikTok as average. Most do not use TikTok as a source of information for school or work, nor would they recommend it as a tool for educational purposes. The research indicates that users do see a certain potential for using TikTok in education, but at the same time, there is skepticism and hesitation. This study, along with future related research, points to the potential of TikTok as a powerful tool that educators (students, teachers, etc.) can use to align teaching—and even science popularization—with the current habits and preferences of younger generations, based on the principles of micro- and nano-learning.

Aligning user preferences with teaching methods could lead to positive results in the educational process, utilizing social media—with all its potential downsides—for positive educational purposes. The findings may also be useful to educational institutions seeking to improve user satisfaction. Given the under-researched nature of this topic, the study contributes valuable new insights

## 3. CONCLUSION

TikTok has rapidly established itself as a global phenomenon, transforming the way users create, view, and share short videos. Its intuitive interface, advanced creative tools, and intelligent content recommendation system based on artificial intelligence and machine learning have enabled the platform to attract hundreds of millions of active users worldwide.

A key factor in TikTok's success is its ability to allow any user to become a creator without the need for expensive equipment or professional production, which has encouraged content diversity and innovation, with a focus on spontaneous videos. The algorithm, by analyzing individual behavior and interests, continuously adapts the feed, resulting in longer engagement within the app and a higher likelihood of reuse. The platform holds special significance for Generation Z, who find a space for self-expression, creative experimentation, and social connection on TikTok, as well as for social activism and raising awareness about important issues. Additionally, the platform provides creative educators with a space for interaction, communication, and knowledge sharing with young TikTok users, many of whom spend long periods of time on the platform. At the same time, the rapid popularity brings challenges related to privacy protection, content moderation, and potential exposure to inappropriate materials. To mitigate these risks, TikTok has tightened posting guidelines, improved privacy options, and introduced reporting systems for unwanted content. Like other social networks, TikTok causes many negative consequences for society, but the very existence of the platform should encourage innovative early adopters among educators to leverage the platform and video format for effective, personalized, and tailored knowledge transfer. This is a method that is acceptable and preferred by younger generations. Despite the challenges, the number of TikTok users continues to grow, which should prompt further research into its impact on users' mental health, the long-term effects of usage on cognitive abilities, and similar studies that should ultimately result in guidelines for enhancing the positive effects of the platform and minimizing its negative aspects.

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# COST MANAGEMENT IN HOTEL MANAGEMENT

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***ABSTRACT***

*In this paper the focus is on cost management within the context of hotel management, with a particular emphasis on cost analysis in Valamar d.d. The aim of the thesis is to explore how costs are managed in the hotel sector, to analyze the development of cost management methods, and to identify the specific characteristics of costs in hotel operations. This thesis will use a combination of descriptive analysis, document analysis, and data from financial statements to investigate the historical development of cost management, cost categorization, cost measurement and analysis methodologies, as well as cost forecasting methods. The data sources will include relevant literature, financial statements of Valamar d.d., and other relevant documentation. Given the importance of timely cost management for business performance, this thesis will examine in greater detail the methods of cost management within the hotel industry, which is a crucial factor for the tourism sector. Considering the significance of tourism in the Republic of Croatia and its contribution to the Croatian GDP, cost management within hotel management is a necessary subject of more detailed study.*

***Keywords****: hotel industry, cost analysis, operational analysis, tourism, hotel operations*

## 1. SPECIFIC CHARACTERISTICS OF COSTS IN HOTEL MANAGEMENT

Costs in the hotel industry differ from those in other industries due to their complexity, variability, and extreme sensitivity to seasonal and market fluctuations. Unlike manufacturing companies, the service industry is characterized by the cost of lost opportunities, as the service of a hotel stay cannot be stored. Therefore, hotels lose revenue opportunities whenever their capacities are not fully utilized, even though they are businesses with multiple revenue streams, such as income from accommodation, food services, additional services like renting event and conference rooms, wellness treatments, access to hotel pools, and more. These multiple revenue sources, as a byproduct, also lead to various categories of costs that are challenging to classify as direct or indirect. To manage such costs effectively, special methods are required to enable timely managerial decision-making and maintain profitability. The hotel industry is known for its high proportion of fixed costs. Given their business operations, hotels usually own or lease a large number of buildings that require regular maintenance to uphold quality standards and reduce the impact of depreciation on asset value. Hotels that operate year-round incur equipment maintenance costs and permanent staff salaries, which remain nearly unchanged regardless of occupancy rates (Drury, 2020, pp. 112–114). This implies that even a slight decline in occupancy can permanently affect profitability, highlighting the need for forecasting and cost simulation. Variable costs in the hotel industry are directly dependent on the number of guests and the usage of additional hotel services. These include costs such as food and beverages, cleaning services, and consumable supplies.

Mixed costs are also very important in the hotel industry, and understanding their behavior is crucial for business operations (Garrison et al., 2015, pp. 74–77). Hotel managers often use regression models and high-low analysis to separate mixed costs into their components for more accurate future cost planning. Another key characteristic of hotel costs is the presence of joint revenues and expenses. This typically refers to package deals that include accommodation, breakfast, and access to wellness facilities. For such packages, it is necessary to allocate joint costs and revenues to individual services. Collini analyzes this challenge and proposes the use of the ABC (Activity-Based Costing) method as a solution to more accurately allocate costs based on actual resource consumption (Collini, 2006, pp. 165–174). To ensure real-time cost monitoring, hotel management often uses ERP systems, which allow for the integration of different data groups—such as financial, HR, and operational costs—and enable more accurate allocation of indirect costs and performance management across departments (Drury, 2020, pp. 222–225). External factors, including changes in tourism trends, regulatory changes, and competitor behavior, significantly affect cost dynamics. Dobbelstein and Brehm (2012) emphasize the importance of forecasting changes in cost structure and the role of human resources as a critical success factor (Dobbelstein and Brehm, 2012, pp. 10582–10584). Since service quality directly impacts guest satisfaction and return rates, it is necessary to keep employees motivated, which brings about training and incentive costs. Dimou, Archer, and Chen (2003) further highlight the importance of including transaction costs in profitability analyses when expanding hotel chains or entering new markets (Dimou, Archer, and Chen, 2003, p. 148). Ignoring hidden costs in standard financial analyses can be detrimental to long-term success. It can be concluded that the specific nature of costs in hotel management stems from the complexity of the service-based business, pronounced seasonality, and a high degree of uncertainty. Proper management of such costs requires a strategic approach that emphasizes discipline, service quality, and business flexibility. When analyzing the internal account structure of hotel companies, which shows that just under half of respondents (46%) include accounts for tracking quality-related costs in a chart of accounts based on USALI standards, the professional experience of management emerges as a key success factor. Such costs are most commonly tracked at the cost center level (30%), responsibility centers (18%), products and services (6%), and processes and activities (3%) (Ribarić Čučković, 2016, pp. 94–95).

## 1.1. Analysis of the Hotel Industry Environment

Due to the dynamic and competitive nature of the hotel industry, effective cost management and strategic decision-making require a thorough analysis of the environment and the position of the observed company in the market. In addition to internal cost control, successful hotel companies must understand the impact of external factors, competitive forces, and their own position within the industry.

To gain a comprehensive picture of the challenges and opportunities faced by a hotel company, various strategic analytical tools are used. Each tool provides insights into different aspects of business operations:
1) PESTLE analysis helps in understanding the broader political, economic, social, technological, legal, and environmental environment.
2) Industry life cycle analysis enables the identification of the development stage of the hotel industry (growth, maturity, decline) and the adjustment of business strategies accordingly.
3) Porter's Five Forces analysis examines competitive dynamics and the bargaining power of buyers and suppliers, threats from substitute products, and new market entrants.
4) Strategic group analysis allows positioning of a hotel relative to competitors and similar companies within a market segment.

All of these methods are discussed below with an emphasis on their application in the context of the hotel industry, providing a foundation for informed and sustainable strategic decision-making and further cost analysis.

## 1) PESTLE Analysis

PESTLE analysis examines the external environment of the company. Its importance is particularly evident in the hotel industry because external factors significantly influence hotel operations and business performance. PESTLE analysis considers the macroeconomic environment across six areas: political, economic, sociocultural, technological, legal, and environmental. Its application enables managers to identify threats and opportunities in a timely manner and align the company's business model with the external environment (Morrison, 2018, pp. 61–66). In this analysis, Valamar Riviera d.d. will be compared with its competitors Liburnia Riviera Hotels d.d., Solaris d.d., and Arena Hospitality Group d.d.

### 1.1) Political Factors

Political stability and tax policies influence the stability of revenue in the hotel industry. Changes in the legal framework—such as stricter conditions for hiring seasonal or foreign workers—can limit the flexibility of hotels during the tourist season and affect their operations and income. For example, if legal constraints prevent a hotel from hiring as many foreign workers as planned, it must find replacements on the domestic labor market, where it must compete with other hotels to attract employees—often by offering better working conditions, including higher wages than those typically paid to foreign workers. All the hotels in this comparison are equally affected by political factors, making this the category over which they have the least control.

### 1.2) Economic Factors

Economic indicators such as the unemployment rate and inflation rate affect the purchasing power of potential guests. During periods of inflation—characterized by rising prices of goods and services—people tend to behave more frugally and reduce the amount of money spent on vacations. This results in fewer bookings and a reduced number of guests choosing to stay in a hotel, especially when more affordable alternatives are available. For this reason, hotels must closely monitor price trends in the market in order to adjust their accommodation and service pricing accordingly.

### 1.3) Social Factors

To maintain stable operations, hotels must continuously adapt to changes in guests' lifestyles in order to meet their expectations. For example, guests today would not be satisfied to find a black-and-white television in their room, as they might have been in the 1940s. Modern guests expect a certain quality standard for the price they pay per night, which increases hotel costs. Given the large number of platforms where guests can compare accommodation features, if a particular hotel does not meet their expectations, they will likely choose a competitor. Valamar's offering includes rooms equipped in line with contemporary standards, and their website provides photos of individual rooms to give potential guests a clear picture of what to expect should they choose to stay at one of Valamar Riviera d.d.'s hotels.

### 1.4) Technological Factors

Investment in digitalization and a strong online presence significantly influences a hotel's likelihood of being chosen as a place to stay. Guests tend to trust hotels that have their own websites where they advertise their services, facilities, and offer online booking. Features like online check-in and dynamic pricing help hotels remain competitive.

Replacing traditional keys with key cards can even reduce operational costs if the cards are linked to electricity usage—lights and appliances automatically turn off when the card is removed from its holder. All the analyzed hotels have their own websites with service overviews and online booking options, so in this regard, Valamar Riviera d.d. does not particularly stand out among its competitors.

## 1.5) Legal Factors

All analyzed hotels are equally subject to the legal framework and must comply with regulations to avoid financial penalties. They are all required to follow current safety regulations in their operations, uphold consumer rights, and invest in the protection of personal data, given that they handle a significant amount of sensitive guest information due to the nature of their business.

## 1.6) Environmental Factors

Environmental considerations and long-term sustainability are important to environmentally conscious guests. Hotels that actively contribute to positive environmental changes will leave a favorable impression. Valamar Riviera d.d. includes an environmental analysis in its annual financial reports, demonstrating its commitment to sustainability.

## 2) **Industry Life Cycle Analysis**

The industry life cycle is divided into three phases: the emergence phase, the maturity phase, and the decline phase.

## 2.1) Industry Emergence Phase

Valamar d.d. was one of the first hotel chains in Croatia. Its operations on the Croatian market began in 1910 with the opening of Hotel Riviera, after which the group was named. The characteristics of this phase include market positioning, establishing quality standards, and expanding the range of services. Observing the historical development of Valamar Riviera d.d., it can be concluded that the company managed this phase of the industry exceptionally well.

## 2.2) Industry Maturity Phase

Valamar Riviera d.d. has been operating in the Croatian market for over 70 years and is currently in the maturity phase of the industry. Due to the number of competitors in this phase, the main focus is on optimizing operations and maintaining competitive performance. As Valamar consistently ranks among the leading companies in the hotel industry year after year, it can be concluded that it is managing the challenges of this industry phase very effectively.

## 2.3) Industry Decline Phase

The arrival of the coronavirus pandemic presented an unexpected challenge for all hotel groups. Many hotels were forced to shut down due to business disruptions. Valamar Riviera d.d. managed to successfully handle the revenue decline, operational restrictions (such as the mandated minimum physical distance), increased costs due to stricter hygiene measures, and reduced occupancy levels. As the decline phase of an industry is characterized by reduced revenues, economic and health crises, and natural disasters, it can be said that, based on how Valamar navigated the global pandemic while maintaining service quality, Valamar d.d. is far from entering the decline phase—this also applies to its main competitors.

### 3) Porter's Five Forces Analysis

The Porter's Five Forces model was developed by Michael Porter to analyze the competitive forces within an industry from the perspective of industrial organization (Kingsnorth, 2019, pp. 12–19). Porter's forces are divided into those representing horizontal competition and vertical competition, as shown in Figure 1.
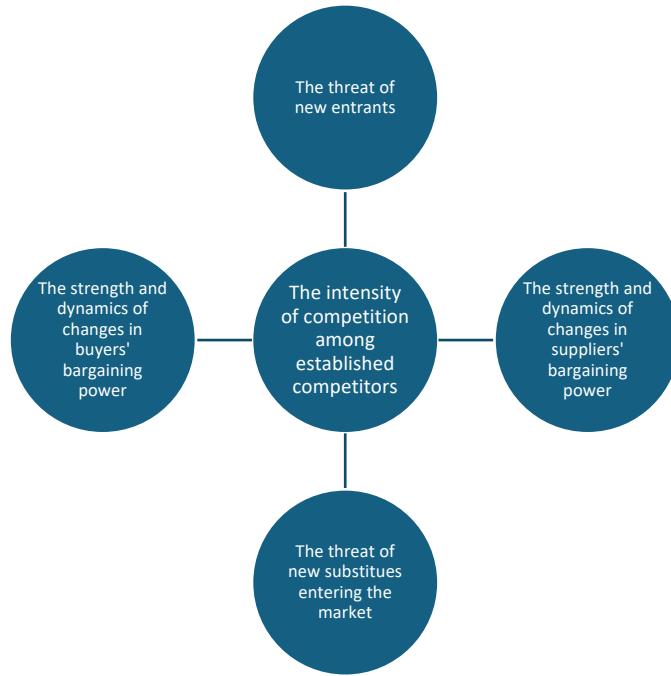


*Figure 1 Porter's Five Forces*
*Source: Kingsnorth, 2019, p. 12.*

Any change in one of the five forces can affect a company's market position, but not all forces have the same impact on the business.

### 3.1) Intensity of Rivalry Among Established Competitors

Established competitors pose the greatest threat in terms of shifts in market power for a hotel. All companies in this category have well-established processes, a stable market presence, competitive marketing budgets, and offer similar services. Valamar d.d.'s main competitors include Liburnia Hospitality Group d.d., Arena Hospitality Group d.d., and Solaris d.d. Of these, only Arena Hospitality Group d.d., alongside Valamar, owns hotels abroad. Their properties are located in Nuremberg, Budapest, Belgrade, Cologne, Nassfeld, and four hotels in Berlin. Valamar, on the other hand, owns just one hotel outside Croatia, located in Obertauern, Austria, placing it at a competitive disadvantage. With fewer international locations, brand recognition is reduced, which directly affects the number of returning guests who may have stayed in a Valamar hotel before and wish to experience other locations. Still, Valamar holds a stronger competitive position compared to the other two competitors. Solaris d.d. operates hotels in only three Croatian cities—Zagreb, Šibenik, and Opatija—while Liburnia's hotels are concentrated solely in Istria, making it the competitor with the smallest geographical coverage. Therefore, the strength of this competitive force is moderate to strong.

### 3.2) Threat of New Entrants

The threat of new entrants is relatively low for Valamar d.d. Entering the hotel market requires significant capital investment, which often takes years to generate a return on investment (ROI), thereby minimizing any potential short-term profits for newcomers.

Beyond the cost of opening a hotel, large funds must be invested in marketing, employee training, salaries, and brand building, none of which guarantee success. A new hotel without a solid market reputation is vulnerable to negative reviews, which could impact guest flow and ultimately affect business performance. A noticeable competitive threat would arise only if a globally recognized hotel chain decided to open a property on the Croatian coast, as such brands already possess a strong reputation and loyal customer base. Therefore, the strength of this force is weak to moderate.

## 3.3) Threat of Substitutes

One of the emerging challenges in the hotel industry is the rise of the sharing economy model, which shifts the balance between fixed and variable costs in the sector. Platforms such as Airbnb reduce capital expenditures and increase operational flexibility, putting pressure on the traditional hotel business model (Akbar & Tracogna, 2018, pp. 92–94). These platforms offer personalized experiences and a close relationship between host and guest, something hotel chains like Valamar d.d. struggle to provide due to the scale of their operations. It is difficult for large hotels to tailor services to every individual guest's needs, especially when those needs exceed the scope of services offered by Valamar. Additionally, Airbnb hosts can respond much faster to market changes, adjusting prices and services more quickly than large hotel chains. However, unlike individual Airbnb hosts, large hotel groups like Valamar d.d. benefit from economies of scale, which allow them to compete using pricing strategies, frequent promotions, and lower prices to attract guests. As a result, substitute services have a moderate impact on Valamar's business, less so than they would on an individual property owner listing on Airbnb. Therefore, the strength of this force is moderate.

## 3.4) Bargaining Power of Buyers

Given the widespread availability of hotel reviews and comparison platforms, every company in the hotel industry must constantly manage its reputation, monitor guest satisfaction, and stay ahead of its competitors. To reach a broad customer base, Valamar d.d. offers a diverse range of accommodation options. These differ not only in room size and amenities, but also in room orientation (e.g., sea view rooms are priced higher than those facing a parking lot), inclusion of meals (bed & breakfast, half board, all-inclusive), and additional services such as wellness, gyms, pools, and conference rooms. Due to its strong market position, the bargaining power of buyers is moderate for Valamar Riviera d.d.

## 3.5) Bargaining Power of Suppliers

Guest satisfaction is directly tied to the quality of food, comfort and cleanliness of accommodations, and service level. To maintain these standards, a hotel must rely on a dependable network of suppliers providing high-quality goods. The more suppliers a hotel has for a particular product, the lower the bargaining power of each individual supplier. However, hotels often prefer to work with trusted and consistent suppliers to ensure uniform quality, which increases the suppliers' power. Since the quality of supplies directly impacts the guest experience, hotels are often willing to pay more for reliable and high-quality goods. Therefore, the strength of this force is moderate to strong.

## 4) Strategic Group Analysis

According to Dimou, Archer, and Chen (2003), the choice of corporate development strategy in the hospitality sector is strongly influenced by the ownership structure and the alignment of interests between managers and owners. This relationship directly affects operational costs and profitability.

|  | Valamar Riviera d.d. | Liburnia Riviera Hoteli d.d. | Arena Hospitality Group d.d. |
|---|---|---|---|
| Total assets | 782.422.702 | 119.959.481 | 395.870.000 |
| Number of employees | 3799 | 831 | 1145 |
| Total revenue | 420.253.776 | 64.351.642 | 142.300.000 |

*Table 1 Indicators in 2024 (in EUR)*
*Source: compiled by the author based on the annual financial statements of the selected companies for the 2023 business year*

Solaris d.d. is not included in the indicator analysis because their annual financial report for 2024 was not published at the time of writing this paper. From Table 1, it can be concluded that the main competitor of Valamar Riviera d.d. on the market is Arena Hospitality Group d.d. Valamar d.d. achieves the highest total revenues among all analyzed companies (Arena Hospitality Group d.d. generates almost three times less revenue), has by far the largest number of employees, and the value of its assets is nearly twice as high as that of Arena Hospitality Group d.d.

|  | Valamar Riviera d.d. | Solaris d.d. | Liburnia Riviera Hoteli d.d. | Arena Hospitality Group d.d. |
|---|---|---|---|---|
| 2020 | 92,494,760.50 € | 15,131,491.14 € | 20,786,000.00 € | 22,254,000.00 € |
| 2021 | 223,268,051.00 € | 40,227,963.77 € | 33,087,796.14 € | 61,145,397.84 € |
| 2022 | 332,091,196.00 € | 56,090,699.00 € | 50,978,830.71 € | 109,536,133.78 € |
| 2023 | 375,406,296.00 € | 55,629,503.00 € | 58,944,076.00 € | 126,500,000.00 € |
| 2024 | 420,253,776.00 € |  | 64,351,642.00 € | 142,300,000.00 € |

*Table 2 Total Revenues. Source: Author's elaboration based on data from the annual financial reports of selected companies for the fiscal years 2020–2024.*
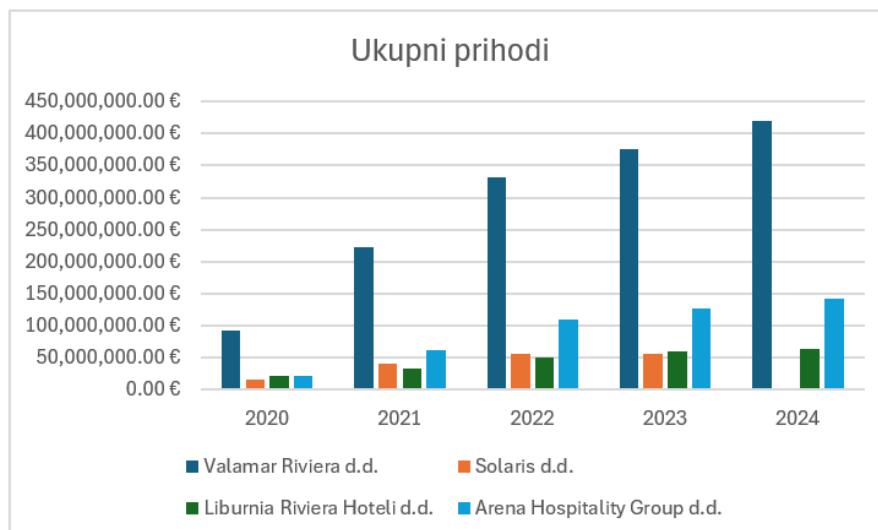


*Chart 1 Total Revenues. Source: Author's elaboration based on data from the annual financial reports of selected companies for the fiscal years 2020–2024.*

In Table 2 and Chart 1, total revenues from 2020 to 2024 are presented (with the exception of Solaris d.d., for which data is only available for the period 2020–2023). A clear upward trend in total revenues can be observed both for Valamar Riviera d.d. and for the competitors analyzed. The intensity of this trend varies among each of the hotel groups examined, and it is evident that Valamar Riviera d.d. is the market leader, generating significantly higher revenues than its competitors. The lower revenues in 2020 were a result of the global pandemic that began at the end of 2019 and had a significant impact on the summer season of 2020.

