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AI, Sustainability and Digital Transformation

Shaping the Future of Business and Society

Editors:

Sándor Remsei

Prashant Pereira

Phoebe Chuah Leininger

Melina Doargajudhur



**SZÉCHENYI
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UNIVERSITY OF GYŐR

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AI, Sustainability and Digital Transformation:

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Part I - Global Challenges and Economic Transformation



Energy Crisis as Catalyst: the Transformation of Energy Awareness and Consumer Attitudes in Hungary

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Abstract: The 2021 energy crisis has had a profound impact on Hungarian consumers, compelling both households and policymakers to reconsider energy consumption habits and the broader concept of energy awareness. This study investigates how the crisis has influenced consumer attitudes, motivations, and behaviors toward renewable energy adoption, with particular emphasis on financial, environmental, and socio-economic determinants. Using an online survey of more than 400 respondents, the research explored knowledge, openness, motivational factors, and perceived barriers to adopting renewable energy. The results demonstrate that financial considerations, including rising utility costs and the aspiration to reduce expenditures, remain the strongest motivators, followed by environmental awareness, the desire for independence from providers, and the crisis itself. Respondents identified high upfront costs, insufficient support schemes, and long payback periods as key barriers to adoption. Consumer responses to rising energy prices were heterogeneous: some adopted immediate energy-saving measures, others relied more heavily on cheaper fossil fuels, while a minority maintained previous consumption patterns. Importantly, the findings highlight a growing openness to educational content and information provided by energy companies and policymakers, suggesting that effective communication and support mechanisms are critical to shaping long-term awareness. In summary, the energy crisis acted as both a disruptive shock and a developmental opportunity, accelerating the spread of energy-conscious attitudes and practices. By strengthening educational initiatives, improving financial support, and fostering reliable communication, Hungary has the potential to cultivate a more energy-conscious society that is resilient to future economic uncertainties and environmental challenges.

Keywords: energy awareness, energy crisis, consumer behavior, renewable energy

JEL Classification: D83, Q20, Q29

1. Introduction

Managing energy responsibly has become indispensable in contemporary society. Establishing and consolidating fundamental consumer habits related to energy awareness remains an exceptionally complex task, as entrenched attitudes and individual preferences are difficult to reshape. Nevertheless, the potential benefits are considerable, particularly in the global fight against climate change. Developing energy-conscious behavior requires clear, comprehensible, and accessible communication and education, which can effectively guide individuals through the complexities surrounding energy (Hassan et al., 2009). The accelerating depletion of fossil fuels, the continuous rise in greenhouse gas concentrations, unfavorable geopolitical developments, and escalating energy prices have all highlighted the vulnerabilities of modern societies – with the energy crisis proving particularly impactful in Hungary (Kolozsi, 2023). Unpredictable energy prices place heavy burdens on consumers, creating uncertainty in their daily lives and worsening living conditions (Baranyai & Banai, 2022). This occurs because their previous energy consumption patterns have become unsustainable, compelling financially less stable households to make difficult choices. Against this backdrop, the present study investigates how the energy crisis has reshaped consumer attitudes, behaviors, and energy awareness in Hungary.

1.1. The impact of the energy crisis on consumer behavior

Hungarian society is currently facing challenges that, due to global developments, may prove decisive for both the present and the future. The increasingly visible consequences of climate change, the structural problems of energy production and consumption, and the instability of energy markets collectively call into question the sustainability of current economic systems and social behavior. In this context, energy awareness and conservation are gaining importance not only from an environmental standpoint but also from economic and social perspectives. The diffusion of energy-efficient and innovative technologies can generate significant savings for both households and companies, while simultaneously strengthening energy security, reducing dependence on imports, and contributing to price stability. Paradoxically, the adverse impacts of the recent energy crisis may serve as a catalyst for the wider adoption of renewable energy sources.

The 2021 energy crisis can be compared to the oil crisis of the 1970s, as both have stimulated research and practical efforts aimed at expanding the use of alternative energy, thereby underlining the critical need to diversify energy supplies (Gajdzik et al., 2024). In Hungary, the crisis appears to have transformed consumer attitudes, with an increasing share of the population regarding renewable energy as an essential pillar of the future. This study therefore seeks to provide a comprehensive analysis of how the energy crisis has fostered the evolution of energy awareness and consumer attitudes. Evidence suggests that a growing proportion of the population has moved beyond awareness to embrace energy efficiency, recognizing the necessity of modifying unsustainable consumption patterns. A fundamental prerequisite for this transformation is the acquisition of reliable knowledge about energy and renewable sources (Meyer et al., 2021). In the absence of credible and accessible information, knowledge gaps are often filled with misconceptions or misinformation, which may lead to apathy, distrust, or outright rejection (Kolozi et al., 2022).