| | Valamar Riviera d.d. | Solaris d.d. | Liburnia Riviera Hoteli d.d. | Arena Hospitality Group d.d. |
|---|---|---|---|---|
| 2020 | 913,077,587.10 € | 179,412,130.47 € | 123,644,568.32 € | 385,966,000.00 € |
| 2021 | 917,585,170.35 € | 183,020,568.32 € | 126,163,308.91 € | 386,015,000.00 € |
| 2022 | 852,054,493.73 € | 172,859,012.00 € | 129,822,076.71 € | 418,667,000.00 € |
| 2023 | 826,211,231.00 € | 198,676,221.00 € | 122,279,381.00 € | 366,154,000.00 € |
| 2024 | 782,422,702.00 € | | 119,959,481.00 € | 357,830,000.00 € |

*Table 3 Total Assets. Source: author's compilation based on data from the annual financial reports of selected companies for the fiscal years 2020–2024.*
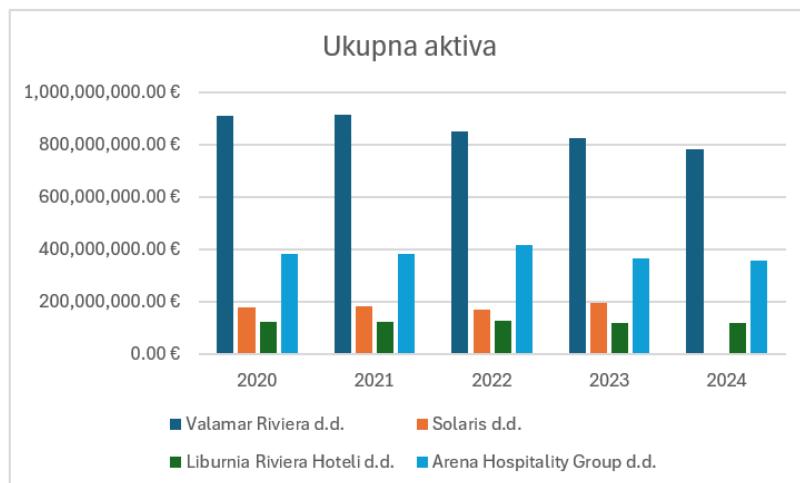


*Chart 2 Total Assets. Source: author's compilation based on data from the annual financial reports of selected companies for the fiscal years 2020–2024.*

Table 3 and Chart 2 show the movement of total assets of the companies from 2020 to 2024. The total assets of Valamar Riviera d.d. are significantly higher than those of the other companies in the group. A slight downward trend in the value of total assets for Valamar d.d. is noticeable, unlike the other companies in the group, whose asset values have remained approximately stable over time.

| | Valamar Riviera d.d. | Solaris d.d. | Liburnia Riviera Hoteli d.d. | Arena Hospitality Group d.d. |
|---|---|---|---|---|
| 2020 | -40,960,000.00 € | -14,961,593.20 € | -21,419,603.16 € | -2,796,000.00 € |
| 2021 | 41,684,000.00 € | 2,156,879.29 € | -12,169,794.68 € | 6,056,000.00 € |
| 2022 | 74,412,000.00 € | 2,631,643.00 € | -553,321.92 € | 7,040,000.00 € |
| 2023 | 24,945,000.00 € | 2,616,181.00 € | 1,401,462.00 € | 6,132,000.00 € |
| 2024 | 25,933,000.00 € | | 4,104,324.00 € | 8,694,000.00 € |

*Table 4 Net Profit (Loss). Source: author's compilation based on data from the annual financial reports of selected companies for the fiscal years 2020–2024.*
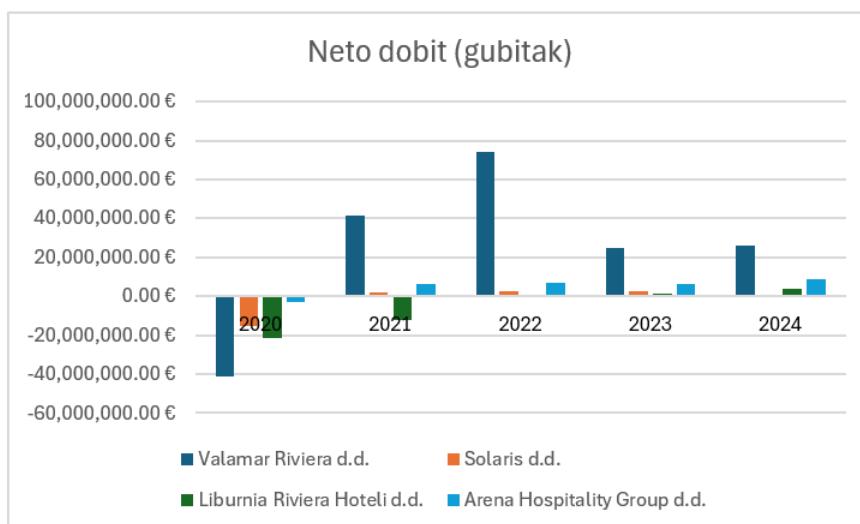


*Chart 3 Net Profit (Loss). Source: author's compilation based on data from the annual financial reports of selected companies for the fiscal years 2020–2024.*

Based on the review of net profit from 2020 to 2024, it can be concluded that the global pandemic had a significant impact on the operations of all observed companies, as all of them operated at a loss due to the consequences of the coronavirus. Market recovery began in 2021, marked by a noticeable increase in net profit for Valamar Riviera d.d., which continued into 2022 before stabilizing at a lower level in 2023 and remaining at that level in 2024. Despite this decline in net profit, Valamar Riviera still maintains a significantly higher profit compared to the observed competitors, although it also recorded considerably larger losses during 2020.

| | Valamar Riviera d.d. | Solaris d.d. | Liburnia Riviera Hoteli d.d. | Arena Hospitality Group d.d. |
|---|---|---|---|---|
| 2020 | 88,384,484.70 € | 1,515,179.64 € | 1,600,902.52 € | 49,177,000.00 € |
| 2021 | 148,020,150.51 € | 4,377,282.10 € | 2,017,386.69 € | 37,899,000.00 € |
| 2022 | 89,299,581.79 € | 4,497,579.00 € | 9,702,037.30 € | 55,575,000.00 € |
| 2023 | 55,185,359.00 € | 1,271,468.00 € | 6,871,496.00 € | 43,371,000.00 € |
| 2024 | 59,754,067.00 € | | 9,774,100.00 € | 23,572,000.00 € |

*Table 5 Cash and Cash Equivalents. Source: author's compilation based on data from the annual financial reports of selected companies for the fiscal years 2020–2024.*
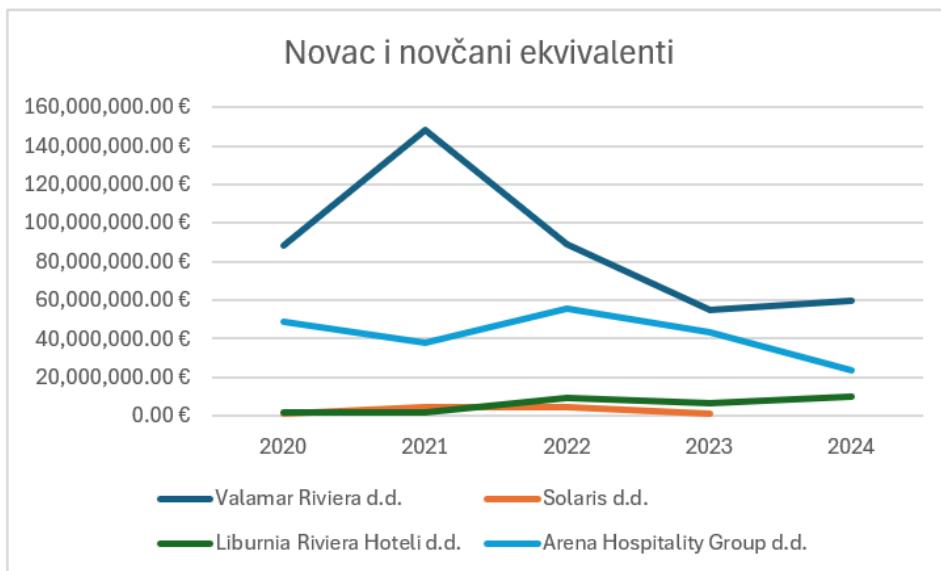
*Chart 4 Cash and Cash Equivalents. Source: author's compilation based on data from the annual financial reports of selected companies for the fiscal years 2020–2024.*

The data shows that Valamar Riviera d.d. has maintained the largest amount of cash and cash equivalents throughout the observed period. From 2021 to 2022, a noticeable decline in cash holdings is evident for Valamar Riviera d.d., while the competing companies show a slight increase during the same period. This downward trend for Valamar continues until 2023, when a modest recovery in cash and cash equivalents occurs.

|  | Valamar Riviera d.d. | Solaris d.d. | Liburnia Riviera Hoteli d.d. | Arena Hospitality Group d.d. |
|---|---|---|---|---|
| 2020 | -6.47% | -19.32% | -26.53% | -1.07% |
| 2021 | 5.54% | 2.72% | -17.74% | 2.86% |
| 2022 | 9.62% | 2.25% | -0.78% | 3.33% |
| 2023 | 3.13% | 2.64% | 2.02% | 1.71% |
| 2024 | 3.23% |  | 5.58% | 2.78% |

*Table 6 Return on Equity (ROE). Source: author's compilation based on data from the annual financial reports of selected companies for the fiscal years 2020–2024.*
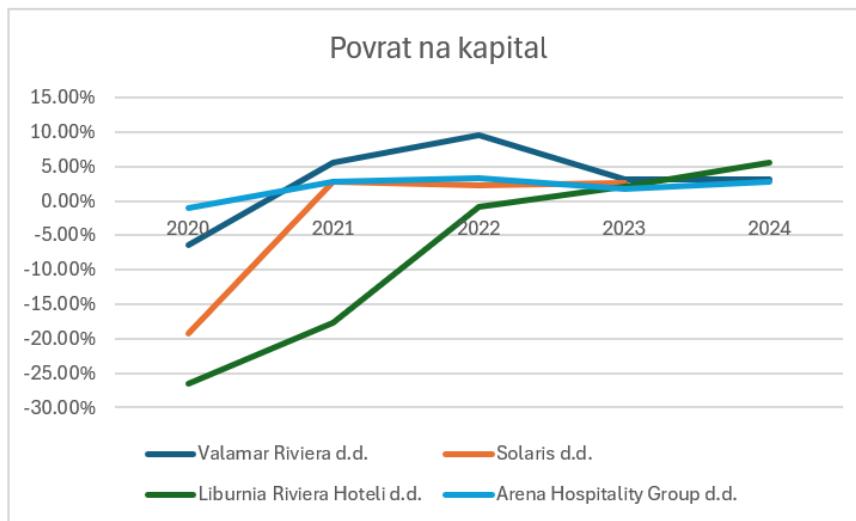
*Chart 5 Return on Equity (ROE). Source: author's compilation based on data from the annual financial reports of selected companies for the fiscal years 2020–2024.*

The attached chart shows one of the most important indicators of a company's performance — the profitability of equity. This indicator is calculated by taking the company's profit (or loss) over a period and dividing it by the amount of equity. From the chart, we can see which companies struggled the most with losses caused by the coronavirus pandemic, namely Liburnia Riviera d.d. and Solaris d.d., which are also the two smallest companies among the competitors analyzed. A sharp rebound in Valamar d.d.'s performance is visible, which decreased in 2023, after which the company has shown a stable, gradual growth.

| | Valamar Riviera d.d. | Solaris d.d. | Liburnia Riviera Hoteli d.d. | Arena Hospitality Group d.d. |
|---|---|---|---|---|
| 2020 | -3.87% | -8.34% | -17.32% | -0.72% |
| 2021 | 3.35% | 1.18% | -9.65% | 1.32% |
| 2022 | 5.59% | 1.33% | -0.43% | 1.54% |
| 2023 | 1.77% | 1.24% | 1.15% | 0.80% |
| 2024 | 1.78% | | 3.42% | 1.30% |

*Table 7 Return on Total Assets (ROA). Source: author's compilation based on data from the annual financial reports of selected companies for the fiscal years 2020–2024.*
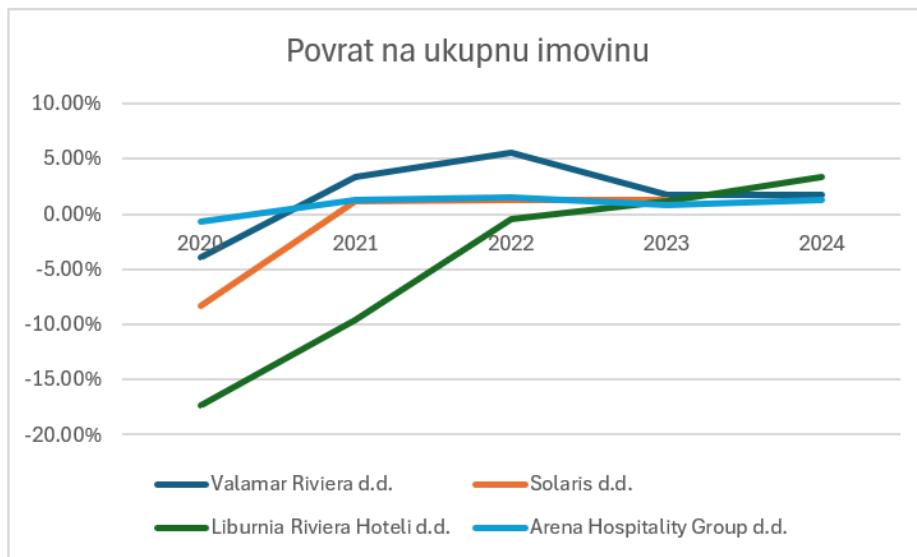
*Chart 6 Return on Total Assets (ROA). Source: author's compilation based on data from the annual financial reports of selected companies for the fiscal years 2020–2024.*

Chart 6 shows the trend of return on total assets from 2020 to 2024 for the observed companies. It is noticeable that there are no significant deviations between the companies analyzed. This indicator reflects the relationship between net profit (loss) and total assets. It can be observed that no company was profitable in 2020, but by 2021, all operated profitably except for Liburnia Riviera Hotels d.d., which needed more time to recover from the crisis caused by the coronavirus.

| | Valamar Riviera d.d. | Solaris d.d. | Liburnia Riviera Hoteli d.d. | Arena Hospitality Group d.d. |
|---|---|---|---|---|
| 2020 | 0.122 | 0.073 | 0.079 | 0.136 |
| 2021 | 0.204 | 0.207 | 0.227 | 0.133 |
| 2022 | 0.301 | 0.32 | 0.369 | 0.239 |
| 2023 | 0.367 | 0.277 | 0.482 | 0.276 |
| 2024 | 0.429 | | 0.536 | 0.311 |

*Table 8 Asset Turnover Ratio. Source: author's compilation based on data from the annual financial reports of selected companies for the fiscal years 2020–2024.*
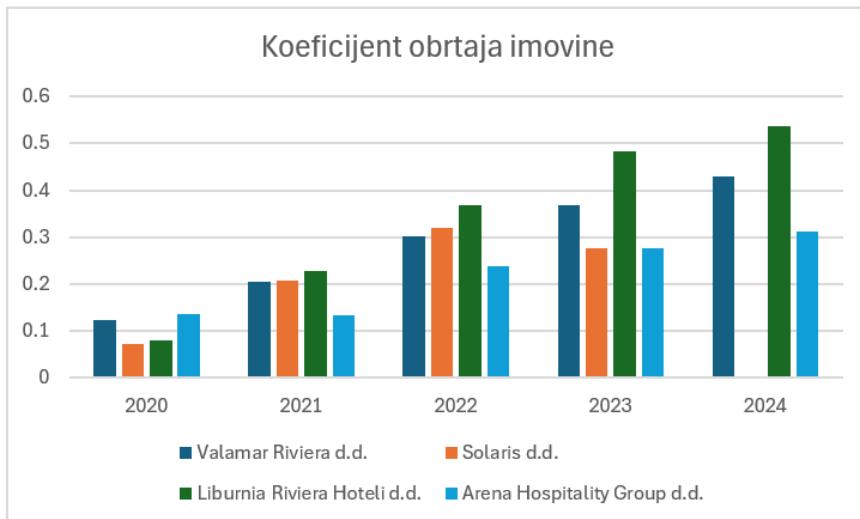
*Chart 7 Asset Turnover Ratio. Source: author's compilation based on data from the annual financial reports of selected companies for the fiscal years 2020–2024.*

The last observed indicator is the asset turnover ratio. This ratio represents the relative efficiency with which assets are used to generate revenue. Most of the analyzed companies fall within the range of 0.1 to 0.3, with a noticeable upward trend led by Liburnia Riviera Hoteli d.d. In 2024, Valamar Riviera d.d. achieves approximately 0.42 euros of revenue for every 1 euro of total assets.

## 1.2. Application of Cost Analysis in Management

One of the key components of strategic management is cost control, making cost analysis extremely important for hotel business planning, especially considering the dynamic market environment and changing business conditions. Through cost analysis, managers can understand the cost structure of a hotel, which is a prerequisite for optimizing operations and developing strategies that will improve business profitability. According to a study published in *Acta Turistica* (2013), analytical tools such as the Consumer Price Index (CPI), Producer Price Index (PPI), and the Service Price Index (SPI) are used to measure the relationship between price levels and the perceived value of provided services. By conducting this analysis, management can align pricing with the level of service provided and with market expectations (*Acta Turistica*, 2013, Vol. 25 No. 2, pp. 129–130). Asset valuation, according to Damodaran (2002), requires analyzing the cost of capital, the risks arising from business operations, and the analysis of future cash flows. This valuation is particularly important in the hotel industry, which is characterized by high entry costs and initial investments with long-term return periods (Damodaran, 2002, pp. 91–98). To understand the relationship between costs and variables such as seasonal demand changes or occupancy rates, Harris (1986) emphasizes the importance of applying quantitative analytical methods such as regression and correlation. These methods enable the mapping of the cost structure, which serves as a basis for creating models that support better decision-making (Harris, 1986, pp. 129–137). Dimou, Archer, and Chen (2003) highlight that ownership structure and management models influence operational efficiency and cost rationalization, particularly in the case of international hotel chains (Dimou, Archer & Chen, 2003, pp. 147–149). In another study, Arbelo, Pérez-Gómez, and Arbelo-Pérez (2016) showed that larger-capacity hotels with centralized operations can achieve greater cost efficiency if they have a strong internal control system (Arbelo, Pérez-Gómez & Arbelo-Pérez, 2016, pp. 1059–1061).

The application of cost analysis in hotel management consists of a wide range of methods, models, and theoretical frameworks aimed at adapting hotel operations to market demands.

## 1.3. Cost-Benefit Analysis

Cost-Benefit Analysis (CBA) is used as a decision-making tool for investments and strategic decisions. Through this method, management quantifies the relationship between the costs of specific activities and the benefits derived from those activities, allowing managers to make informed decisions about resource allocation in order to maximize overall value for the company. A particular feature of the hotel industry is that hotels often offer their services as bundled packages. In such arrangements, services such as accommodation, meals, and additional options are combined into a single price, which complicates the allocation of individual costs within the package and makes it difficult to apply the traditional ABC (Activity-Based Costing) method. Therefore, managers also include the allocation of indirect costs in the analysis and consider perceived value (*Acta Turistica*, 2013, Vol. 25 No. 2, pp. 138–139). When analyzing benefits, it is crucial to also include intangible effects such as destination reputation and hotel image, as these play a significant role in benefit analysis by influencing consumer decisions, which will ultimately be reflected in the hotel's financial results. Benefit analysis must also incorporate elements such as hotel branding and customer loyalty, which requires a combination of quantitative and qualitative indicators. Introducing a system of continuous cost and benefit monitoring positively impacts long-term business sustainability by allowing flexible adaptation of the service offering to demand, guest preferences, and market conditions (*Acta Turistica*, 2013, Vol. 25 No. 2, pp. 138–139).

## 1.4. Costing Methods in the Hotel Industry

The hotel industry is characterized by a high proportion of fixed costs, seasonal business fluctuations, and high operating costs. The costing methods that will be explained include ABC analysis, CVP analysis, fixed and variable cost analysis, cost of quality analysis, and relevant cost analysis.

### 1) ABC Analysis

ABC analysis (Activity-Based Costing) is used to allocate costs based on the activities that caused them. This method allows for more accurate allocation of indirect costs and is particularly useful in hotels offering a wide range of services, as it enables analysis of the profitability of those services (Collini, 2006, pp. 165–187; Drury, 2020, pp. 257–263). This method was developed to improve traditional cost analyses, which often allocate costs based on a single category, such as employee work hours — an approach that can lead to a distorted picture of costs. For greater accuracy, ABC analysis uses cost drivers to show the causal relationship between activities and the costs they generate (Drury, 2020, p. 264). The first step in conducting this analysis is identifying the activities within the company that consume resources. These activities are grouped according to their similar nature. In the second step, each group of activities is assigned costs, which are then distributed to products and services using cost drivers, such as the number of orders, hours worked, etc. As a result of the analysis, a clearer picture emerges of which products and services are driving costs (Horngren, Datar & Rajan, 2011, p. 160). In the hotel industry, the ABC method can be used to understand how activities such as room cleaning, front desk operations, and other indirect costs contribute to the total cost of a guest's stay.

**2) CVP Analysis (Cost-Volume-Profit)**
CVP analysis identifies the break-even point in business operations and helps in understanding how changes in prices, sales volume, and costs will affect profit. This analysis is used in decision-making related to pricing strategies and discounts (Garrison et al., 2015, pp. 218–225; Drury, 2020, pp. 172–180). The primary goal of CVP analysis is to determine the point at which total revenues cover total costs. Beyond this point, the business starts generating profit, while operating below it leads to losses. For this reason, CVP analysis is one of the fundamental techniques used in managerial accounting (Horngren et al., 2011, p. 90). To conduct a CVP analysis, certain assumptions must be met: all costs can be classified as fixed or variable, the selling price per unit can be determined, variable and fixed costs per unit remain constant within the relevant range, and the number of units produced equals the number of units sold — meaning the business is operating at full capacity (Drury, 2020, p. 178). Key components of this analysis include contribution margin, profit point, target profit, and margin of safety. These elements allow managers to assess business risk and react to changes in cost levels and business volume (Horngren et al., 2011, p. 98). In the hospitality industry, this analysis can guide decisions related to changing the assortment of products or services — for example, assessing the profitability of different offers provided by a hotel. Limitations of CVP analysis become apparent when cost categories are unstable and change with volume, which is especially true for variable costs.

**3) Fixed and Variable Cost Analysis**
The classification of costs into fixed and variable is one of the most important distinctions for organizing business operations, as it provides insights into the cost structure necessary for business planning. Fixed costs remain constant regardless of the level of business activity, while variable costs fluctuate depending on the volume of operations (Drury, 2020, pp. 154–159; Garrison et al., 2015, pp. 202–205). By using this analysis, managers can decide which costs to reduce or avoid when there is a change in business volume. Quantitative methods such as the high-low method and regression analysis are most commonly used to conduct this analysis (Horngren et al., 2011, p. 236). These methods allow for the separate evaluation of fixed and variable costs. In hotel operations, understanding the behavior of fixed and variable costs can support decisions about seasonal capacity planning. For example, the costs of front desk staff can be considered fixed, while room service expenses are variable since they depend on occupancy rates.

**4) Cost of Quality Analysis**
Cost of quality includes preventive costs such as staff training, appraisal costs like quality control, and internal and external failure costs, which include guest complaints. Analyzing these costs helps management understand how quality affects the financial performance of the business (Dobbelstein & Brehm, 2012, pp. 10578–10583; Drury, 2020, pp. 401–407). Preventive costs include investments in employee education to ensure consistent quality standards, process control expenses, and design improvements — covering inspections and testing. Internal failure costs refer to repairs, rework, or inadequately cleaned rooms that are identified before delivery to the guest. External failure costs refer to complaints, returns, and loss of reputation (Horngren et al., 2011, p. 718). The purpose of cost of quality analysis is to increase error prevention and reduce their occurrence, ultimately enhancing customer satisfaction.

**5) Relevant Cost Analysis**

Relevant cost analysis refers to those costs that will change as a result of making a particular decision. This analysis is used when deciding whether to outsource services, introduce new services, or discontinue underutilized services (Drury, 2020, pp. 294–298; Garrison et al., 2015, pp. 312–316). It is primarily applied in short-term decision-making. The foundation of this analysis lies in identifying the costs that will vary depending on the considered option. Relevant costs will change based on the chosen alternative, while irrelevant costs remain unchanged regardless of the decision made (Drury, 2020, p. 450). In hotel operations, this analysis can be used to assess whether it is profitable to accept a group reservation at a discounted rate. In such a case, the relevant costs are the additional service-related expenses, while fixed costs will be incurred regardless of whether the reservation is accepted or not (Drury, 2020, p. 450). One of the main limitations of this analysis is the subjectivity involved in estimating future costs, which may influence the final outcome.

## 2. CONCLUSION

The conducted analysis shows that the hotel industry is significantly influenced by external factors over which hotel companies have little or no control, yet these same factors have a considerable impact on their operations. Beginning in 2020, the challenges brought about by the pandemic—which triggered an economic crisis and a drop in demand for services, especially luxury ones such as holidays and hotel stays—caught all observed companies by surprise. Suddenly, they had to cope with social distancing measures, reduced capacities, and operational losses. All of the analyzed companies, particularly Valamar Riviera d.d., managed to adapt to the situation in a short period and return their operations to pre-pandemic levels. Nevertheless, the year 2020 and all the business challenges that had to be overcome will serve as a valuable reference point for preparing for potential future crises with similar negative impacts. The data shows that the unstable political situation in parts of Europe, including the war between the Russian Federation and Ukraine, has not had a significant effect on hotel profitability. This is largely because tourists from these regions do not make up a considerable share of Croatian tourism, and their absence did not meaningfully impact business performance. Through all the analyses conducted, Valamar Riviera d.d. confirmed its position as the market leader in Croatia, with no competitors currently posing a serious threat to its business. However, the question arises as to how long this leadership can be maintained if competitors—especially Arena Hospitality Group d.d.—decide to invest in expanding their accommodation capacities and Valamar fails to respond with a similar strategy. Given the consistent growth in overnight stays and the number of guests throughout the observed period—and the expectation that this trend will continue—it is reasonable to assume that Valamar anticipates a stable period of operations, provided that external conditions remain unchanged. However, this raises concerns about how sustainable it is for local tourism to continue increasing overnight stays and guest numbers without making adjustments to the organizational structure and infrastructure of the local communities in which these hotels operate. Although Valamar Riviera d.d. has no direct influence over local government decisions, it is nonetheless obligated to comply with them as a part of the local community.

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# CHALLENGES AND SOLUTIONS FOR TIMETABLE GENERATION IN HIGHER EDUCATION: A CASE STUDY IN SOUTHERN ANGOLA

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### *ABSTRACT*

*The creation of school timetables in higher education institutions (HEIs) is often pointed out as one of the most complex logistical challenges in semester academic planning. This is a process that requires meeting several constraints: availability of teachers, the workload of curricular units, capacity and availability of classrooms, interdependence between courses, and even individual preferences. Despite the existence of commercial software aimed at timetable management, many solutions prove insufficient to deal with the operational peculiarities of institutions in contexts with limited resources. This article presents a case study conducted in twelve HEIs located in the provinces of Huíla, Namibe, and Cunene, in Angola, with the objective of diagnosing the methods currently used in the creation of timetables and identifying the main obstacles faced by academic managers. To this end, structured questionnaires were applied to course coordinators and those responsible for planning, seeking to map both manual procedures and computerized systems used. The results reveal a clear predominance of manual practices or practices assisted by systems with restricted functionalities: there is no automatic generation of conflicts nor dynamic recording of teacher unavailability, which leads to intense work and risks of inadequate allocation of resources. In addition, there is low compliance with equity criteria in the distribution of timetables, generating dissatisfaction among teachers and students. As central contributions, the study proposes the adoption of platforms based on combinatorial optimization algorithms and artificial intelligence, capable of processing multiple variables simultaneously, identifying viable solutions autonomously, and allowing adjustments in real-time according to changes in availability or infrastructure. We concluded that the incorporation of these technologies can increase efficiency, reduce operational costs, and ensure greater transparency and flexibility in the process of preparing academic timetables.*

*Keywords: Timetabling, Artificial Intelligence, Algorithms, and Optimization*

## 1. INTRODUCTION

The creation of university timetables, although a routine activity in higher education institutions (HEIs), is one of the biggest logistical challenges faced at the start of each semester. Department directors and course coordinators often experience high-pressure situations when trying to ensure the right conditions for the start of teaching activities, due to the complexity inherent in this task. This complexity arises above all from the need to reconcile the availability of teachers with the balanced distribution of curricular units, while respecting various restrictions, such as the overlapping schedules of teachers and students (Schaerf, 1999; Vieira & Macedo, 2011). Although there are commercial tools for automated timetable generation, many of these solutions are not suited to the specificities and operational limitations faced by many institutions. As a result, many universities end up resorting to manual methods, often using spreadsheets, which, although they offer some flexibility, increase the propensity for errors and inconsistencies.

Recent studies indicate that hybrid approaches, based on optimization algorithms combined with artificial intelligence techniques, have the potential to substantially improve the quality of resource allocation and reduce scheduling conflicts (Akkan & Gülcü, 2018; Song et al., 2018). This article presents a case study focusing on the challenges and solutions associated with timetable generation in Higher Education Institutions located in southern Angola, with a focus on the provinces of Huíla, Namibe, and Cunene. The study involved twelve institutions, eight of which were located in the province of Huíla, two in Namibe, and two in Cunene, chosen both for their academic tradition, especially in Huíla, and for the diversity of administrative contexts, these factors which highlight the breadth and complexity of the problem analyzed. The relevance of this study lies in the need to understand the challenges faced by institutions when creating timetables that take into account the availability of teaching staff while ensuring a fair and efficient distribution of teaching activities. The main objective is to analyze the generation methods currently used, identify their limitations, and propose solutions based on intelligent technologies, namely through the application of optimization algorithms and artificial intelligence. This article is structured in five chapters: Chapter 1: Introduction, Chapter 2: State of the Art, Chapter 3: Methodology, Chapter 4: Presentation and Discussion of Results, and Chapter 5: Conclusion, with proposals for future research.

## 2. STATE OF THE ART
### 2.1. The complexity of university timetable generation
Creating academic timetables in higher education is recognized as a highly complex combinatorial problem, classified in the literature as NP-hard (Schaerf, 1999). This difficulty results from the need to simultaneously reconcile multiple variables: the availability of teachers, the efficient use of spaces, teaching periods, the courses offered, and institutional preferences. All of these dimensions must be organized while respecting rigid restrictions (such as the absence of overlapping classes for the same teacher) and flexible ones (such as timetable preferences) (Ceschia et al., 2012). The initial formalization of the exam scheduling problem is often attributed to Gotlieb (1963), who proposed an approach based on heuristic programming. Later advances, such as the mathematical models proposed by Broder (1964) and Carter & Laporte (1996), allowed for greater robustness in the representation of constraints. The methodological evolution moved on to heuristic algorithms and, more recently, to approaches based on artificial intelligence (AI), especially genetic algorithms, metaheuristics, and hybrid strategies (Soria-Alcaraz et al., 2014; Moreira, 2008). Lewis & Thompson (2015) introduced an innovative approach by treating the timetabling problem as a graph coloring problem, in which each event is represented by a vertex and conflicts are represented by edges. This representation reinforces the applicability of heuristics derived from graph theory, maximizing computational efficiency in the search for viable solutions. For their part, Goh et al. (2019) explore the concept of simulated annealing with adaptive reheating and reinforcement learning, allowing for the dynamic selection of more promising neighborhoods. This technique has proven effective in international benchmarks, outperforming traditional algorithms. Phillips et al. (2015) propose models based on integer programming applicable to large universities, demonstrating that, even with complex formulations, it is possible to solve real problems of room and timetable allocation using lexicographic techniques. Lewis & Thompson (2015) reinforce the importance of the connectivity of the solution space; the greater the connectivity, the easier it is to navigate through neighborhoods that optimize flexible constraints without violating rigid ones.

## 2.2 Innovative algorithmic solutions

The growing complexity of scheduling problems has led to the development of sophisticated computational solutions. Theses include genetic algorithms, iterative local search, hyperheuristics, integer programming, and hybrid approaches (metaheuristics). Akkan & Gülcü (2018) propose robust multicriteria genetic algorithms capable of generating adaptive solutions to last-minute changes, a common aspect in the university context. Song et al. (2018) contribute a strategy based on iterated local search with mild perturbations, suitable for situations where stability and adaptability are equally desired. Soria-Alcaraz et al. (2014) advance hyperheuristics that dynamically learn from the performance of operators, continuously improving the quality of solutions. In the African context, the work of Pillay (2014) stands out for its application of machine learning algorithms and hyperheuristics in the scheduling of South African schools, showing that adaptive approaches are effective even in scenarios with limited computational resources. In Brazil, Fonseca et al. (2016) applied metaheuristic approaches to the problem, with significant gains in benchmarks, validating the viability of the combined use of variable neighborhood search and mathematical programming. Kheiri & Keedwell (2017) present the use of hidden Markov models in hyperheuristics, promoting algorithmic autonomy in choosing the most appropriate heuristics. Post et al. (2014) introduced the XHSTT library, standardizing international instances to facilitate comparison between solutions. Table 1 shows the main algorithmic techniques.

| Approach | Main features | Advantages | Limitations | Main authors |
|---|---|---|---|---|
| Classic heuristics | Simple rules, manual or semi-automatic programming | Low computational cost | Not very scalable, suboptimal solutions | Gotlieb (1963); Carter & Laporte (1996) |
| Genetic Algorithms | Evolution of solution populations | Robust and adaptable solutions | Requires parameter adjustment | Akkan & Gülcü (2018) |
| Iterative Local Search | Successive perturbations to refine solutions | Stability and local exploitation | Can converge to local optima | Song et al. (2018) |
| Hyperheuristics | Dynamic selection of heuristics with learning | High adaptability | Complex implementation | Soria-Alcaraz et al. (2014); Pillay (2014) |
| Simulated annealing + Reinforcement | Adaptive reheating and learning | High performance in benchmarks | Parameter setting required | Goh et al. (2019) |
| Integer programming | Mathematical modeling with multiple constraints | Optimal solutions | High computational cost | Phillips et al. (2015) |
| Matheuristics | Integration between heuristics and mathematical programming | Fast and accurate | Require advanced modeling | Fonseca et al. (2016) |
| Hidden Markov Models | Probabilistic Heuristic Pattern Learning | More autonomous algorithms | Requires well-structured historical data | Kheiri & Keedwell (2017) |

*Table 1: Main algorithmic techniques*

## 2.3 Existing tools and limitations in the Angolan context

Despite theoretical advances and the availability of commercial tools, the Angolan institutional reality presents limitations that compromise the effectiveness of these solutions.

Data collected from twelve HEIs in the provinces of Huíla, Namibe, and Cunene reveal the prevalence of manual or semi-computerized methods, with poor integration of critical functionalities such as the insertion of teaching availability or automatic generation of timetables. Among the most used commercial tools internationally, UniTime, aSc TimeTables, and FET (Free Timetabling Software) stand out. These solutions offer accessible interfaces and efficient algorithms (Ceschia et al., 2023), being used in universities on different continents. However, its use in African institutions faces serious barriers: the requirement for robust technological infrastructure, stable internet connection, dedicated servers, and continuous technical training (Mathevula & Uwizeyimana, 2014). The high turnover of teachers, frequent curricular changes, and the limited number of available rooms are examples of contextual restrictions that these platforms rarely consider. Müller et al. (2019) highlight that even in contexts with greater technical capacity, adapting these tools requires specific developments. In Angola, the lack of local technical support and versions adapted to the national reality worsens the problem. Furthermore, few institutions use their own systems, and when they do, they lack regular maintenance and intelligent decision support algorithms. Reliance on spreadsheets or limited modules of systems such as SIGA prevents full automation of the process, resulting in administrative overhead, scheduling conflicts, and inefficiency.

## 2.4 Gaps identified and justification of the study

Despite the vast literature on solutions to the timetabling problem, there is a significant gap concerning its practical application in African contexts with structural and technological limitations. The lack of local studies, the unavailability of tools that fit the needs of Angolan higher education institutions, and the absence of input from users like teachers and coordinators in making timetables show that we need more tailored approaches. This study seeks to respond to these gaps, proposing solutions based on good international practices but adjusted to the institutional reality of southern Angola. The research, therefore, stands out not only for its comparative analysis of existing methods but also for its potential contribution to the formulation of innovative, inclusive, and technically viable tools for the Angolan higher education system.

## 3. METHODOLOGY

This study follows a quantitative and qualitative, descriptive and applied approach, with the aim of understanding the methods, limitations, and opportunities associated with timetable management in HEIs in southern Angola. To this end, the multiple case study strategy was adopted, as recommended by Yazan (2015), as it allows an in-depth analysis of complex phenomena in their real context.

## 3.1 Sample

The sample was made up of 12 higher education institutions, 8 of which were located in the province of Huíla, 2 in Namibe and, 2 in Cunene. The selection includes public and private institutions, with different organizational models, which allowed heterogeneous practices in timetable management to be observed. The selection criteria were based on accessibility, institutional proximity and acceptance of participation, ensuring operational viability and territorial representation.

## 3.2 Data collection instrument

The main instrument used was a questionnaire survey, developed specifically for this study. The questionnaire was structured into closed and open questions, aiming to collect both objective data and qualitative perceptions from the participants.

It was aimed at course coordinators, academic directors and department heads, who are the main agents involved in preparing timetables at HEIs. Part of the questionnaire content:

- Type of system used (manual, mixed or computerized)
- Automatic timetable generator
- Possibility for teachers to enter their availability
- Evaluation of the efficiency of existing systems
- Difficulties encountered in drawing up timetables
  Suggestions for improving timetable management systems

*3.2.1 Application of the questionnaire*

The questionnaire was administered in digital format, depending on the availability of the participants. Before the general application, an informal pretest was carried out with three academic managers in order to validate the clarity and relevance of the questions.

**3.3 Data triangulation**

In addition to the questionnaire, the analysis was complemented by informal interactions with the heads of the Information and Communication Technology (ICT) departments of some of the institutions. These interactions, although not structured as formal interviews, made it possible to collect relevant contextual data, supported by the previous professional experience of one of the researchers as head of an ICT department in one of the participating institutions. This methodological triangulation strategy (Flick, 2009) helped to strengthen the credibility and validity of the data collected.

**3.4 Data treatment and analysis**

The data was processed using descriptive analysis techniques. The closed answers were organized in tables and graphs, allowing frequency and distribution patterns to be identified. The thematic content analysis technique was used to process the open answers, identifying emerging categories and grouping them by recurring topics.

The quantitative data was systematized using Microsoft Excel, while the interpretation of the open-ended responses followed the principles of qualitative coding, making it possible to understand the operational challenges, institutional perceptions, and proposals for improvement directly provided by the participants.

**4. PRESENTATION AND DISCUSSION OF RESULTS**

**4.1 Characterization of the institutions surveyed**

Twelve institutions took part in the study. The geographical distribution revealed a greater number of institutions in Huíla province (66.66%), followed by Namibe (16.67%) and Cunene (16.67%). This predominance reflects the historical concentration of educational institutions and infrastructure in the city of Lubango, the capital of Huíla.
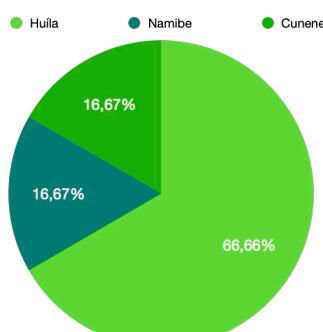


*Figure 1: Geographical distribution of the institutions surveyed by province*

In addition, there was a balanced representation between public and private institutions (50% each), which guarantees a diversity of visions and administrative practices, as illustrated in the graph in Figure 2. This diversity is important, as strategies for managing schedules vary between centralized models (public) and more flexible and decentralized models (private).
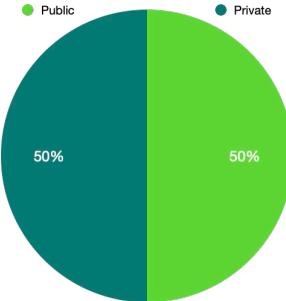


*Figure 2: Proportion of Public and Private Institutions Participating in the Study*

## 4.2 Timetabling management systems used

According to the data in the graph in Figure 3, 50% of institutions use computerized systems, 33% operate with mixed methods (combining spreadsheets and specific software) and 17% still rely exclusively on manual methods. This last category is particularly worrying, as it reinforces the dependence on processes that are time-consuming, prone to errors and not very scalable.
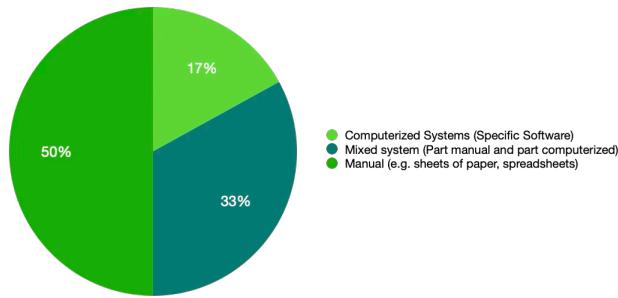


*Figure 3: Timetabling management systems at HEIs*

Even among institutions with computerized systems, the functionality for entering teaching availability (Figure 4) is absent or not very accessible in most cases. Only 25% allow this functionality directly, which limits flexibility and fairness in timetable distribution.
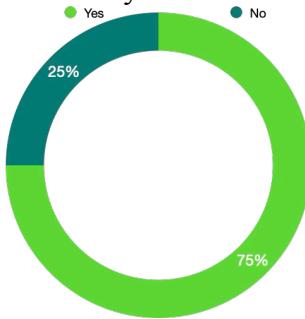


*Figure 4: Insertion of availability by teachers*

## 4.3 Absence of automatic generators

The graph in Figure 5 shows that 58% of institutions do not have an automatic timetable generator, forcing managers to generate timetables manually. The absence of effective automatic tools creates overload and increases the likelihood of conflicts and overlapping classes, as reported by Lewis & Thompson (2015) and Rezaeipanah et al. (2021).
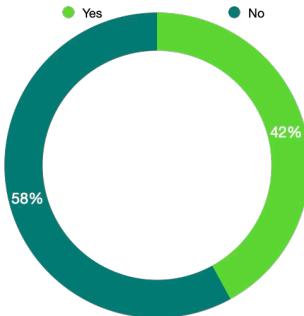
*Figure 5: Lack of automatic generator in the systems used by HEIs*

Despite this, when present, automatic generators were considered efficient, which demonstrates the positive potential of their adoption. These results suggest that the issue is not only technical, but also institutional, related to prioritizing investments and training staff.
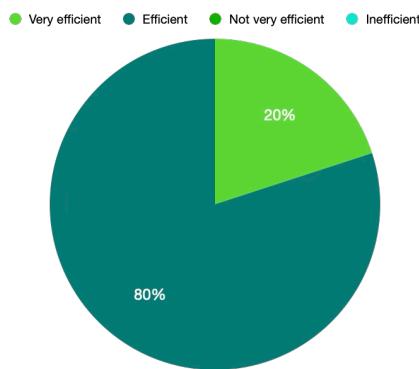


*Figure 6: If the automatic generator is efficient*

## 4.4 Perception of the benefits of an intelligent system

More than 80% of the institutions recognize that the implementation of an automatic generator would bring concrete benefits (Figure 7), such as: greater balance in the workload; reduction of conflicts; time savings.
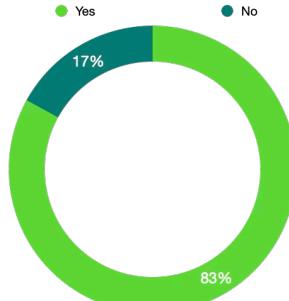


*Figure 7: Benefits of an intelligent system*

This suggests institutional openness to innovation, which can be exploited in future phases of implementing adapted solutions.

## 4.5 Contribution to academic planning

The graph in Figure 8 reinforces the importance of timetable generation systems in the strategic planning of teaching activities: 91.7% of the institutions surveyed consider that these systems contribute a lot to the organization of teaching activity. This result is in line with the conclusions of Goh et al. (2019), who highlight the strategic role of timetabling in improving the academic experience and institutional productivity.
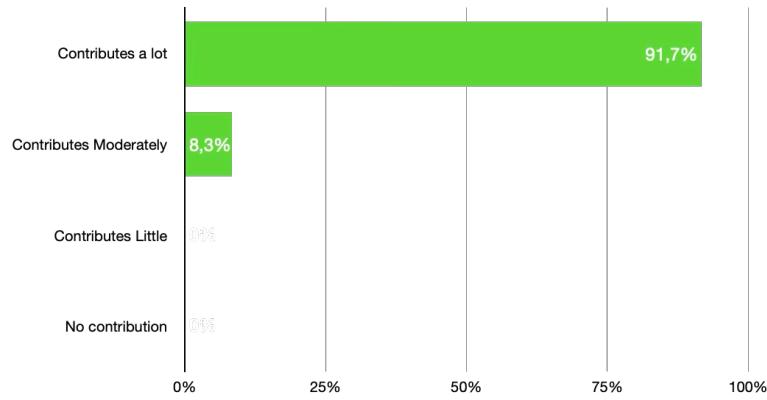
*Figure 8: Systems' contribution to academic planning*

## 4.6 Difficulties with the systems used

The main difficulties mentioned were: difficulty inserting availability (33.3%); lack of flexibility and functionalities (25%); and an unfriendly interface (16.7%). These limitations reflect technical, structural and cultural barriers. In line with Fonseca et al. (2016) and Pillay (2014), the lack of adaptation of systems to local realities hampers their effective use. There is also a need for greater customization and specialized technical training.
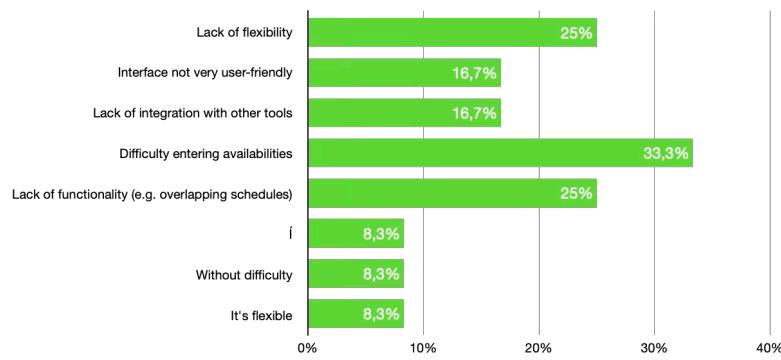


*Figure 9: Difficulties with the systems used by HEIs*

## 4.7 Origin of the systems used

50% of institutions use commercial systems and only 8% have resorted to in-house solutions. The reliance on tools such as SIGA or Excel reinforces the urgency of investing in specialized platforms that are better adapted to local requirements and constraints.
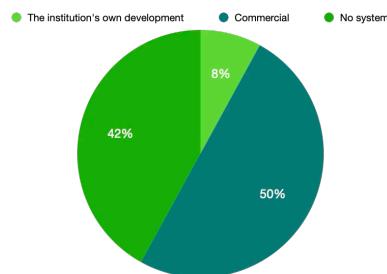


*Figure 10: Origin of the systems used by HEIs*

Table 2 confirms the dependence on SIGA and solutions such as Excel, which reinforces the urgency of investing in specialized platforms.

| Nº | System Name | Institutions | % |
|---|---|---|---|
| 1 | Academic Management IT System | 1 | 8,3% |
| 2 | Integrated Academic Management System | 4 | 33,3% |
| 3 | Elaboration via Excel | 5 | 41,6% |
| 4 | Acacia | 1 | 8,3% |
| 5 | Integrated University Management System | 1 | 8,3% |

*Table 2: Systems used by HEIs*

## 4.8 Analysis of the institutions' suggestions

The suggestions collected were grouped into three categories:

1. Desired functionalities: insertion of availability by teachers and automatic generation based on historical data;
2. Cultural limitations: the lack of habit of planning ahead and communicating unforeseen events;
3. Technical improvements: creation of specific systems and more interaction between users and platforms.

These suggestions show an institutional culture that is still in transition, with a high dependence on key people and a low level of automation. However, the existence of constructive proposals from respondents reveals an openness to innovation and the adoption of adapted technological solutions.

## 4.9 Practical implications

Based on the data analyzed, some practical implications can be highlighted:

- HEIs should prioritize the adoption of automated systems, with intelligent generators and mechanisms for entering teachers' availability;
- It is necessary to invest in the technical training of coordinators and those responsible for drawing up timetables;
- Solutions with local technical support and adapted to the existing infrastructure should be promoted;
- The platforms should allow for greater customization, in order to take into account contexts with high teacher turnover and limited resources.

## 5. CONCLUSION

This study aimed to analyze the methods, limitations, and potentialities related to academic timetable generation in Higher Education Institutions (HEIs) located in the provinces of Huíla, Namibe, and Cunene in Angola. Through a multiple case study, it was possible to identify a strong dependence on manual or semi-automated practices and a limited adoption of advanced computerized systems. Despite this, there was a significant institutional openness to the implementation of innovative solutions, especially those that increase the efficiency, equity and sustainability of the timetable-making process. The main challenges identified include: the difficulty teachers have in entering their availability; the lack of essential functionalities in existing systems; the fact that most institutions do not have automatic timetable generators; and the poor integration of systems with other academic management platforms. These limitations create work overload for coordinators, increase the likelihood of conflicts and directly affect the quality of teaching. The study showed awareness of the heterogeneity of practices between public and private institutions, reflecting different levels of digital maturity. It also highlighted the technological and operational difficulties faced by many Angolan HEIs, which reinforces the credibility of the proposals presented. As a concrete proposal, it is recommended that an intelligent timetable management system prototype be developed, based on international best practice but adapted to Angola's institutional realities.

This system should be modular, with features such as the insertion of availability by teachers, automatic generation of timetables, adaptation to different shifts and courses, and integration with platforms such as SIGA. It is essential that it has a user-friendly interface and local technical support.

For future research, we propose: (1) expanding the sample to other regions of the country; (2) implementing and validating the suggested system on a pilot basis in one or more of the institutions in the sample; and (3) using advanced statistical analysis to explore correlations between institutional variables and time management practices. These actions will make it possible to deepen knowledge on the subject and encourage the construction of more effective institutional policies. This article thus contributes not only to the diagnosis of the local reality, but also to the proposal of viable and sustainable technological solutions. By proposing a system adapted to the Angolan reality, the research offers practical support for the digital transformation of HEIs, promoting greater equity, efficiency and quality in the organization of teaching activities in Angola. This article thus aims to contribute not only to the diagnosis of the local reality, but also to the construction of sustainable and contextually appropriate solutions that raise the level of organization and quality in Higher Education in Angola.

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# CULTURAL HERITAGE AS A DEVELOPMENT RESOURCE - SUSTAINABLE TOURISM PERSPECTIVE

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***ABSTRACT***
*Over the past two decades, the role of cultural heritage in the context of regional development continues to be the subject of debate in many research fields. Cultural heritage has been recognized as a fundamental resource of territorial attractiveness, as a source of creativity and innovation, and the driver of culture-led regeneration. The developmental effects of cultural heritage can be observed in the spatial, economic, and sociological domains. In the contemporary tourism development, the significance of cultural assets is constantly growing, with the concept of heritage no longer being a static category, but increasingly characterized by thematic expansion, by the synergy between tangible and intangible cultural resources, and the consideration of heritage within a spatial context. Recent approaches to understanding the spatial paradigm of cultural tourism development are based on the concept of territorial capital (Camagni, 2008) and understanding its impact in achieving social, cultural, and economic development goals. The emphasis is put on the necessity of finding a balance between public interests, private investors, and community initiatives, where the principles of participation and responsibility are essential for the successful implementation of public policies. The main objective of this paper is to analyse the modalities of cultural heritage valuation, as the most important resources whose historical and cultural value must not be compromised by tourism development. This conceptual paper aims to contribute to a better understanding of the interrelation between culture and tourism in the context of sustainable development challenges.*
***Keywords:*** *cultural heritage, tourism, territorial capital, sustainable development*

## 1. INTRODUCTION

The significance of cultural heritage as a valuable asset for sustainable territorial development and economic growth is being increasingly acknowledged. Recognizing the potential of cultural heritage in development requires an understanding of its contribution to economic advancement and its influence on the allocation of resources for social and cultural objectives. Recent studies underscore the need for a more integrated, cross-sectoral approach to cultural heritage. Panzera (2022) argues that cultural heritage holds unique and multifaceted value, positioning it as a distinctive catalyst for development. Neuts et al. (2021) identify several key contributions of cultural heritage to development, including enhancing the attractiveness of regions, stimulating investment in cultural tourism, fostering innovation and creativity, driving heritage-led regeneration, and ultimately improving quality of life. Camagni et al. (2020) further conceptualize cultural heritage as a component of 'territorial capital.' Its impact on local development stems from its interaction with other elements of territorial capital, particularly intangible assets such as creativity, identity, human capital, and effective governance. However, while cultural heritage holds significant potential to drive sustainable development and strengthen territorial capital, its increasing integration with the tourism sector presents notable challenges. The very qualities that make heritage attractive, its uniqueness, cultural importance, and experiential richness, also make it vulnerable to overexploitation, commodification, and mismanagement. As tourism increasingly becomes a primary means of valuing heritage, conflicts can emerge between the need for conservation and commercial interests. This raises significant concerns about the long-term sustainability of both cultural and natural resources.

These challenges are particularly evident in regions affected by overtourism, where the tourism industry disrupts the delicate balance between economic growth and the well-being of society, the environment, and local cultures (Petrić et al., 2025). Contributing factors include a lack of effective collaboration among stakeholders in the tourism and cultural sectors, limited public awareness of the broader societal value of heritage, insufficient long-term investment in sustainable development, and a general underestimation of tourism's environmental footprint (ESPON, 2020). These concerns underscore the pressing need to reassess how cultural heritage is valued and integrated into tourism and development strategies. Rather than allowing heritage to be compromised by short-term economic pressures, it is essential to adopt frameworks that recognise its long-term cultural, social, and developmental significance. In light of these challenges, this conceptual paper seeks to explore the modalities of cultural heritage valuation, emphasising its role as a critical resource whose historical and cultural integrity must be preserved in tourism development.

Accordingly, the paper addresses the following key questions: *What is the role of cultural heritage as a resource for development? How can the synergies between culture and tourism contribute to sustainable development, particularly through the lens of the UN Sustainable Development Goals?* The main aim of this paper is to critically examine the modalities of cultural heritage valuation within the context of tourism development, with a particular focus on ensuring that heritage's historical and cultural significance is not compromised by economic imperatives. By examining the role of cultural heritage as a resource for sustainable development, this paper aims to promote a more comprehensive and long-term approach to heritage management. This paper contributes to the literature by offering a conceptual framework that bridges cultural heritage studies and sustainable tourism development. It highlights the need for cross-sectoral approaches that align heritage preservation with the broader goals of sustainable development, particularly as outlined in the UN Sustainable Development Goals (SDGs). It also sheds light on the tensions between conservation and commercialisation, and underscores the importance of governance, stakeholder collaboration, and cultural awareness in shaping sustainable heritage-tourism synergies.

The paper is structured as follows: Section 1 provides theoretical background about cultural heritage as potential development resource, while Section 2 describes interrelation between cultural heritage and tourism. Section 3 analyse cultural tourism contributions to Sustainable Development Goals and finally, last section provides concluding remarks.

## 2. CULTURAL HERITAGE AS DEVELOPMENT RESOURCE
Today, it is widely recognized that regional attractiveness is closely linked to the cultural dimensions of the space (Servillo et al, 2012). It is undeniable that cultural heritage contributes to regional distinctiveness. Although cultural heritage is most often thought of as a legacy from the past, it is also a contemporary living resource that stimulates a wide range of economic activities with significant short-term and long-term impacts on society and the economy (ESPON, 2019). In this context, approaches to explaining the concept of cultural heritage are shifting from static, prominent features of an area to drivers of social and economic dynamics within a community (ESPON, 2006).

The concept of heritage increasingly exhibits thematic expansion, consideration of cultural context and the significance of identity (Vecco, 2010). It is increasingly interpreted within a developmental context. This approach focuses on the "*spatial effects of cultural heritage and the dynamic interconnections between heritage and identity, as well as social and economic development trends*" (ESPON, 2006: 8).

The evolving understanding of cultural heritage concept is also reflected in the Faro Convention (Council of Europe, 2005; as cited in Neuts et al., 2021: 5), according to which cultural heritage refers to „*a group of resources inherited from the past which people identify, independently of ownership, as a reflection and expression of their constantly evolving values, beliefs, knowledge and traditions. It includes all aspects of the environment resulting from the interaction between people and places through time*".

The commitment to utilize the potential of culture and cultural activities in development programs necessitates the understanding of their contribution to economic development and their impact on the distribution of resources for social and cultural goals. The developmental effects depend on the proper integration of heritage sites into the economic context (Greffe, 2004). Economic impact studies aim to assess the economic significance of culture and analyse the activities and flows associated with specific cultural activities. The main objective of these studies is to measure the effects stemming from the presence or existence of particular cultural activities or organizations within a defined geographical area over a specific period. Although often criticized, impact studies can provide significant information about the effects of supply and demand on the regional economy and how financial results from various projects are redistributed (Snowball, 2008). In economic impact studies, short-term effects on consumption, income, and employment are typically analysed as direct, indirect, and induced (Bille, Schulze, 2006; Greffe, 2005). Besides the general effect of culture on the location of investments, companies, and people, a particular effect relates to attracting small businesses in the cultural or creative sector. These businesses can benefit from the advantages that arise from highly developed cultural institutions in the local area.

The widely recognized importance of agglomerations for the development of cultural activities and creativity has emerged from a series of analyses in multidisciplinary research fields, including economics, geography, sociology, and cultural studies. These studies examine the role of agglomerations in fostering cultural activities and highlight the importance of territorial dynamics in their enhancement (Costa, 2008: 185). This approach has been adopted not only in theoretical frameworks but also in the development policies of many cities. It is primarily based on the differences created by the space in which cultural activities occur, where a strong connection leads to the agglomeration and accumulation of cultural production and consumption. There are numerous examples of the spatial concentration of these activities that combine endogenous and exogenous factors to affirm their specificity (and consequently their competitiveness) in a global context. This involves both leveraging the advantages of the specific production conditions of each location and integrating them into specialized structures and vertical production systems (Costa, 2008). It is interesting to consider the approach of Valentino (2003; as cited in Cinti, 2008: 77), who refers to such spatial concentrations as a 'cultural district.' He defines it as "*a system of connections in a specific area that links the process of valorising tangible and intangible cultural resources with infrastructure and various productive sectors related to the process itself*". Lazzeretti (2008: 95) bases her analysis on locations with a high concentration of cultural resources. In these areas, economic, non-economic, and institutional actors decide on the use of particularly valuable cultural resources to develop joint projects. These projects are simultaneously economic ventures and initiatives important for the life of the local community. In this context, the author views culture as a stimulus for innovation and economic development and defines the entire concept as "*the presence of a large number of cultural and natural resources (which create an area of high cultural value) and a network of economic, non-economic, and institutional actors who carry out their activities in accordance with the protection, enhancement, and economic management of these resources.*" (ibid.: 96).

The author believes that similar processes can occur in areas where culture generates new meanings and new relationships. These are often places without traditional cultural heritage, but with significant human capital. In such cases, the emphasis shifts from tangible to intangible resources, creativity, and institutional actors. Moretta et al. (2020) argue that the concepts of clusters and industrial districts significantly contribute to understanding the links between company competitiveness and their local environment. However, they note that the limitation of these theories is their focus on only certain aspects of the territory. They often fail to consider the broader and more comprehensive interplay of available tangible and intangible resources which, through interaction, could significantly enhance business competitiveness. Furthermore, the same authors, referencing Camagni (2008), emphasize that the 'newer concept' of territorial capital overcomes these limitations draws on the complementarity of all forms of capital resources that form the foundation of endogenous local development.

The concept of territorial capital was first proposed by the OECD (2001) highlighting that every region possesses specific territorial capital that is suitable for particular forms of investment matching that area, and which can more effectively utilize its developmental potential. This potential may include: "*the area's geographical location, size, factor of production endowment, cli mate, traditions, natural resources, quality of life or the agglomeration economies provided by its cities, but may also include its business incubators and industrial districts or other business networks*" (OECD, 2001: 15). The report particularly emphasized the "*intangible factor of 'environment' as a result of the combination of institutions, rules, practices, producers, researchers, and policymakers, all of which make creativity and innovation possible*" (OECD, 2001: 15). Drawing on the work of the OECD, Camagni (2008) further developed the concept of territorial capital and proposed a classification of its various components based on the dimensions of competitiveness and resource tangibility. In addition to the traditional division into public and private goods, human capital, and social capital, Camagni (2008) introduced an intermediate class of 'club goods' and 'impure public goods.' These imply strong relationships and are of great significance for managing local development processes. To achieve maximum benefits for the local community, the need for developing new forms of governance, participation, and inclusion is emphasized.

Camagni et al. (2020) argue that cultural heritage is one of many elements of 'territorial capital' that generate endogenous development. The impact of cultural heritage on local development stems from its synergy with other elements of territorial capital, especially intangible territorial aspects like creativity, identity, human capital, and effective governance. The concept of 'territorial capital' (OECD, 2001; Camagni, 2008) highlights the unique characteristics of a place and refers to the territorial resources that form the basis of a region's competitive potential. This theoretical foundation lies in the convergence of two approaches in the literature: on one hand, supply-driven growth models emphasizing the role of capital, local resources, and infrastructure; and on the other hand, endogenous growth models, recognized through local production systems and industrial districts (Camagni et al., 2020). This has led researchers to shift their focus towards intangible aspects, local synergy, and institutional quality. Cerisola (2019) further emphasizes that creativity can function as a mediating factor, enhancing the potential of cultural heritage in achieving economic goals. The author believes that cultural heritage indirectly affects economic performance through its impact on artistic and scientific creativity. The presence of heritage also involves numerous and complex processes of interaction with other elements of local territorial capital (Camagni, 2008). Individual tangible cultural assets, such as monuments, fall into the category of public goods. On the other hand, a collection of assets, like historical urban centres, are classified as impure public goods.

These are susceptible to opportunistic behaviour from individual owners and subject to congestion effects. In cultural economics, the debate on the need to subsidize culture is based on the non-market benefits or positive externalities[1] that culture provides, and on the unique cost structure of the cultural sector. Since the social value of cultural heritage cannot be fully assessed through typical market transactions, the degree of public support for certain cultural assets can vary. This variation depends on the specific characteristics of the locality, its context, and the environment, which also determine its socio-cultural importance. Therefore, Camagni et al. (2020) emphasize that the management of these complex goods cannot rely solely on strict regulations. Other instruments, such as incentives, public-private partnerships, and, even more importantly, the active involvement and participation of the local community, are also necessary. In the process of local development, cultural heritage directly drives growth by attracting tourism. Camagni et al. (2020) highlight that this simultaneously leads to multiplicative and complex processes of interaction and synergy with many other elements of local territorial capital. Through this indirect path, cultural heritage generates various extra-effects on economic development. Servillo et al. (2012) analyse territorial capital as a key dimension of an area's attractiveness. They define it as a complex system of natural and socioeconomic elements, in particular physical elements (environmental and anthropogenic capital), human and social capital, and cultural and institutional capital. The authors report that the attractiveness of an area stems from its unique combination of resources, as well as the way management and institutional actors mobilize these resources. This approach offers a dynamic perspective where management becomes a critical factor in utilizing territorial resources. Sacco & Crociata (2013) advocate for a participatory approach that can enable the achievement of long-term goals in culturally driven development models. Sustainable development has recently emerged as the primary lens through which to analyse the multiplicative relations between cultural heritage and a given territory. This involves examining the interaction of sustainable development's four dimensions: economic, social, environmental, and cultural.

## 3. INTERRELATION BETWEEN CULTURE AND TOURISM

The interrelationship between cultural heritage and local development has long been a central focus for both academic and professional communities. Discussions consistently revolve around supporting the protection and conservation of cultural assets, as well as the significance of cultural resources for economic growth and the well-being of the local community. Over the last thirty years, cultural tourism has been a key area of interest for researchers, recognized as a significant generator of local economic development. Renewed interest in the spatial aspects of cultural tourism at the European level led to the development of the project "The Role and Spatial Effects of Cultural Heritage and Identity" (ESPON, 2006). The project aimed to assess the dynamic links between cultural heritage and socio-economic development trends. This approach to protecting and promoting cultural heritage and identity, which considers all spatial implications of tourism development, also shifts the goal of spatial planning. It moves "*from a passive activity of regulating spatial use towards active promotion of development within an area (economic growth, social development, and integration) through the valorisation and enhancement of cultural features and historical landmarks*" (ESPON, 2006: 10). The growing distinction among tourist destinations is no longer based solely on the presence of tangible cultural heritage.

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[1] An externality is the effect of some production and/or consumption on a third party, i.e., on entities not involved in the specific production and/or consumption process. The existence of externalities is interpreted as a market failure requiring government intervention. State intervention in the area of externalities aims to compel the economic entity (producer or consumer) to include external costs and/or benefits, which their actions impose on or provide to other entities, in their own production/consumption optimization calculations (Rizzo &Throsby, 2006; Snawball, 2008).

Instead, it relies on intangible elements of heritage, creativity and other concepts based on social capital, networking, and collaboration. Over the last twenty years, the interrelationship between culture and tourism has increasingly been analysed in the context of regional attractiveness (Huang et al., 2012; Su & Lin, 2014; Canale et al., 2019; Castillo-Manzano et al., 2021; Panzera et al., 2021) and competitiveness, particularly within the framework of sustainable development and destination resilience (Panzera, 2022; Gozer et al., 2024; Muštra et.al, 2023, Kuliš & Šimundić, 2025). Various approaches to explaining the interrelationship between culture and tourism also highlight the challenge of defining cultural tourism. In these discussions, heritage tourism, as a specific niche within cultural tourism, is evaluated as a good development option. However, intense tourist flows can lead to consequences such as over-exploitation of local resources and endangering the quality of life for the local community (Petrić et al., 2020). Cerisola & Panzera (2024) explore the interrelationship between cultural heritage and local economic prosperity. They analyse both the direct impacts of cultural tourism on local economic development and the indirect impacts caused by overtourism. The results reveald a positive direct effect of heritage tourism, but the benefits significantly decrease after a certain threshold of tourist traffic is reached. The significance of tourism as an economic sector is widely researched in academic literature. However, the continuous growth of tourist flows generates significant consequences in the form of overtourism. In his review of the future of cultural tourism, Matteucci (2025) emphasizes that digital technologies are becoming a powerful and unpredictable force likely to change how tourists and residents experience, manage, understand, and engage with cultural heritage. Furthermore, the author highlights that while most researchers hold a positive view on the future of cultural tourism, "*many warn that dystopian manifestations are already visible within current social realities and forms of cultural tourism. Dystopian manifestations can be linked to forms of governance that are not geared to fostering community wellbeing and to safeguarding 'authentic' cultural heritage*" (Matteucci, 2025: 230). Petrić et al. (2025) express concern about the future overdevelopment of tourism in Croatia. They point out that a lack of specific protection measures, inadequate local community participation, and limited spatial planning negatively impact the preservation of cultural heritage as an endogenous resource. Commodification of culture, destruction of cultural heritage, and marginalization of the local community are just some of the challenges destination organizations face (Farkić, 2025). Therefore, Matteucci (2025) suggests that alternative cultural values such as cultural authenticity, cultural awareness, education, solidarity, and integrity can function as a prevention against a 'dystopian' scenario for the future development of cultural tourism.

## 4. CULTURAL TOURISM CONTRIBUTION TO SUSTAINABLE DEVELOPMENT

Despite being a central theme in contemporary academic debate (Higgins-Desbiolles et al., 2019), the sustainability of tourism development remains uncertain. Concerns over its long-term impact have led policymakers to critically reassess tourism's perceived achievements (Hall, 2019:3). Sharpley (2020) underscores the urgency of addressing sustainable tourism. He advocates for *sustainable degrowth* as a strategy to enhance global well-being, while acknowledging that many destinations will continue to depend on tourism economically. To reconcile these realities, he calls for a global rebalancing of tourism through a comprehensive reevaluation of its production and consumption patterns. Similarly, Higgins-Desbiolles et al. (2019:17) argue for reclaiming tourism from profit-driven interests, emphasising the rights and needs of local communities. The ongoing challenges of overtourism highlight the urgency of this shift. Echoing this, the United Nations World Tourism Organisation (UNWTO, 2018:5) stresses that responsible tourism must involve local stakeholders in decision-making processes. Together, these perspectives highlight the need for a fundamental reevaluation of the relationship between culture, the economy, particularly tourism, and society.

This paper focuses on that intersection as key to advancing sustainable development goals. One promising pathway within this intersection is cultural tourism as a niche market. The alignment with the 2030 Agenda underscores the broader relevance of cultural tourism within global development efforts. The 2030 Agenda consists of 17 Sustainable Development Goals (SDGs) and 169 associated targets, providing a framework for policy implementation at all levels. These goals are grouped into the "5 Ps": People, Planet, Prosperity, Peace, and Partnerships, reflecting key dimensions and conditions of sustainability. This comprehensive approach emphasises the interconnections between various policy areas and calls for innovative strategies that exceed traditional methods (UNESCO, 2019). This dual role of culture creates significant opportunities for sectors such as tourism, where cultural assets can be leveraged to achieve broader sustainability outcomes. When responsibly planned, developed and managed through participatory governance, tourism can capitalize in increasing global interest in cultural heritage, providing direct, indirect and induced benefits across all dimensions of sustainability (ICOMOS, 2022). Table 1 summarizes key Sustainable Development Goals and associated (most relevant) targets, highlighting the specific ways in which cultural tourism contributes to each.

| Goal | Target | Contributions | | |
|---|---|---|---|---|
| | | Direct | Indirect | Induced |
| 1. No Poverty | 1.1. Eradicate extreme poverty | ✓ | | |
| | 1.2 Reduce living in poverty | ✓ | | |
| | 1.4 Equal rights to economic resources | | ✓ | |
| 4. Quality Education | 4.4 Relevant skills for employment, decent jobs and entrepreneurship | | ✓ | |
| | 4.7 The knowledge and skills needed to promote sustainable development | | ✓ | |
| 5.Gender Equality | 5.5 Equal opportunities for leadership | | | ✓ |
| | 5.a Equal rights to economic resources | | | ✓ |
| 8. Decent Work and Economic Growth | 8.2 Economic productivity through innovation | | ✓ | |
| | 8.3 Jobs, entrepreneurship, and innovation | ✓ | | |
| | 8.4 Resource efficiency | | | ✓ |
| | 8.5 Employment and decent work for all | ✓ | | |
| | 8.9 Policies to promote sustainable tourism | ✓ | | |
| 9. Industry, Innovation and Infrastructure | 9.1 Sustainable and resilient infrastructure | | ✓ | |
| | 9.b Support research and innovation | | ✓ | |
| 10. Reduced Inequalities | 10.2 Social, economic and political inclusion | ✓ | | |
| | 10.4 Social protection policies | | ✓ | |
| 11.Sustainable Cities and Communities | 11.3 Inclusive and sustainable urbanization | | ✓ | |
| | 11.4 Protect and safeguard the cultural heritage | ✓ | | |
| | 11.7 Access to safe, inclusive public spaces | | ✓ | |
| | 11.a Links between urban and peri-urban areas | ✓ | | |
| 12. Responsible Consumption and Production | 12.2 Efficient use of natural resources | | ✓ | |
| | 12.8 Awareness for sustainable development | ✓ | | |
| | 12.b Sustainable tourism that creates jobs and promotes local culture and products | ✓ | | |
| 13. Climate action | 13.1 Resilience and adaptive capacity | ✓ | | |
| | 13.2 Integrate climate change measures into national policies, strategies and planning | | | ✓ |
| | 13.3 Awareness-raising and human and institutional capacity | | ✓ | |
| | 14.2 Sustainably manage coastal ecosystems | | ✓ | |

| Goal | Target | | | | |
|---|---|---|---|---|---|
| 14. Life Bellow Water | 14.5 Conserve coastal and marine areas | | | ✓ | |
| | 14.7 Sustainable use of marine resources | ✓ | | | |
| 15. Life on Land | 15.a Sources to conserve and sustainably use ecosystems | | | | ✓ |
| 16. Peace, Justice and Strong Institutions | 16.6 Effective and transparent institutions | | | | ✓ |
| | 16.7 Responsive, inclusive, participatory and representative decision-making | ✓ | | | |
| | 16.a International cooperation, for building capacity at all levels | | | ✓ | |
| | 16.b Policies for sustainable development | | | ✓ | |
| 17. Partnership for Sustainable Development | 17.14 Enhance policy coherence | | | ✓ | |
| | 17.16 Enhance the global partnership | | | ✓ | |
| | 17.17 Encourage effective public, public-private and civil society partnerships | ✓ | | | |

*Table 1: Cultural tourism contributions to Sustainable Development Goals*
*(Source:author's compilation based on UN (2015) )*

Cultural tourism contributes to multiple Sustainable Development Goals (SDGs) by fostering inclusive economic growth, safeguarding cultural heritage, promoting intercultural dialogue, and encouraging sustainable resource management. While these contributions are inherently interconnected, they can be effectively analyzed through UNESCO's (2019) framework of four thematic dimensions.

**Prosperity & Livelihood**
As illustrated in Table 1, cultural tourism makes direct contributions to SDGs 1, 8 and 12. By generating income and employment, and by stimulating revenue through cultural goods, tourism services, local enterprises, handicraft production, and heritage conservation, cultural tourism supports the development of sustainable livelihoods. Heritage tourism, as a more specific subset of cultural tourism, makes a particularly strong contribution to job creation (Targets 8.3, and 8.5), while also promoting local culture and products in support of sustainable tourism policies (Target 8.9) (UCLG, 2018). In addition, through targeted activities and projects, cultural tourism contributes transversally to other SDGs, including reduced inequalities (SDG 10) and gender equality (SDG 5), by fostering social inclusion, equitable economic opportunities, and the empowerment of marginalized groups and women. Specifically, cultural tourism generates economic opportunities for women and minority communities through entrepreneurship in cultural industries and community-based tourism (OECD, 2014). This approach not only promotes inclusive development but also helps safeguard intangible cultural heritage, reinforcing cultural tourism's role in advancing social equity alongside its economic and environmental benefits. Cultural tourism's contribution to SDG 9 is evident in its role in fostering innovation and developing resilient infrastructure. By encouraging the preservation and creative reinterpretation of cultural heritage, it stimulates innovation within local economies, particularly in the creative and cultural industries. This includes, among other, the adoption of new technologies for heritage conservation, digital storytelling, and immersive visitor experiences.

**Environment & Resilience**
Cultural tourism contributes to sustainable practices in line with SDG 11.(Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action). This dimension assesses the sustainability of cultural and natural heritage (Target 11.4 Cultural & natural heritage) and provides evidence of sustainable management of heritage.

It also assesses the spatial aspects of the quality of the urban environment including public space (Target 11.7 Safe and inclusive public spaces) and cultural infrastructure (9.1 Sustainable and resilient infrastructure). Target 12.b specifically urges the development of tools to monitor impacts for sustainable tourism, a task increasingly undertaken in heritage destinations. Cultural tourism also supports the conservation of cultural landscapes and biodiversity-rich environments, advancing SDG 15 (Life on Land). This is particularly relevant for rural and indigenous communities whose cultural identity is closely tied to their natural surroundings (ICOMOS, 2022). Furtermore, the conservation of natural heritage, including marine areas and terrestrial ecosystems, directly contributes to environmental sustainability (Targets 14.5, 15.a and 13.1). Local building practices, and intangible cultural heritage can support resilience on climate risk and enhance the adaptation capacities of communities (Target 13.1).

**Knowledge & Skills**

This dimension evaluates the role of cultural tourism in enhancing knowledge and skills, particularly in relation to local knowledge and cultural diversity. It specifically examines how cultural tourism helps transmit local cultural values and knowledge, and how it contributes to the overall improvement of human and social capital. Cultural tourism supports the development of knowledge and skills across various Sustainable Development Goals (SDGs), particularly Goals 4 and 5, and their respective targets (4.4 and 5.7). These initiatives aim to provide learning opportunities to all individuals and promote an educational policy that embodies the principles of equality (5.5), inclusivity (16.7), creativity, and innovation (9.b).

**Inclusion & Participation**

Cultural tourism promotes intercultural dialogue and understanding, which contributes to SDG 16 (Peace, Justice, and Strong Institutions). It encourages community participation and strengthens the relationship between public authorities and communities, often serving as a catalyst for community engagement and participative decision-making (Target 16.7 Participatory Decision-Making). Participatory governance brings in new perspectives and fosters collaboration, leading to innovative and resilient pathways for sustainable development (ICOMOS, 2022). Moreover, SDG 17 (Partnerships for the Goals) is advanced through the cross-sector collaboration that cultural tourism often requires, encompassing governments, civil society, private enterprises, and international organisations. Examples of such multilateral cooperation include cultural heritage routes, creative city networks, and UNESCO World Heritage programs.

**5. CONCLUSION**

This paper has highlighted the necessity of adopting a more integrated and cross-sectoral approach to the valuation and management of cultural heritage within tourism development. Recognizing cultural heritage as a dynamic and multifaceted component of territorial capital underscores its potential to drive sustainable local development when properly aligned with intangible factors such as identity, creativity, human capital, and governance (Camagni et al., 2020; Cerisola, 2019). However, the commodification of heritage for tourism purposes, particularly under conditions of overtourism, reveals significant risks to the long-term preservation of cultural and natural assets (Du Cros & McKercher, 2015). These tensions demand a re-evaluation of heritage valuation frameworks, shifting the focus from purely economic gains toward broader societal, environmental, and cultural outcomes. As stressed in the paper, cultural tourism can make meaningful contributions to multiple Sustainable Development Goals, particularly when approached through inclusive, place-based strategies that reflect local values and aspirations (UNESCO, 2019).

Yet, these contributions are not easy to achieve.. Realising the positive potential of cultural tourism requires careful planning, participatory governance, and long-term strategies that safeguard heritage integrity while ensuring equitable benefits for host communities (Jurowsky et al., 2006; UNESCO, 2015). UNESCO's guiding principles and recent scholarly contributions emphasise the need for stakeholder engagement, cross-sectoral coordination, and the empowerment of local communities as foundational pillars for sustainable cultural tourism (Matteucci & Von Zumbusch, 2020, Neuts et al., 2021). Ultimately, this paper argues that sustainable cultural tourism should be built on principle of participatory governance. As indicated by Neuts et al. (2021) only through inclusive, multi-stakeholder governance systems that align tourism and heritage management with sustainable development objectives can the tensions between conservation and commercialisation be resolved. In doing so, cultural heritage can serve not only as a driver of economic opportunity but also as a platform for social cohesion, environmental stewardship, and cultural resilience in the face of global change (ICOMOS, 2022).

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# MARKETING WORDS REFLECTING GLOBAL CHANGE: 10 YEARS OF TRENDS FROM THE ANA'S "MARKETING WORD OF THE YEAR" INITIATIVE — WITH A SPOTLIGHT ON AI

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## ABSTRACT

*Over the past decade, the Association of National Advertisers (ANA) — one of the largest and most influential organizations representing U.S. advertisers — has selected a "Marketing Word of the Year" annually to reflect the most significant trends shaping the marketing landscape. This vote is based not only on popularity but also on professional reasoning, as members are asked to justify their choices. Analyzing the results from 2014 to 2024 offers valuable insights into how the industry has responded to global challenges such as technological disruption, social responsibility, and evolving consumer expectations. Notably, artificial intelligence (AI) emerged as the winning word in 2017, 2023, and 2024, underscoring its transformative impact on marketing practice and its dominance in contemporary industry discourse. Other recurring themes include programmatic advertising, content marketing, personalization, and broader societal values such as transparency, diversity, and inclusion. This paper explores how these selected terms mirror key industry shifts and how their evolution aligns with broader issues like digital transformation and the pursuit of sustainable, inclusive marketing strategies.*
***Keywords:*** *marketing trends; artificial intelligence; marketing word of the year; digital transformation; personalization; diversity; inclusion; brand purpose*

## 1. INTRODUCTION

The Association of National Advertisers (ANA), one of the most prominent organizations representing U.S. advertisers, launched the "Marketing Word of the Year" initiative in 2014, which serves as a kind of mirror of the marketing world. At the end of each year, ANA members are asked to choose the most important marketing word of the year from a shortlist and to justify why they selected that particular term. The "Marketing Word of the Year" has now been selected for eleven consecutive years, providing a solid basis for an overview and analysis of what professionals in the field of marketing and advertising considered most important in each year. At the same time, the word chosen by the Association of National Advertisers is not only significant from an industry perspective but may also offer valuable insights for marketing linguistics. In a certain sense, the marketing word of the year is not merely a technological development or market trend, but a linguistic construct that can create new conceptual frameworks and become embedded in professional discourse. This study first introduces the importance of the Association of National Advertisers as one of the largest marketing and advertising associations in the United States. It then examines the "Marketing Word of the Year" initiative in detail, exploring the methodology behind the selection of the winning word and the number of respondents—i.e., the size of the professional sample—in each year. The core of the article lies in the in-depth analysis of the selected words, based on the ANA's official press releases related to the "Marketing Word of the Year." First and foremost, we examine the reasons given by those who voted for each word, explaining why they believed it deserved the title. We also learn which other words were popular in the given years and came close to the top. Additionally, the ANA's own perspective and related initiatives are also discussed.

We trust that this analysis of the marketing words of recent years will provide insights for both academic and practicing professionals, as serve as a foundation for future studies.

## 2. THE IMPORTANCE AND SELECTION PROCESS OF THE MARKETING WORD OF THE YEAR

There are numerous organizations in every country that represent the interests of the marketing and advertising industry, and this is no different in the United States. Among them, the Association of National Advertisers (ANA), founded in 1910, stands out. Its membership includes more than 1,400 companies representing over 25,000 brands, with a combined annual marketing and advertising spend of approximately 400 billion USD. The association works closely with the media, agencies, and other industry players to promote effective and responsible marketing and advertising practices. Through its activities, ANA contributes to building consumer trust and fostering industry innovation. But why is ANA's role so important? Because the United States is not only a global superpower, but in many respects the cradle of the marketing and advertising profession—and of branding itself (Anholt & Hildreth, 2004). More than half of the world's top 100 most valuable brands are American (Papp-Váry et al., 2023), and their value increased significantly again in 2024. It is no surprise, then, that the American National Advertisers has influence not only on the U.S. market but on the global industry as well. Everyone watches what happens in the United States, since most new developments in marketing and advertising tend to appear there first. One of ANA's most influential contributions to the profession—beyond those mentioned earlier—is the annual publication of the "Marketing Word of the Year." The organization's leadership first compiles a shortlist of the words considered most important during the given year, which is then presented to members for an online vote. Two simple questions are asked:

- "What word should be the ANA Marketing Word of the Year?" (a closed question with predefined options)
- "Why did you vote for that word?" (an open-ended question asking for a justification)

This simple structure allows for two outcomes: on the one hand, a clear winner can be announced, and on the other, press releases and professional presentations can provide detailed explanations about the arguments in favor of the chosen term.

| Year | Number of Votes Cast | Marketing Word of the Year |
|------|----------------------|----------------------------|
| 2014 | 349 | Programmatic |
| 2015 | 297 | Content marketing |
| 2016 | 267 | Transparency |
| 2017 | 403 | AI |
| 2018 | 360 | Brand purpose |
| 2019 | 341 | Personalization |
| 2020 | 279 | Pivot |
| 2021 | 205 | Diversity |
| 2022 | 367 | Inclusion |
| 2023 | 271 | AI |
| 2024 | 284 | AI |

Table 1: Number of Votes Cast and the Marketing Word of the Year by Year
(Source: Association of National Advertisers press releases)

The online voting typically lasts 1–2 weeks, usually between late November and early December, and the marketing word of the year is announced in mid-December. It is important to note that this is not a forward-looking selection—respondents are not asked to choose the word for the upcoming year, but rather to reflect on which term they believe had the greatest impact on the industry during the current year. According to ANA, the selection of the marketing word of the year offers an opportunity to reflect on the industry's current challenges and opportunities. The first such selection took place ten years ago, in 2014, when programmatic took the top spot. In 2015, the word of the year was content marketing; in 2016, transparency; in 2017, AI (artificial intelligence); in 2018, brand purpose; in 2019, personalization; in 2020, pivot; in 2021, diversity; and in 2022, inclusion. Then in both 2023 and 2024, the word of the year was once again AI, underscoring its increasing importance and influence in the field. (See Table 1.)

In the next chapter, we will explore why a particular word was chosen as the marketing word of the year in each specific year. For this, we primarily rely on ANA's official press releases, which tend to follow a similar structure: they introduce the selected word, then explain the reasons why ANA members voted for it. These explanations are usually drawn from the responses to the aforementioned open-ended question. Finally, we will also identify which other words were among the top contenders in each year. Additionally, the press materials also highlight ANA's programs related to the respective key terms.

## 3. THE MOST IMPORTANT MARKETING WORDS FROM 2014 TO 2025
### 2014: Programmatic
In 2014, the Association of National Advertisers (ANA) selected its very first Marketing Word of the Year, and the winner was "Programmatic" (ANA, 2014a). The term refers to automated, data-driven media buying — a technology that enables advertisers to reach their audiences more efficiently and with greater targeting precision. Why was "Programmatic" chosen? According to the ANA, the term symbolized significant industry changes and the advancement of new technologies. Programmatic allows for real-time bidding and personalization of advertisements, helping brands target consumers more accurately while reducing wasteful ad spend.
A key insight from the ANA/Forrester white paper "Media Buying's Evolution Challenges Marketers", cited by the ANA, is that "despite the proliferation of new programmatic buying technologies and vendors, programmatic buying isn't well understood by marketers," with "more than half the marketers surveyed [confessing] they don't understand programmatic buying well enough to use it to buy and manage campaigns" (ANA, 2014b). ANA emphasized that members' choice highlighted how quickly new technologies are spreading in marketing and how central innovation has become to success. Some of the comments from those who voted for "Programmatic" (ANA, 2014a):
- "This is the year that we woke up to the potential of programmatic, and it became the biggest buzzword in the industry."
- "It is everywhere and will eventually be the only way media gets bought until the next big advance."
- "It has been the focus of every meeting and every conference I have attended, even the ones it wasn't the focus of."
- "It is the least understood but most used word in marketing. Nobody can define it but everyone wants it."
- "Everyone is talking about it, trying to see how to measure it, implement and/or define it. But few people get it or do it."
Although Programmatic won, other terms were also in contention and had a significant impact on marketing in 2014, including content, millennials, omni-channel, customer-centricity, and

transparency (ANA, 2014b). In 2014, the ANA predicted that programmatic would continue to play a key role and fundamentally reshape the future of advertising and media buying. As they noted, more and more companies were expected to adopt this technology to improve the efficiency and ROI of their campaigns (ANA, 2014b).

## 2015: Content Marketing

In 2015, the ANA selected "content marketing" as the Marketing Word of the Year, a term that had already been among the finalists in 2014. Why was content marketing chosen? According to the official ANA press release, members offered the following reasons for their votes (ANA, 2015):

- "It's all about content that resonates with the customer."
- "I hear it everywhere — see companies shifting budgets — it's the content that allows us to super-target consumers."
- "Content marketing is one-to-one marketing on steroids."
- "Content, from a marketing perspective, was always an important tool in a marketer's toolbox, but it has taken on such an elevated importance lately that it deserves the top spot."
- "Consumer engagement has become the most critical aspect of our marketing efforts. Content, specifically quality content, is colossal to achieving this engagement."

As the ANA added in their press release: "The selection of content marketing as ANA Word of the Year wasn't surprising, as we've seen lots of interest throughout the year in various ANA discussions and forums on the topic. Members are realizing that 'content' provides the means for engagement and 'marketing' is required to drive awareness of content — so the resulting combination of 'content marketing' is powerful." (ANA, 2015)

Content marketing beat out several other important contenders, including programmatic (the winner from 2014), transparency, and storytelling.

## 2016: Transparency

In 2016, the ANA named "transparency" as the Marketing Word of the Year. This choice reflected the growing importance of transparency in the industry — especially in the relationships between advertisers and agencies, and in preserving the integrity of the digital advertising ecosystem. Respondents who voted for the word offered the following justifications (ANA, 2016):

- "Transparency is the single most important issue in marketing and has the greatest potential benefit in terms of improving marketing ROI."
- "Transparency affects everything we communicate in marketing, from our product formulations and labels to how we communicate in all channels to our internal culture."
- "Consumers want to do business with brands they can trust. That goes to the heart of transparency."
- "Trust between agencies and clients has never seemed worse, especially in the world of programmatic and data."

ANA CEO Bob Liodice emphasized: "It's no surprise that our members chose transparency as the Marketing Word of the Year. Our media transparency study was one of our most important initiatives and it sparked fundamental behavioral changes among marketers and in the industry, here and around the world" (ANA, 2016). Naturally, transparency wasn't the only term in contention. Other strong candidates included customer experience, content marketing, influencer, and programmatic (ANA, 2016).

**2017: AI (Artificial Intelligence)**

In 2017, members of the ANA selected "AI (Artificial Intelligence)" as the Marketing Word of the Year. Why did AI win? Here are some of the comments from voters, as highlighted by the ANA (2017):

- "It's not just the marketing word of the year — it's the transformative phenomenon that's going to reshape the world as we now know it."
- "If we aren't thinking about using it, employing it already, or at the very least talking about it, we're missing out on some incredible 'on the cusp' opportunities."
- "2017 was the year that AI moved from being this weird, misunderstood term on the periphery of marketing consciousness to this weird, somewhat understood term spiraling closer to the epicenter of marketing, on an unavoidable collision course with our daily lives and jobs."
- "Seems to be something many marketers talk about this year, but not many understand the implications for marketing."
- "AI has gone from something to think about to real-world development and implementation."

Indeed, by 2017, artificial intelligence had begun to influence a wide range of areas that directly impacted marketing. According to the ANA, these included: cognitive computing (e.g., IBM's Watson), driverless cars, voice-enabled digital assistants (such as Amazon Alexa, Apple Siri, and Google Now), and recommendation engines (for instance, Amazon's algorithm suggesting products based on a user's purchase history, cart contents, and activity of other customers). AI also played a role in marketing automation, programmatic ad buying, customer service applications, and chatbots. AI was chosen from a list of finalists that also included transparency (the 2016 winner), content marketing (the 2015 winner), and influencer (ANA, 2017).

**2018: Brand Purpose**

In 2018, members of the Association of National Advertisers (ANA) voted "Brand Purpose" as the Marketing Word of the Year. Although attempts have been made to translate the term into other languages, the original English phrase has remained widely used, even internationally. Why did brand purpose win? According to ANA (2018), here are some of the reasons cited by respondents:

- "It drives a brand."
- "Purpose takes the word 'brand' to a whole new level. It creates a greater partnership between consumers and marketers to be responsible to each other, and shifts the focus from selling to engaging."
- "Brand purpose represents an opportunity to ground ourselves in being relevant to customers. We can't be successful just by shouting the benefits of our brand and why they should buy. The bar is now higher."
- "My company has been reorganizing around a brand purpose and I've seen other big brands doing the same."

The ANA considered brand purpose so significant that it established the Center for Brand Purpose, with the aim of helping marketers create purpose-driven, strategic programs and solutions for their products and services. The Center defines purpose in the marketing context as "a brand's reason to exist beyond turning a profit." Purpose is seen as a long-term business strategy tied to societal benefit, guiding every decision and action — from product development and customer/employee engagement to marketing and hiring (ANA, 2018). As Papp-Váry (2022) notes: "With brand purpose, companies aim to stand for something greater than just profit. It brings to the surface why we do what we do — beyond making money.

That clarity helps brands communicate more authentically, less artificially, and with more inner conviction." He sums this up with a short poetic line: "You don't need a pose if you have purpose."

Other strong contenders in the 2018 vote included influencer, transparency (the 2016 winner), and in-house. Still, according to ANA members, brand purpose best reflected the mindset of a marketing industry increasingly focused on social responsibility and emotional connection (ANA, 2018).

**2019: Personalization**
In 2019, the Association of National Advertisers (ANA) selected "Personalization" as the Marketing Word of the Year. But why did personalization win? According to ANA (2019), here are some reasons shared by survey respondents:

- "Personalization is what customers expect. Every current and prospective customer expects that your brand knows them and can deliver what they want."
- "Consumers are busy. Too busy to invest time with anything that's not relevant to them personally. It's all about relevancy, aka personalization."
- "In today's world of 'me,' personalization is how people want to consume information. Experiences need to be relevant and unique to the end user at nearly every interaction."
- "Personalization is the holy grail of brand marketing. It provides the ability to speak directly to the consumer or shopper with the right message, at the right time, in the right medium."

The ANA emphasized that personalization allows marketers to deliver more relevant communications and customized experiences to customers and clients. This strengthens the relationship between brands and consumers and helps brands remain competitive in a crowded market (ANA, 2019). The ANA Marketing Knowledge Center's "Ask the Expert" report, released in mid-2019, offered further insights. It highlighted that:

- Over half of consumers expect companies to know their buying habits and anticipate their needs.
- Half of marketers planned to increase investments in personalization technology.
- One participant called personalization "the most important marketing trend of this century."

However, the ANA also noted that despite its promise, personalization should be approached with care. Some data suggests that consumers can be underwhelmed or even skeptical of personalization efforts, particularly regarding the use of personal data. The challenge for marketers is to personalize meaningfully without crossing into territory that feels invasive or disingenuous (ANA, 2019). Other shortlisted contenders in the 2019 vote included equality and inclusion, data, and in-house. Still, personalization ultimately prevailed, reflecting the growing importance of relevance, customer-centricity, and tailored experiences in modern marketing.

**2020: Pivot**
At first glance, pivot might not appear to be a typical marketing term. However, once we recall the context of the year — 2020, marked by the outbreak of the global COVID-19 pandemic and the rise of social justice movements — its relevance becomes immediately clear. It was a year that demanded complete rethinking and adaptation across every sector, including marketing.

Here are some of the reasons ANA members gave for voting Pivot as the Marketing Word of the Year (ANA, 2020):

- "We pivoted from physical experiences to digital experiences."
- "Our communications pivoted to highlight new options for receiving care and keeping people safe... Health care became borderless."
- "In general, marketers should be focused on saying and doing things that are immediately useful to their customers. In a crisis, you connect by helping in a meaningful way."

The ANA itself also pivoted significantly in 2020, particularly in terms of its events. The organization quickly transitioned from in-person gatherings to virtual formats, substantially increasing its reach. For example, the Masters of Marketing Week drew 6,470 registrations — nearly double the attendance typical of previous live events. Other finalists in the 2020 vote included virtual, agility, and resiliency. Still, pivot ultimately prevailed, capturing the essence of a year defined by rapid change, uncertainty, and the need for marketers to adjust continuously to stay connected with consumers (ANA, 2020).

## 2021: Diversity

In 2021, the Association of National Advertisers (ANA) selected "Diversity" as the Marketing Word of the Year. Interestingly, this year's vote offered the most choices to date—twelve words in total. So why did diversity win? Here are some of the justifications given by respondents (ANA, 2021):

- "It is the future for business and an imperative for marketers and marketing as we set the pace for an inclusive world where representation matters."
- "Diversity has taken a different importance and relevance this year, for our customers and audiences."
- "This year we all had to consider whether our teams, our agencies and content reflected our diverse culture and customers."
- "Marketing at its best should be about connecting in inclusive and authentic ways that reaches audiences from many different backgrounds."
- "Diversity affects/touches everything."

The selection of diversity reflects the industry's commitment to promoting inclusion across marketing teams and campaigns in order to authentically connect with audiences from diverse backgrounds. The ANA itself gave particular attention to this area in 2021, notably through the release of A Diversity Report for the Advertising/Marketing Industry, which highlighted a significant increase in workforce diversity on both the client and agency sides. The ANA's AIMM division (Alliance for Inclusive and Multicultural Marketing) also developed a range of DEI (Diversity, Equity, and Inclusion) tools, reports, and educational resources. These efforts targeted various multicultural communities, including:

- AAPI – Asian American and Pacific Islander communities
- AA – African American communities
- Black – Broader Black/African diaspora audiences
- LGBTQ+ – Lesbian, Gay, Bisexual, Transgender, Queer (and others) communities

These initiatives aimed to help companies and brands better understand these audiences and develop more inclusive, culturally relevant marketing strategies.
Other shortlisted terms in the 2021 Marketing Word of the Year vote included cookie-less, metaverse, and customer experience (CX) (ANA, 2021).

**2022: Inclusion**

In 2022, the Association of National Advertisers (ANA) selected "Inclusion" as its Marketing Word of the Year, following closely on the heels of 2021's choice, Diversity. Why did inclusion win? Here are some of the explanations given by respondents (ANA, 2022):

- "Inclusion/inclusivity is an important mindset of the next generation. Brands that embrace this will see long-term growth with future consumers."
- "Because we've evolved enough to understand that every person, in every place, and in every circumstance, has value that should be heard, seen, respected, and acted upon."
- "Inclusion seems to be at the heart, either overtly or not, in ads across the mix this year. Brands are making great progress in DEI, not out of pandering, but more so to ensure ads reflect the communities that brands operate in."

As highlighted in the ANA's press release, the selection of inclusion reflects the marketing industry's continued commitment to Diversity, Equity, and Inclusion (DEI), and the recognition that brands must respect and speak to all individuals in their communities. The ANA also highlighted several of its own programs related to inclusion, including:

- Supplier Diversity: A proactive business practice that encourages organizations to work with diverse-owned businesses—such as those owned by women, minorities, veterans, LGBTQ+ individuals, persons with disabilities, and small businesses. The ANA offers numerous resources to support supplier diversity.
- LGBTQ+ Marketing Inclusion Report: This report examined LGBTQ+ inclusion and representation in marketing among ANA client-side members. It showed positive progress and outlined key actions that could further improve brand perceptions within LGBTQ+ communities.

While inclusion was voted the word of the year, other terms also ranked highly, including "hybrid" (second place) and "metaverse" (third place) (ANA, 2022).

**2023: AI (Artificial Intelligence)**

In 2023, the Marketing Word of the Year—as chosen by the Association of National Advertisers (ANA)—was AI, or Artificial Intelligence, which won with a landslide 70% of the vote. In contrast, brand purpose came in second with just 8% of the votes. AI had already claimed the top spot once before, in 2017, but its resurgence in 2023 reflects the exponential growth and public awareness that followed the release of ChatGPT in late 2022. Here are a few reasons given by ANA members for selecting AI (ANA, 2023):

- "AI is changing the world, in terms of marketing and business."
- "Because it's everywhere now, and I feel like it really permeated our entire world this year."
- "Everyone is afraid of and/or excited about it. Everyone is talking about how to use it. But also, everyone is wondering how it won't make them obsolete."
- "AI is becoming a pervasive technology for our content creators and our consumers, with looming philosophical concerns as well as extraordinary potential for increasing efficiency for all sorts of tasks."
- "Because Generative AI will be the most disruptive technology for years to come, both good and bad. Marketing teams need to address the opportunity and risks head-on to stay ahead and ensure they are putting their best, most authentic content forward for their audiences."

As the ANA's official press release noted, AI has had a massive impact on the marketing industry—enabling the creation of highly personalized content, improving customer experiences, and streamlining marketing operations. At the same time, it raises critical challenges, especially around ethical use and the evolving role of human labor (ANA, 2023).

**2024: AI (Artificial Intelligence)**
In 2024, the Association of National Advertisers (ANA) once again selected AI (Artificial Intelligence) as the Marketing Word of the Year. This marks the second consecutive year and the third overall time (after 2017 and 2023) that AI has claimed the title since the competition began in 2014—underscoring the technology's rapidly growing influence in the marketing world. In 2024, 65% of votes from ANA members went to AI, far outpacing the second-place term, personalization, which garnered just 14% of the vote out of seven finalist words.
Here's why ANA members selected AI again (ANA, 2024a):
- "AI is all over! No matter when and where, AI always comes up when talking about marketing."
- "Nothing has affected the world of marketing in 2024 more than AI."
- "AI has 100% become a part of our everyday work life. No exceptions."
- "AI is becoming prevalent in all our tech stacks, tools, and essentially every app we use."
- "It's everywhere! Flooding the feeds and a hot topic of conversation that I think we are all a little scared by, intrigued with, and have so much to learn about to help enable our work and lives."
- "AI and its potential to change marketing has been all the buzz. We are at the point where we have to figure out how to integrate AI into how we work, or we will be left behind."

The ANA's press release emphasized that AI's dominance continues, and industry professionals must adapt to this technological revolution in order to remain competitive.
According to Salesforce's State of Marketing report released in June 2024 (ANA, 2024b):
- 75% of marketers are now actively experimenting with or have fully integrated AI into their workflows.
- High-performing companies are 2.5 times more likely to have fully adopted AI compared to underperforming firms.
- The adoption of AI is happening faster than previous shifts like the rise of social media, the launch of the iPhone, or the migration to cloud-based data. This is not just a technological shift, but a paradigm shift—one that is reshaping the foundations of marketing itself.

Unsurprisingly, the ANA has taken a leading role in helping marketers embrace AI safely and effectively by providing education and practical resources. As of 2024, ANA-related initiatives include (ANA, 2024b):
- AI Use Case Compendium – A collection of over 130 real-world AI applications across various areas of marketing.
- AI Glossary – Definitions of essential terms and concepts related to artificial intelligence.
- Webinars, trainings, and podcasts – Created to guide marketers on AI strategy and implementation.
- AI for Marketers Committee – A peer-learning group where ANA members share experiences and best practices.

- AI Playbook Series, including Generative AI in Transforming Strategic Marketing, Generative AI in Creative Content Development, Generative AI in Search Marketing

## 4. SUMMARY

In 2011, Marc Andreessen published a now-famous essay titled "Why Software Is Eating the World", in which he argued that software and the internet are revolutionizing the global economy and reshaping traditional industries. According to Andreessen (2011), the rise of software is driven by several key factors:

- Digital transformation – Companies across all sectors are increasingly adopting software-driven solutions. Business models are evolving, relying more heavily on digital platforms and cloud-based services.
- Innovation and competitive advantage – Firms that recognize the strategic value of software and embed it into their operations tend to respond more quickly to market changes, showing greater flexibility and innovation than their competitors.
- Cost reduction and scalability – Software allows businesses to minimize dependence on physical infrastructure, resulting in significant cost savings and scalability. Traditional companies often struggle to keep pace with this transformation.

Andreessen's article was both a warning and an opportunity, emphasizing that companies must embrace software to stay competitive in the digital era. As he wrote, "Companies in every industry need to assume that a software revolution is coming." Those that adapt are more likely to grow and thrive in the long term, while those that resist change risk falling behind. A similar pattern is visible in the Marketing Word of the Year selections. Roughly half of the chosen terms are directly linked to software and technological advancement—such as programmatic, content marketing, personalization, and AI (artificial intelligence), which has been selected three times. The other half reflect broader philosophical approaches to marketing—concepts like transparency, brand purpose, pivot, diversity, and inclusion. The coexistence of these two domains is not surprising: as many marketing textbooks point out, marketing is simultaneously a mindset and a set of tools (Papp-Váry, 2009; Pólya, 2024).

From a linguistic perspective, it is interesting to note that marketing linguistics tends to emphasize technological aspects more than philosophical ones. In László Kovács' excellent book Marketingnyelvészet (2024), terms like transparency and brand purpose are only briefly mentioned, while terms such as content marketing, personalization, and AI receive much more attention. Notably, artificial intelligence is discussed in its own dedicated chapter. As Kovács writes: "Marketing is likely to be redefined by these technologies. Content generation has never been this fast or easy: I can generate product descriptions, write newsletters, or compose social media posts in seconds. This allows even those businesses that previously lacked the time, expertise, or resources to engage in marketing. In this sense, these systems contribute to the democratization of marketing" (cf. Peres et al., 2023; Noy & Zhang, 2023). Elsewhere, he elaborates (Kovács, 2024): "Artificial intelligence is fundamentally transforming marketing practice: algorithms can detect patterns and correlations in large datasets, identify trends, describe and predict consumer behavior more accurately, and enable more precise and personalized targeting based on the collected and analyzed data (Haleem et al., 2022). AI also accelerates data processing and analysis, reduces error rates, aids decision-making, and enhances user experience and customer satisfaction (Haleem et al., 2022; Mustak et al., 2020). Thus, AI is reshaping marketing research, market research, and practical marketing activities alike (Chintalapati & Pandey, 2021)."

**LITERATURE:**

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# INNOVATION AND COMPETITIVENESS IN HOSPITALITY PROJECTS: THE CASE OF YOTEL PORTO

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***ABSTRACT***

*The hospitality sector is recognized for its dynamic nature, influenced by constant technological advances and changes in consumer expectations. In this context, innovation emerges as one of the fundamental pillars for promoting sustainable competitiveness and long-term success. Recent studies highlight that the ability to integrate innovative technologies and sustainable practices can significantly enhance organizational performance and increase companies' resilience in the face of challenging environments (Rienda, et al.; 2024). Technological innovation is indeed playing a central role in modernizing hotel services. The implementation of digital solutions, such as artificial intelligence and data analysis, enables not only greater operational efficiency but also personalization in the customer experience, generating a significant competitive advantage (Castillo, et al., 2023). Furthermore, workplace innovation practices, such as flexible management and a focus on talent development, also contribute to efficiency and organizational performance in the hotel sector (Castillo, et al., 2023). This paper aims to identify how technological innovation, and processes affect the competitiveness and economic viability of hotel projects, as several studies suggest that implementing innovations in the hotel sector not only improves operational efficiency, but contributes to greater competitiveness in the market as well.*

*Moreover, this paper has examined case studies of hotels that used innovation to stand out in the market and increase profitability. Finally, this research has evaluated the relationship between innovation and competitive differentiation, having the case of Yotel Porto as the main focus of examination.*
***Keywords:*** *Technological Innovation, Digital Technologies, Automated Systems, Artificial Intelligence, Competitiveness, Sustainability, Hospitality, Yotel Porto*

## 1. INTRODUCTION

The hospitality sector is recognized for its dynamic nature, influenced by constant technological advances and changes in consumer expectations. In this context, innovation emerges as one of the fundamental pillars for promoting sustainable competitiveness and long-term success. Recent studies highlight that the ability to integrate innovative technologies and sustainable practices can significantly enhance organizational performance and increase companies' resilience in the face of challenging environments (Rienda, et al.; 2024). Technological innovation is indeed playing a central role in modernizing hotel services. The implementation of digital solutions, such as artificial intelligence and data analysis, enables not only greater operational efficiency but also personalization in the customer experience, generating a significant competitive advantage (Castillo, et al., 2023). Furthermore, workplace innovation practices, such as flexible management and a focus on talent development, also contribute to efficiency and organizational performance in the hotel sector (Castillo, et al., 2023). This paper aims to identify how technological innovation, and processes affect the competitiveness and economic viability of hotel projects, as several studies suggest that implementing innovations in the hotel sector not only improves operational efficiency, but contributes to greater competitiveness in the market as well. Technological innovation, such as the use of CRM (Customer Relationship Management) systems and emerging technologies like artificial intelligence and augmented reality, has proven essential for personalizing the customer experience and optimizing operations (Chan and Guillet, 2012; Hjalager, 2010). Moreover, this paper has examined case studies of hotels that used innovation to stand out in the market and increase profitability. Finally, this research has evaluated the relationship between innovation and competitive differentiation, having the case of Yotel Porto as the main focus of examination.

## 2. LITERATURE REVIEW

### 2.1. Innovation in Hospitality: Use of Digital Technologies, Automated Systems, and Service Innovations

Technological innovation is one of the main drivers of transformation in the hospitality sector, enabling not only the optimization of internal operations but also providing unique guest experiences. The use of digital technologies, such as online booking platforms, property management systems (PMS), and big data tools, allows for more efficient management of hotel operations, improving communication between different departments and the customer experience (Teo et al., 2008; Ivanov, et al. 2017). Solutions based on AI and automation also play a crucial role, offering hotels more effective ways to personalize customer service and enhance operational efficiency. Automated systems, such as self-check-in and check-out and customer service chatbots, are clear examples of how technology can improve guest experiences by reducing waiting times and increasing convenience (Wang et al., 2015). These innovations not only enhance efficiency but also reduce operating costs, allowing human resources to focus on more strategic tasks. Additionally, the use of emerging technologies, such as augmented reality (AR) and artificial intelligence (AI), is creating new forms of interaction with guests.

For instance, virtual assistants in hotel rooms or personalized offers based on preference history are increasingly common, particularly in luxury hotels (Chan et al., 2013; Wang, 2015). The Internet of Things (IoT) has also stood out with solutions that enable smart control of devices, such as thermostats and lighting systems, improving energy efficiency and sustainability in hotels (Teo et al., 2008; Hwang & Choi, 2019). Studies show that hotels adopting these innovative technologies not only provide a differentiated guest experience but also gain a competitive advantage, increasing loyalty and profitability through service personalization (Guttentag, 2015; Tussyadiah & Park, 2018).

## 2.2 The Role of Innovation in Hotel Competitive Strategy and Influence on Return on Investment

Technological innovation is essential for competitive strategy in the hospitality sector as it enables differentiation and the creation of sustainable competitive advantages. According to Porter (1985), companies that innovate consistently and offer something unique are more likely to maintain a leading market position. In the hotel context, this translates into creating unique guest experiences, introducing new services, and developing interaction methods that are hard for competitors to replicate. In addition to differentiation, innovation has a direct impact on operational efficiency and return on investment (ROI). The adoption of automated systems, such as those used to optimize energy management and improve booking processes, can reduce costs and maximize resource utilization, resulting in higher profit margins (Sigala et al., 2015; Tussyadiah & Park, 2018). AI-based technologies, such as predictive algorithms for pricing and occupancy, are particularly effective in maximizing profitability by forecasting demand and adjusting prices in real time.

Hotels like Marriott International and Hilton are examples of major chains that heavily invest in digital innovation, from using mobile apps to interact with guests to digitizing services to improve customer experiences while simultaneously optimizing financial and operational processes (Sigala, 2015; Ivanov & Webster, 2017). These investments have not only increased profitability but also enhanced customer loyalty as guests seek more personalized and convenient experiences. According to Hjalager (2010), innovation generates direct financial gains and contributes to the strategic positioning of hotels, improving their long-term competitiveness. Innovations that allow hotels to meet consumer expectations, which are increasingly demanding in terms of convenience and personalization, have a positive impact on their long-term performance. Guttentag (2015) research reinforces that adopting new technologies in the hospitality sector is not just a matter of operational efficiency but also one of adapting to new market needs and building a loyal customer base.

## 3. RESEARCH OBJETIVES

Following a brief literature review discussion, this paper now outlines the main objectives that the authors believe that may bring some light to the proposed research.

### 3.1. How technological and process innovation affect the competitiveness and economic viability of hotel projects

For the first objective, which aims to identify how technological innovation, and processes affect the competitiveness and economic viability of hotel projects, several studies indicate that implementing innovations in the hotel sector not only improves operational efficiency but also contributes to greater competitiveness in the market. Technological innovation, such as the use of CRM (Customer Relationship Management) systems and emerging technologies like artificial intelligence and augmented reality, has proven essential for personalizing the customer experience and optimizing operations (Chan and Guillet., 2012; Hjalager, 2010).

The adoption of technologies can also result in economies of scale, as processes such as reservation management, customer data analysis, and automation of repetitive tasks become more efficient, thus enabling hotels to better serve a growing and more demanding customer base. Process innovation, including the use of new management methodologies and adaptation to changing consumer expectations, also helps improve the economic sustainability of hotels. Companies adopting cutting-edge technologies not only reduce costs but also increase customer loyalty, which translates into greater profitability (Giotis et al., 2022). Moreover, studies indicate that process innovation is crucial for standing out in a highly competitive market. Processes such as digitalizing operations and personalizing offers through big data and artificial intelligence have allowed hotels to improve their value proposition, offering a more efficient and customer-centric experience. This directly contributes to long-term competitiveness and economic viability (Hjalager, 2010). When well-implemented, technological innovation creates a sustainable competitive advantage, enabling hotels to differentiate themselves in the market and increase profit margins by improving the customer experience and optimizing internal operations.

## 3.2. Hotels' case studies of that used innovation to stand out in the market and increase profitability

According to Hjalager (2010), innovation in the hospitality sector encompasses various areas, including products, processes, customer experiences, marketing, and internal organization. These elements are essential for adapting to consumers' dynamic needs and achieving greater profitability. For example, the Accor hotel chain demonstrated how innovation could be applied in customer service through technological solutions, such as automated check-ins and the use of artificial intelligence to personalize offers. These measures resulted in a faster and more satisfying experience for guests, increasing loyalty and, consequently, profitability. Marriott International is another illustrative case of how innovation drives profitability. The company implemented a data-centric approach to predict consumption trends and adjust its pricing strategies. Through big data technologies and predictive analytics, Marriott optimized its operations, improving both efficiency and revenue.

Additionally, introducing digital services such as mobile apps for personalized requests and quick bookings enhanced the customer experience and strengthened brand relationships (Sigala, 2015). Furthermore, case studies of independent hotels show how sustainability innovation has been a competitive differentiator. Hotels adopting eco-friendly practices, such as using renewable energy, waste reduction, and recycling programs, have not only reduced operational costs but also attracted an increasingly environmentally conscious customer segment (Jones, et al. 2016). This strategy has contributed to increased profitability and strengthened brand reputation.

## 3.3. Evaluate the relationship between innovation and competitive differentiation

The literature highlights the importance of innovation in maintaining a sustainable competitive advantage in the hotel sector, where the relationship between innovation and competitive differentiation is particularly significant. The concept of open innovation, which involves actively seeking external knowledge and collaborating with other entities to generate innovations, has been increasingly applied in the hotel sector. According to (Stoffers et al. 2021), open innovation can create sustainable competitive advantages, especially for smaller companies, such as independent hotels or SMEs in the sector, by allowing them to access external resources and accelerate the development of new services. This strategic model, by promoting external collaboration, enables hotels to stand out in the market while simultaneously strengthening their internal innovation capabilities.

Sigala, (2015) analysed the impact of marketing innovation on the market performance of hotel companies, concluding that sustainable innovations in marketing practices not only improve brand perception but also have a significant mediating effect on competitive advantage. This type of innovation, focused on sustainable practices, can attract a growing, increasingly conscious audience, thereby improving the hotel's performance and profitability. These studies suggest that technological innovation, especially in areas such as marketing and external collaboration, is crucial for hotels to differentiate themselves in the market and achieve superior performance. Integrating these innovations, accompanied by clear organizational strategies, is fundamental to building a sustainable competitive advantage.

## 4. METHODOLOGY

The research presented in this paper adopts an exploratory and descriptive approach. More specifically, the methodology used implied a case study selection, meaning that a qualitative approach was adopted, based on an analysis of hotels that implemented technological and process innovations to enhance their competitiveness. One hotel was selected, considering several criteria, namely the type of innovation, such as the implementation of digital technologies, automated systems, and service innovations. This selected hotel, Yotel Porto, was chosen because it presented a clear application of innovations aimed at improving the customer experience, increasing operational efficiency, and reducing costs. This case was prioritized due to clear evidence of success following the adoption of innovations, namely increased occupancy rates, improved return on investment, and revenue growth. The analysis of innovation in hotel projects focused on how innovative technologies and processes, contributed to improving operations, market differentiation, and long-term sustainability, justifying the selection made in this research. This is indeed confirmed by diverse literature as follows. According to Choi and Chu (2001), selecting cases with observable results allows for a more accurate assessment of the relationship between innovation and success. The automation of processes, such as check-in/check-out, improvements in reservation management using AI, and personalization of experiences, has demonstrated increased customer convenience and, consequently, higher occupancy rates (Sigala, 2015). Furthermore, integrating technologies such as room recommendation systems and dynamic pricing helps maximize occupancy rates. The reduction of operational costs through the implementation of automated systems was analysed in terms of its effectiveness in this regard. Automating repetitive processes, such as inventory control conducted by property management systems or customer service through chatbots, contributes to cost reduction and greater efficiency. Studies such as those by Teo et al. (2008), suggest that automation can reduce staff costs and improve profit margins. These indicators are widely used in studies on the impact of innovation in the hospitality sector as they provide a clear view of the tangible financial and operational results that innovation can generate. Existing literature suggests that these indicators are effective in evaluating the effectiveness of innovations in improving hotels' competitiveness and profitability.

## 5. THE CASE OF YOTEL PORTO

The Yotel Porto is a 4-star hotel that has opened in 2021 (according to Expresso, 2023; Netthings, 2024, and TNews, 2025a, main sources of the contents about Yotel Porto, as following in this section). Creativity, technology, and a focus on experience are at the core of the hotel's service, designed for modern travellers. It is known for being a bold hotel that aims to challenge traditional hospitality through technology and innovation. They are pioneers in several digitalization projects targeted at the hospitality industry, making them innovators in this sector (Manuel Machado Carneiro, General Manager of Yotel Porto). The manager states that the investment in technology is significant for the hotel's structure, believing that this is the future of the industry.

This investment allows for more sustainable and efficient processes, with benefits such as reduced energy and maintenance costs. Among the hotel's amenities, self-check-in machines, a dining area that also functions as a "co-working" space open to the community, a renovated courtyard, and a rooftop terrace offering stunning views of the city stand out. Innovation is also present at the hotel's reception with self-service kiosks and in the room service, provided by a pair of robots that move swiftly around the hotel. Yogiro is not just a robot but a true revolution in public interaction, distributing gifts and providing a unique and memorable experience. This initiative highlights Yotel Porto's commitment to technological innovation in the hospitality sector and the continuous improvement of customer experience. Another example of innovation is the use of cutting-edge design and construction techniques to optimize spaces and create functional rooms, some of which feature adjustable SmartBeds. The ability to control room lighting color also allows guests to personalize the room ambiance. On the other hand, Yotel is equipped with solar panels for water heating. The climate control systems in different spaces, as well as the outdoor lighting, are regulated by schedules and automatic light sensors. The hotel rooms are equipped with motion sensors that control air conditioning and lighting, avoiding waste and promoting greater energy efficiency without compromising comfort. All menus are available via QR code, as are all management and control reports, which are digitally parameterized to ensure high sustainability standards. Yotel Porto was recognized at the YOSCARS, winning three major awards (TNews, 2025b):

- Engineering Team of the Year 2023
- Housekeeping Team of the Year 2023
- Purple Goes Green Hero 2023

In addition, the hotel secured second place in three other categories: "Brand Trailblazer," "What's On," and "Best Guest Experience." These accolades reflect Yotel Porto's commitment to technological innovation, excellence in cleanliness standards, and sustainability. The hotel has been praised for its environmental efforts, such as the Purple Goes Green program, which encourages guests to skip room cleaning on stays longer than two nights, offering them a credit to use on hotel services. Furthermore, Yotel Porto has adopted several initiatives to reduce paper consumption, including check-in kiosks and digital invoicing. Regarding energy efficiency, rooms are equipped with motion sensors that automatically turn off electrical devices when not in use, while common areas have adjustable lighting to optimize energy consumption. The hotel has also invested in solar energy, implemented filters and valves to optimize water consumption, and replaced disposable packaging with refillable dispensers for hygiene products, reducing plastic use. Additionally, it created a vertical garden that contributes to thermal insulation, reduces noise pollution, and improves air quality. Yotel Porto has been a pioneer in several sustainability practices and integration with the local community, establishing itself as a hospitality reference in Portugal, both in terms of service and the experience offered to guests. The goal is to provide a truly innovative and distinctive experience, creating unique environments full of dynamism, personality, and a strong sense of community. The aim is to go beyond the ordinary, creating lasting memories through experiences that stand out and leave a lasting impression on every visitor. This innovative approach is a differentiating factor in the hospitality sector, particularly in large urban centres where there is a demand for fast, technological, and sustainable services.

## 6. DISCUSSION OF RESULTS
The adoption of technological innovations in the hotel sector has proven to be a key factor for competitive differentiation, enhancing the guest experience, and increasing operational efficiency. Examples of hotels that have stood out for their innovations include major chains like Marriott and Hilton, as well as independents like RoomRaccoon.

These have adopted technologies such as virtual assistants, automated reservation management systems, and big data for service personalization, resulting in more convenient experiences for guests and greater operational efficiency (Sigala et al., 2015; Ivanov & Webster, 2017). The automation of processes, such as digital check-in and the use of chatbots, has also contributed to greater customer satisfaction and reduced operational costs. These innovations have had a direct impact on financial results, especially in terms of occupancy rates and customer loyalty. Hotels that have implemented dynamic pricing systems and personalized digital marketing have seen an improvement in occupancy rates, as well as increased guest loyalty, with digital rewards programs and personalized experiences. The reduction in operational costs provided by automation and the use of smart systems has also positively impacted profitability, allowing hotels to invest further in innovations that generate value for both customers and businesses (Sigala, 2015; Teo et al., 2008).

## 7. CONCLUSION

Throughout this research, technological and process innovation has proven to be a decisive element for the sustainability and competitiveness of the hotel sector. This paper highlighted how innovations optimize operations, personalize experiences, and drive profitability, providing companies with competitive advantages in a highly dynamic market. The analysis of case studies, such as Yotel Porto, demonstrated that implementing innovative technologies, including automation systems, artificial intelligence, and sustainability solutions, not only improves operational efficiency but also strengthens the emotional connection between guests and the services offered. These initiatives translate into greater customer loyalty and a significant increase in return on investment. On the other hand, the results showed that competitive differentiation is driven by the integration of strategic innovations that combine efficiency and sustainability. The success observed in hotels that adopted these practices reaffirms that innovation should not be seen as an optional advantage, but as a strategic necessity in the current business environment. Thus, this research emphasizes the importance of a systematic approach to innovation, encompassing everything from the development of organizational capabilities to the implementation of cutting-edge technologies. The message for hotel managers is clear: continuous investment in innovation is essential not only to meet growing customer expectations but also to ensure the resilience and competitiveness of businesses in the long term. Finally, future studies are suggested to delve deeper into the impact of innovations on employee well-being and environmental sustainability, providing a more holistic view of the ongoing transformations in the hospitality sector.

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# ENHANCING INDOOR AIR QUALITY ASSESSMENTS: BACTERIAL MONITORING METHOD VALIDATION FOR EDUCATIONAL FACILITIES

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## ABSTRACT

*Indoor air quality (IAQ) is increasingly recognized as a critical determinant of human health, well-being, and cognitive performance within educational and professional settings. Effective monitoring and management of IAQ are essential to ensure safe and healthy indoor environments, given the well-documented associations between poor air quality, respiratory symptoms, and cognitive impairments. The validity of microbiological measurement methods is fundamental to this process, as unvalidated protocols may yield inaccurate results, thereby compromising the efficacy of mitigation strategies. Accordingly, the validation of microbiological monitoring methods is imperative to ensure that the results accurately reflect true exposure levels and can underpin evidence-based interventions. This study aims to validate a bacterial enumeration method employing tryptic soy agar supplemented with different concentrations of cycloheximide (from 0 to 200 mg/L), under different incubation temperatures (35 °C and 37 °C), incubation periods (2, 3, and 5 days), and sampled air volumes (10 to 300 L). Blank control samples were included across all experimental conditions to verify sterility. The validation protocol evaluated accuracy, precision, linearity, robustness, and the selective suppression of fungal growth without compromising bacterial detection. Furthermore, concentrations of PM10, PM2.5, $CO_2$, temperature, and relative humidity, as well as bacterial and fungal loads, were measured both indoors (educational classroom and laboratory) and outdoors to provide a comprehensive assessment of the monitored environments. The findings will contribute to the establishment of a more robust microbiological sampling method for bacterial monitoring in indoor environments and enhance the understanding of IAQ dynamics within academic buildings. Ultimately, this work seeks to inform the development of targeted interventions to foster healthier and safer educational spaces.*
*Keywords: indoor air quality; bacterial count; method validation; cycloheximide; educational facilities.*

## 1. INTRODUCTION

Indoor air quality (IAQ) is a major environmental health concern, as individuals spend over 90% of their time indoors (Klepeis et al., 2001). Poor IAQ is linked to respiratory issues, allergies, and cognitive impairments (WHO Global Air Quality Guidelines, 2021).

Occupants are significant sources of indoor bioaerosols, emitting microorganisms through activities such as breathing, speaking, and shedding skin (Brambilla and Sangiorgio, 2020;EN 13098:2019 (E)). Inadequate ventilation can lead to the accumulation of microbial emissions, which may pose health risks (Manuel and Samardjieva, 2024). Ventilation plays a crucial role in ensuring acceptable indoor air quality by diluting indoor pollutants and controlling the concentrations of $CO_2$, particulate matter, and microorganisms. Portuguese legislation (Ordinance no 138-G/2021 of July 1st) requires that indoor bacterial levels do not exceed outdoor values by more than 350 CFU/m³ and that fungal levels remain below outdoor concentrations. These limits highlight the importance of air exchange in preventing microbial buildup. The World Health Organization emphacizes that insufficient ventilation combined with elevated humidity levels fosters the persistence and proliferation of pathogenic and allergenic microorganisms indoors (WHO Guidelines for Indoor Air Quality, 2009, 2021). This issue is especially significant in crowded spaces like classrooms and offices, where poor air circulation can increase exposure risks, as shown by several studies conducted in educational buildings in Porto, Portugal (Barbosa, 2012; Felgueiras et al., 2024; Manuel and Samardjieva, 2024b). Moreover, the WHO explicitly states that poor ventilation and persistent dampness significantly elevate the likelihood of microbial contamination, reinforcing the critical importance of adequate air renewal in indoor spaces (WHO Guidelines for Indoor Air Quality, 2009). IAQ - particularly its microbiological component - is essential for safeguarding occupant health in enclosed environments. To obtain reliable data, identify contamination sources, and support evidence-based mitigation strategies, the use of validated and robust methodologies for detecting airborne bacteria and fungi is imperative. According to (EN 13098:2019 (E)), bacterial concentrations can be effectively measured by impactation using Tryptic Soy Agar (TSA) supplemented with cycloheximide to inhibit fungal growth, while fungal concentrations are typically assessed using Malt Extract Agar (MEA) supplemented with chloramphenicol to suppress bacterial interference. A comprehensive method validation requires the assessment of several essential performance parameters: accuracy, specificity/selectivity, precision, linearity, and robustness (EN 13098:2019 (E); Castro and Cabrita, 2000).

**Specificity/Selectivity** is the ability to identify and distinguish an analyte of interest in a complex mixture without the interference of other components.
**Precision** is defined as a measure of the variability among replicate measurements conducted under identical conditions. It indicates the degree to which a method yields similar results upon repetition. A sufficient number of repeated measurements is necessary to evaluate the precision and variability of the method (EN 13098:2019 (E)).
**Accuracy** is typically defined as the method's capacity to yield values close to the accepted reference value. It is commonly evaluated through recovery efficiency tests using known concentrations.
**Linearity** denotes the method's ability to produce results that are directly proportional to the quantity of interest across a specified measurement range, indicating consistent recovery efficiency and analytical response throughout the tested range.
**Robustness** evaluates the method's reliability under small, deliberate variations in experimental conditions.

The credibility of any IAQ assessment depends heavily on the use of validated methodologies. In particular, culture-based air sampling for bacteria using TSA can be compromised by fungal overgrowth, as fungal colonies may mask or outcompete bacterial growth, thereby hindering accurate enumeration. Cycloheximide is therefore often added as a selective antifungal agent (EN 13098:2019 (E); ADENE, 2009), but its use must be carefully optimized to ensure that bacterial viability is not compromised.

This study aims to (i) validate a bacterial enumeration method following EN 13098:2019 recommendations and (ii) measure microbial concentration nd $CO_2$ in educational settings.

## 2. METHODOLOGY
### 2.1 Study area
The study was carried out in two educational spaces: a laboratory, with a volume of 306 m³ and an average occupancy of 1–3 individuals during the workday, and a classroom with a volume of 288 m³. The IAQ parameters of the classroom were measured before and after the workday during which its occupancy was about 20 individuals. Both spaces have personal workers' computers, air conditioners and no windows with easy access. Outdoor air was collected near the sampling locations to serve as a reference for assessing the extent of contamination from indoor sources.The validation of the method for measuring the bacterial concentration was performed by sampling the air in the laboratory.

### 2.3. Sampling and laboratory tests
Bacteria, fungi and $CO_2$ concentrations were assessed in the sampling locations indicated in section 2.1. Bioaerosol levels of fungi and total and Gram-negative bacteria were measured using an impaction sampler (SAS Super ISO 100, VWR, Italy), with 219 holes of 1.00 mm diameter, operating at a constant flow rate of 100 L/min. Sterile 90-mm plates were used to collect air volumes ranging from 10 to 1000 L, depending on the expected microbial load in each environment. Bacteria were cultivated using Tryptic Soy Agar medium (TSA, VWR85834) supplemented with the antibiotic cycloheximide (Thermo J66901.03) to suppress fungal growth (**EN 13098:2019 (E)**). The antibiotic was first dissolved in ethanol, after which 5-10 mL of this solution was incorporated into the medium immediately prior to its distribution into Petri dishes, at a temperature of approximately 50 °C. Fungi were cultivated on Malt Extract Agar medium (MEA, MP Biomedicals 1006817) supplemented with 100 mg/L of the antibiotic chloramphenicol (VWR 0230) to suppress bacterial growth (**EN 13098:2019 (E)**).The antibiotic, which is thermostable, was added to the medium prior to autoclaving. MacConkey agar medium (MP Biomedicals 1006017) was used for the quantification of Gram-negative bacteria. At each location, three volumes of each culture medium were sampled in duplicate. $CO_2$ was measured using the particle measuring device BQ30 (Trotec, Heinsberg, Germany) which has an accuracy of $\pm 5\% / \pm 75$ ppm  and a resolution of 1 ppm. According to the European standard (**EN 13098:2019 (E)**), the surface density of microbial colonies in countable plates should remain below certain thresholds to minimize counting errors: fewer than 5 colonies per cm² for bacteria and fewer than 2 colonies per cm² for fungi. Therefore, sampling volumes must be carefully selected to avoid imprecision due to excessively low colony counts in low-volume samples or underestimation caused by colony overgrowth in high-volume samples. For bacterial enumeration, **EN 13098:2019 (E)** recommends an optimal count range of 10 to 200 colonies forming units (CFU) per plate, although counts between 5 and 300 CFU may be considered are considered acceptable. For fungi, the optimal range is 10 to 100 CFU per plate, although acceptable the counts range from 5 to 150 CFU for analytical purposes. The concentration of microorganisms was determined following the SAS manufacturer's recommendations (**Avantor VWR, 2021**).The number of organisms counted on the surface of the countable plates were corrected for the statistical possibility of multiple particles passing through the same hole using a correction table. The corrected CFU count was then used to calculate de concentration of bacteria and fungi according to the formula:

$$\text{Concentration } = \frac{\text{Corrected CFU}}{\text{V (m}^3)} \qquad\qquad Eq.\,1$$

In this study, a dual-volume method was also used to broaden robustness of the results (**Manuel and Samardjieva, 2024a**). Considering the recommendations of **EN 13098:2019 (E)** of using two consecutive dilutions to calculate the microorganism concentrations, the concentration was determined using two sampled volumes if the plates were countable:

$$\text{Concentration } = \frac{\sum_i^n (\text{Corrected CFU})_i}{\sum_i^n V_i \text{ (m}^3)} \qquad\qquad Eq.\,2$$

**2.3. Quality Control**

Blank control samples were included under all experimental conditions to confirm the sterility of media and exclude potential contamination during handling or incubation. After preparing the culture media, blank plates were placed in triplicate at 4ºC, 37ºC and 25ºC or at room temperature for 3 days.

For each experimental condition — namely, the culture medium (TSA and TSA supplemented with cycloheximide at various concentrations, MEA supplemented with chloramphenicol and Mac Conkey agar), incubation temperature (35 °C and 37 °C), and incubation period (2, 3, and 5 days) — non-exposed plates were processed identically to test samples but not subjected to air sampling.

**2.4. Method validation for bacterial enumeration**

**Specificity/Selectivity** was assessed by examining CFUs grown on a culture medium plates where bacteria were easily distinguished from filamentous fungi. To identify the best conditions for fungal growth inhibition without significantly compromising bacterial recovery, the antibiotic cycloheximide was added to TSA plates with increasing concentrations in the range of those found in literature (0 to 200 mg/L). The plates were incubated at $37 \pm 1°C$ for 2 days and the relative difference of bacterial CFUs between plates containing cycloheximide and control plates without antibiotics was obtained by:

$$\text{Relative difference (\%)} = \frac{\text{Count}_{\text{TSA+cycloheximide}} - \text{Count}_{\text{TSA control}}}{\text{Count}_{\text{TSA control}}}.\,100 \qquad Eq.\,3$$

**Precision** was quantified using the coefficient of variation (CV) of bacterial concentrations obtained under equal conditions, which was calculated as follows:

$$\text{CV (\%)} = \frac{s}{\bar{x}}.\,100 \qquad\qquad Eq.\,4$$

where $\bar{x}$ is the mean and $s$ is the standard deviation of the bacteria concentration. Ten replicates of plates containing air samples of 100 L and 300 L were incubated at temperatures of $35 \pm 1$ °C and $37 \pm 1$ °C for periods of 2, 3, and 5 days.

**Accuracy** could not be tested because the bacteria concentration in laboratory air was neither known nor controlled.

**Linearity** was assessed by analyzing the correlation between the sampled air volume and the corresponding number of CFU, ensuring a consistent increase in CFU counts with increasing sampled volumes.

**Robustness** was assessed by examining the consistency of results across changes in incubation parameters, including temperature, duration and sampled air volumes. Experimentally, 100 L and 300 L of air were sampled onto TSA plates and incubated for 2, 3, and 5 days in two incubators set at $35 \pm 1\,°C$ and $37 \pm 1\,°C$ to encourage the growth of bacteria from human sources expected in the sampled locations. Temperatures were measured using a thermometer and recorded as 34 °C and 36 °C, respectively.

## 2.5. Statistical Analysis

The experimental data were analyzed using IBM SPSS Statistics (version 30). Normality was assessed using the Shapiro-Wilk test, which indicated that not all datasets followed a normal distribution ($p < 0.05$), and therefore further analysis was performed using non-parametric tests. The Mann–Whitney test was used to compare the means of two independent samples, such as those collected at different temperatures or in different locations. The Wilcoxon test was used to compare the means of two paired samples, such as those measured on different days at the same temperature. Spearman's rank correlation ($\rho$) was used to assess the existence and the strength of the relationship between the parameters, such as the CFU counts from different sampled volumes.

## 3. DATA ANALYSIS AND RESULTS

### 3.1. Quality Control

To ensure the reliability and validity of the microbiological results, a series of Quality Control procedures were systematically implemented during the preparation of the three culture media and throughout the experimental setups. Control plates underwent the full field procedure without active air exposure and showed no microbial growth, thus verifying sterility.

### 3.2. Method Validation

**Accuracy**. Due to the unknown and non-standardized microbial load of indoor air, accuracy could not be directly quantified in this study. **Specificity/Selectivity.** Bacterial and fungal CFUs were determined in TSA media supplemented with various concentrations of cycloheximide and were compared to control conditions (0 mg/L) to calculate relative recovery reduction (Table 1). Among the tested concentrations, 15 to 30 mg/L suppressed fungal growth, with no significant inhibitory effect on bacterial recovery. At 50 mg/L, complete fungal suppression was obtained, albeit with a slight reduction in bacterial viability. Based on these findings, 15 mg/L appears to be the most suitable concentration for air samples collected from environments such as educational facilities, as it minimizes the use of the antibiotic, preserves bacterial detection capability, and substantially reduces fungal interference.

| Cycloheximide (mg/L) | N | Relative reduction (%) of bacteria concentration | Fungal contamination |
|---|---|---|---|
| 0 | 4 | 0 | Many plates with 3-11 CFU |
| 4 | 4 | -12* | Many plates with 2-6 CFU |
| 15 | 6 | 14 | Few plates with 1-3 CFU |
| 30 | 9 | -21* | Few plates with 1 CFU |
| 50 | 5 | 36 | Not observed |
| 100 | 5 | 55 | Not observed |
| 200 | 5 | 46 | Not observed |

Table 1. Effect of cycloheximide concentration on bacteria and fungi growth for 2 days at 37°C on TSA medium supplemented with cycloheximide. (* - Negative values indicate that higher concentrations were obtained compared to the controls.)

Nonetheless, in highly contaminated and complex environments, such as those in waste-sorting plants, higher concentrations like 50 mg/L may be more appropriate to guarantee a more effective fungal suppression. Bioaerossol studies were found reporting using 50 mg/L of cycloheximide developed in a university, biowaste plant and public transports **(Schmidt *et al.*, 2012; Baldelli *et al.*, 2022; Rasmussen *et al.*, 2023)**, while **Brągoszewska *et al.* (2020)** and **Tolabi *et al.* (2019)** used a ten-fold higher concentration (500 mg/L) in a waste-sorting plant and a hospital. Hardy Diagnostics recommended the use of TSA with 50 mg/L of cycloheximide for a general growth for the isolation and cultivation of microorganisms while inhibiting fungal organisms **(Hardy Diagnostics, 2020)**. A study from **Ha *et al.* (1995)** reported that bacterial populations from animal feed were not significantly affected by increasing concentrations of cycloheximide from 10 to 300 mg/L, observing total elimination of fungal contamination at the highest concentration. **Precision**. Precision was evaluated by the coefficient of variation for replicate air samples under different experimental conditions (Table 2). The observed CVs ranged from 23.3 % to 49.4 %, reflecting the variability of this type of samples across the tested conditions, independently from the sample volumes and incubation temperatures and periods. These levels of variability are consistent with those reported by **Bartlett and Lee (2003)** (13-44%) and in **EN 13098:2019 (E)** (20-50%) for bioaerosol sampling. Such variability is characteristic of microbiological air sampling due to the inherent heterogeneity of airborne particles and microbial distribution.

| Incubation Temperature (°C) | Incubation period (d) | Volume (L) | Mean Concentration (CFU/m³) | CV (%) |
|---|---|---|---|---|
| 35 | 2 | 100 | 140.0 | 25.9 |
|  |  | 300 | 109.7 | 31.7 |
|  | 3 | 100 | 175.0 | 26.4 |
|  |  | 300 | 117.0 | 28.6 |
|  | 5 | 100 | 261.1 | 25.5 |
|  |  | 300 | 155.2 | 29.0 |
| 37 | 2 | 100 | 112.2 | 49.4 |
|  |  | 300 | 108.3 | 30.4 |
|  | 3 | 100 | 117.8 | 44.1 |
|  |  | 300 | 116.3 | 32.1 |
|  | 5 | 100 | 208.8 | 28.8 |
|  |  | 300 | 170.8 | 23.3 |

Table 2. Mean and coefficient of variation (CV) of bacterial concentration obtained for different temperatures, incubation time and sampled air volume. Each condition corresponds to 10 replicates.

**Linearity**. In this study, linearity was evaluated by determining CFU counts for laboratory air samples at volumes ranging from 10 to 300 liters, using both TSA supplemented with 15 mg/L of cycloheximide and non-supplemented TSA (Figure 1). Although some variability was observed, Figure 1 demonstrates a strong positive linear trend ($\rho = 0.858$, p < 0.01) across the tested volume range, confirming the method's linearity under the evaluated conditions. Although a linear relationship was observed between CFU counts and sampled air volume, it is equally important that the calculated bacterial concentration (CFU/m³) remains unaffected by the sampled volume. This is demonstrated by the horizontal trendline in Figure 2, which shows a similar bacterial concentration ($\approx 250$ CFU/m³) in the laboratory air across different sample volumes.
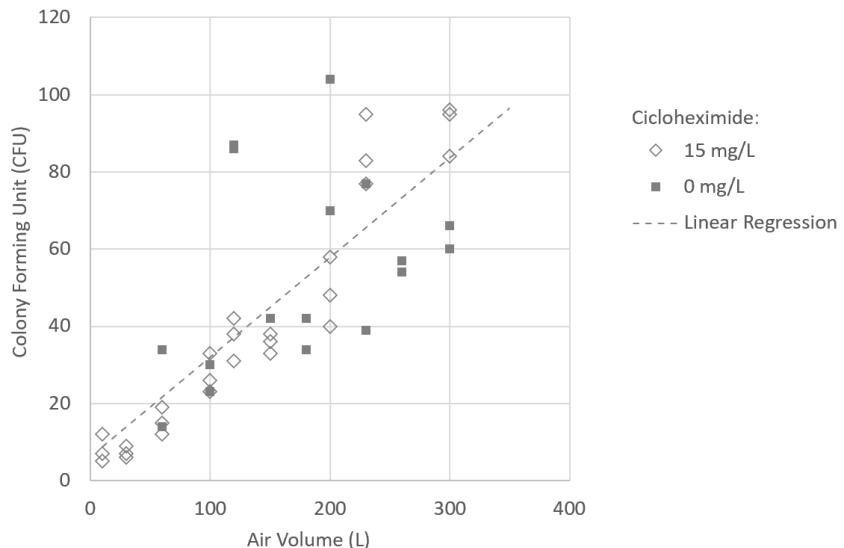
**Figure 1.** Bacterial colony forming units after 2 days of incubation on TSA and TSA+15mg/L cycloheximide. Each condition corresponds to 2-3 replicates.
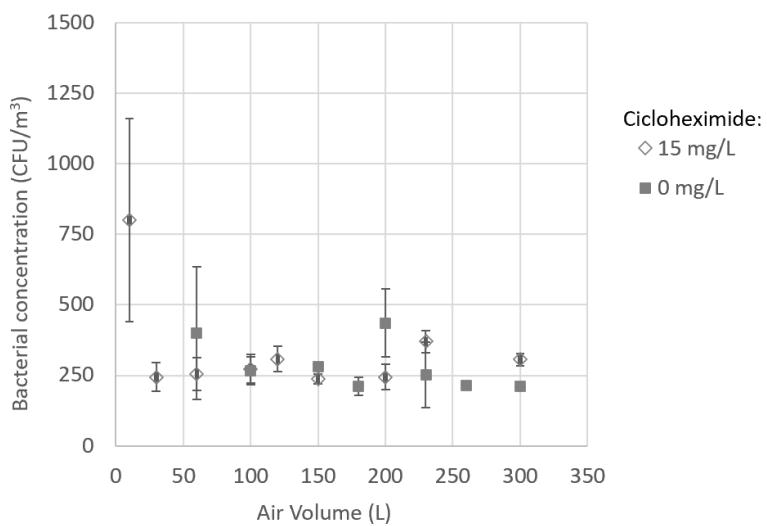


**Figure 2.** Bacterial concentration after 2 days of incubation on supplemented TSA with cycloheximide and non-supplemented TSA. Each condition corresponds to 2-3 replicates.

The two lowest volumes may provide unreliable estimates of bacteria concentration for the tested air, as the CFU counts were between 5 and 10 colonies per plate, although in the acceptable range, the CFUs are low, which could increase the quantification uncertainty. Based on these findings, the most appropriate sampling volumes lie between 100 and 300 L, provided that the resulting CFU counts fall within the statistically countable range. If counts fall outside this range, adjustments to the sampling volume should be made accordingly to ensure accuracy and compliance with methodological best practices. According to the technical note NT-SCE (**ADENE, 2009**), 250 to 300 L are the most commonly used sampling volumes. **Robustness.** Robustness was evaluated by analyzing the effects of variations in sampled volume, incubation temperature and duration. For bacteria associated with human sources, incubation at 35–37 °C is widely recognized as optimal, as it reflects the microorganisms' natural habitat temperature prior to sampling (**ADENE, 2009**) and the recommended incubation duration in this case is 48 hours. Alternative incubation temperatures may be applicable depending on the microbial group; for instance, mesophilic bacteria are typically incubated at 25–30 °C for 3 to 5 days, while thermotolerant species may require temperatures between 50–56 °C.

According to **EN 13098:2019 (E)**, the most appropriate temperature for cultivation is close to that of microorganisms' natural habitat prior to sampling. Regular monitoring is essential to observe colony development and overgrowth during incubation, as this can compromise the accuracy of colony counting. Statistical comparison for each temperature showed that microbial counts differed significantly across incubation times ($p < 0.05$). This confirms that plate readings should be performed after exactly 2 days to ensure consistency. In contrast, comparisons between the two incubation temperatures at each time duration, revealed no statistically significant differences ($p > 0.05$). This indicates that the method is robust to the variations in incubation temperature within the recommended range for bacteria from human sources.
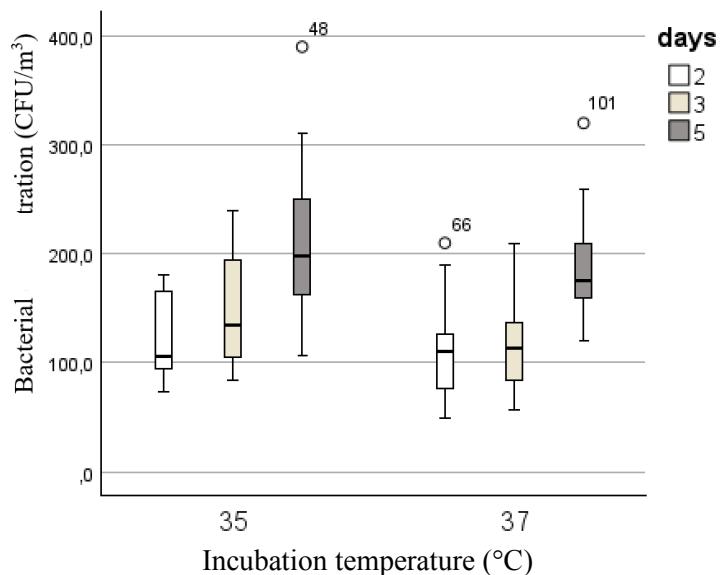


**Figure 3.** Bacterial concentration ($CFU/m^3$) measured in air samples at different incubation temperature and duration (n = 20 replicates). Data points in positions 48, 66 and 101 in the dataset are considered outliers.

### 3.2. Parameters of the quality of the indoor air in an educational institution

Microbial and carbon dioxide concentrations were measured in a laboratory and a classroom before and after the workday started, as well as in an outdoor location used as a reference (Figure 4). According to the Portuguese regulation on IAQ for commercial and service buildings (**Ordinance no 138-G/2021 of July 1st**), bacteria concentration should not exceed outdoor levels by more than 350 $CFU/m^3$, and indoor fungal concentration should remain below the outdoor level as indicated in Figure 4 by the dashed lines. All measurements remained within the recommended limits, except for the classroom prior to its occupancy, where levels were significantly above the recommended threshold. As expected, bacterial levels increased throughout the workday, likely due to human presence. Fungal concentrations were initially very high, likely due to the previous day's occupancy combined the fact that the HVAC system was not activated and all windows and doors were closed. However, levels decreased after the exam, which can be attributed to improved air circulation during the day, when the doors remained open. Gram-negative bacteria were not detected in any of the sampled environments. **Ordinance no 138-G/2021 of July 1st** recommends Gram-negative bacteria enumeration in locations with concern about health risks associated with airborne pathogens or where the indoor bacteria concentration exceeded the outdoor value by more than 350 $CFU/m^3$ and the indoor $CO_2$ levels were below 1000 ppm. Carbon dioxide concentrations remained below the regulatory protection threshold of 1250 ppm (**Ordinance no 138-G/2021 of July 1st**) in all of the monitored areas.

As expected, $CO_2$ levels were high in the sampled air collected in the afternoon from the laboratory and in the classroom after the workday, reflecting the human occupancy. Maintaining $CO_2$ at recommended levels not only improves air quality but also reduces fatigue, enhances cognitive performance, and promotes occupant comfort.
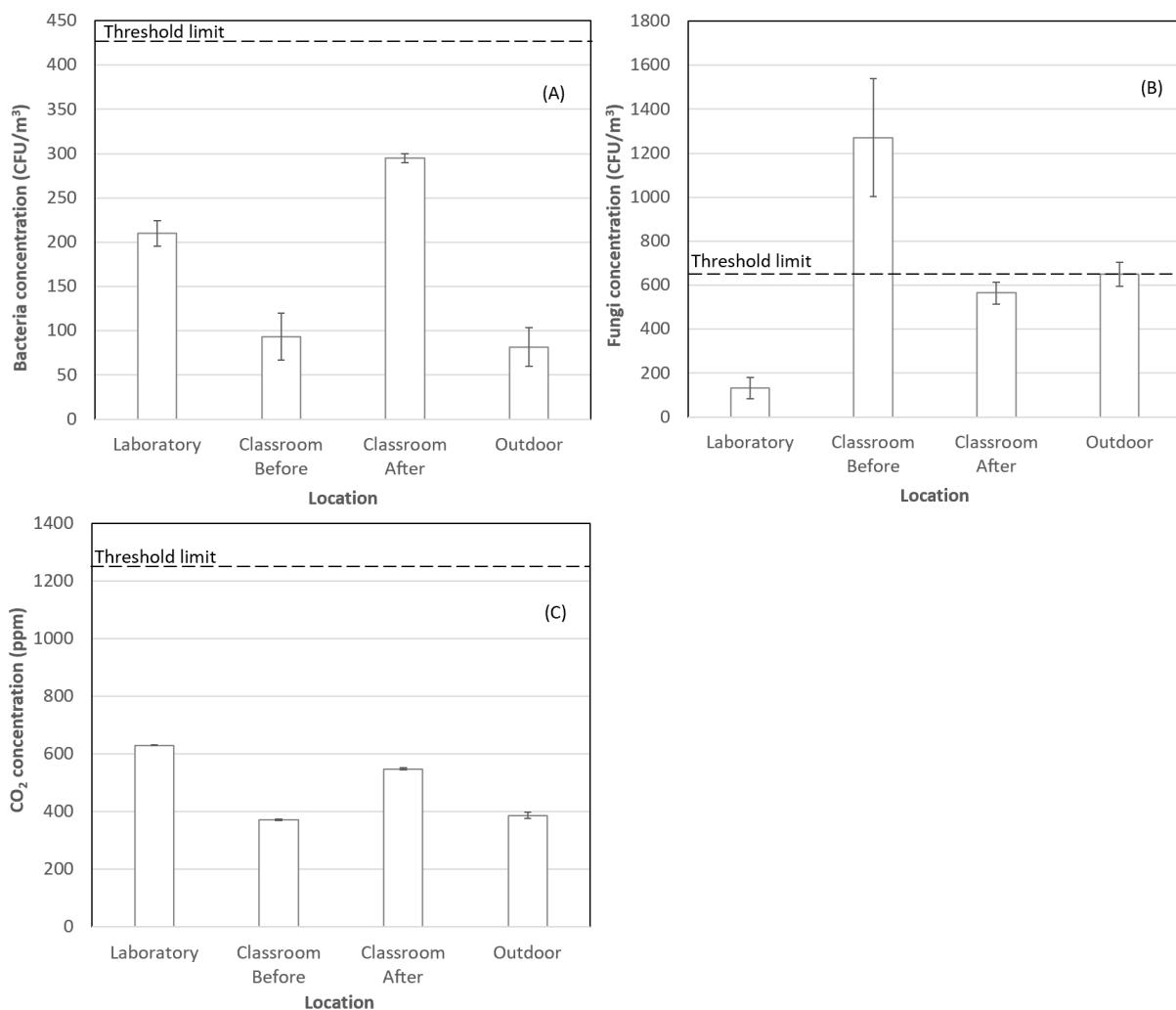


**Figure 4.** Concentration of (A) bacteria, (B) fungi and (C) $CO_2$ in the air collected inside educational facilities.

In a study conducted in an educational institution in Porto (Portugal), non-conforming results of bacteria concentration were also identified in some educational rooms and it was observed that the ventilation was not sufficient to guarantee adequate $CO_2$ levels during periods of full occupancy (Barbosa, 2012). Other studies measured in schools, offices and residentials spaces in Porto (Portugal), $CO_2$ levels exceeding 1000 ppm in offices during afternoon working hours, highlighting the limitations of mechanical ventilation systems in maintaining air quality during prolonged occupancy (Almeida *et al.*, 2009; Felgueiras *et al.*, 2024; Madureira *et al.*, 2015; Manuel and Samardjieva, 2024b). These findings clearly highlight the importance of ensuring effective ventilation to prevent the accumulation of $CO_2$ and other indoor air pollutants. Adequate air exchange can be achieved through regular window opening in naturally ventilated spaces or by implementing well-designed and properly functioning mechanical ventilation systems.

In buildings equipped with such systems, it is essential to guarantee that they are correctly dimensioned, regularly inspected, and continuously operated to comply with legal requirements, which typically set the maximum allowable indoor $CO_2$ concentration at 1250 ppm. Controlling microbial contamination, particularly from bacteria and fungi, requires diligent moisture management and strict hygiene of indoor spaces and HVAC systems. According to Portuguese technical regulations (NT-SCE-02) and other studies, microbial growth indoors is closely linked to excessive humidity, water leaks, and poorly maintained ventilation systems (ADENE, 2009; Fonseca et al., 2019)

To prevent this, it is crucial to eliminate sources of water infiltration, reduce condensation, and maintain relative humidity between 40% and 60% (Wolkoff et al., 2021) or between 50% and 70% (Decree-Law no 243/86 of August 20th). In addition, air ducts, filters, and diffusers must be inspected, cleaned, and replaced as necessary to avoid the accumulation and dissemination of bacteria and fungal spores. Failure to properly maintain these systems not only compromises IAQ but can significantly increase the risk of respiratory infections and allergic diseases. Finally, regular monitoring of IAQ, combined with preventive and corrective measures, is essential to keeping $CO_2$, bacteria, and fungi within acceptable levels. These assessments enable early detection of non-compliance and guide targeted actions, such as improving ventilation, eliminating sources of contamination, or implementing disinfection technologies, such as UV-C irradiation, which has demonstrated high effectiveness in reducing airborne microbial loads in critical environments (Manuel and Samardjieva, 2024). When properly implemented, these good practices contribute to creating healthier, safer, and more comfortable indoor environments, significantly reducing the health risks associated with poor IAQ.

## 3. CONCLUSION
The validation of the bacterial monitoring method demonstrated acceptable specificity/selectivity, precision, linearity, and robustness, confirming its suitability for assessing airborne bacterial concentrations in indoor educational environments. The monitoring results confirm that human occupancy and ventilation have a significant impact on indoor air quality. Bacterial concentrations increased after classroom use, while fungal levels decreased due to improved air circulation. All values remained within threshold limits, except for fungi levels before classroom use, most likely because the room had been closed and unventilated since the previous day. No Gram-negative bacteria were detected. $CO_2$ concentrations remained below the regulatory limit, though they increased with the occupancy.

These findings emphasize the need for effective ventilation and regular air quality monitoring in educational settings. This study has several limitations relating to the educational institution sampling that should be acknowledged. Sampling was restricted to a limited number of indoor spaces within a single educational facility, which may limit the generalizability of the results to other institutions with different architectural designs, occupancy patterns, or ventilation systems. Additionally, measurements were conducted over a short time frame and did not capture seasonal or long-term variability in indoor air quality. The microbiological assessment focused exclusively on culturable bacteria and fungi, potentially underestimating total microbial diversity by excluding non-culturable or dormant organisms. Finally, while $CO_2$ levels were used as a proxy for occupancy and ventilation performance, no direct measurements of air exchange rates or ventilation flow were performed, which would have provided a more accurate characterization of indoor air dynamics.

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