The determinants of energy consciousness are complex and multidimensional, spanning psychological, sociological, economic, and environmental domains (Mansor et al., 2019). Numerous studies confirm that an energy-conscious mindset can most effectively be cultivated by transforming entrenched, inefficient habits. Such change results from the interaction of psychological factors and external influences, which together shape the persistence of old patterns and the willingness to adopt new ones (Sheau-Tingi et al., 2019).

1.2. The evolution of energy awareness in Hungary

Psychological factors exert a direct influence on consumer decisions, motivation, and the inclination to adopt energy-conscious behavior, while other determinants operate indirectly by shaping intentions (Gârdan et al., 2023). Energy awareness, therefore, largely depends on willingness; without it, the transformation of consumer habits remains inconceivable. Within the Hungarian energy market, the concept of energy awareness can be interpreted at both the household and corporate levels. The present study focuses on individuals, examining their attitudes, habits, and behaviors. In this regard, generational differences also play a decisive role: younger consumers tend to be more open to experimenting with new technologies and adopting energy-saving habits, while older age groups display more conservative attitudes, often due to lower financial flexibility or limited access to information.

Consumer responses to the negative consequences of the energy crisis, such as rising energy prices, can be assessed from multiple perspectives. Household energy consumption is strongly influenced by socio-economic and demographic characteristics (e.g., household size, age, financial status), lifestyle, childhood experiences, and inherited behavioral patterns. Technical aspects, including the type, efficiency, and

condition of dwellings and appliances, further shape consumption patterns (Slupik et al., 2021). Knowledge related to energy also plays a crucial role, affecting both intentions and concrete behaviors. Previous studies confirm a direct relationship between energy awareness and energy-saving practices (Zhao et al., 2019). As consumers acquire reliable information and recognize the tangible benefits of modifying their habits and living conditions, they can achieve significant reductions in consumption through more responsible energy management. In this way, energy awareness expands not only as a mindset but also as a practice, whereby individuals set an example that encourages others to follow (Gadenne et al., 2011). Beyond personal experience, the role of mass communication and digital media has become decisive, as reliable online content and targeted campaigns provide opportunities to translate abstract concepts of sustainability into everyday practices.

Despite the proliferation of offline and online information sources in recent years, energy awareness continues to represent a critical societal issue. According to survey participants, however, the proportion of genuinely energy-conscious Hungarians remains low: only 12.5% consider the population to be energy-conscious. Regional variations further complicate the picture, as levels of knowledge, access to information, and willingness to adopt energy-saving practices differ across the country. These disparities are closely linked to educational attainment, household living conditions, and other socio-economic variables (Szakály et al., 2020). While some consumers have already reformed their energy habits as a result of the crisis, the absence of willingness continues to prevent meaningful change. This factor thus emerges as a decisive condition for adopting an energy-conscious mindset and achieving sustainable energy use (Wall et al., 2021). Moreover, the influence of peers and social networks should not be underestimated: households that witness positive examples in their immediate environment are more likely to engage in similar practices, creating a diffusion effect that can gradually raise the overall level of energy awareness in Hungarian society.

1.3. New consumer attitudes due to the energy crisis

In recent decades, numerous sustainability-oriented concepts have emerged, primarily centered on renewable energy, climate change mitigation, and environmental responsibility. As a result, the Hungarian public has been increasingly exposed to global debates through diverse sources of information, and environmentally focused campaigns have reached consumers with growing intensity. Initially, however, these initiatives had only a limited effect on individual responsibility, as energy was long perceived as a mere necessity and the concept of utilities as a “necessary evil.” Definitions such as energy awareness, energy efficiency, or ecological footprint were absent from everyday discourse for years. Consequently, the population had to undergo a long transition before recognizing the value of energy and the necessity of handling resources responsibly rather than wastefully. Over time, individuals became more conscious, and new internal motivators began to emerge in consumer behavior. Yet it was the energy crisis as a global shock that truly accelerated this process, forcing society to reconsider unsustainable consumption habits and creating the conditions for the formation of distinct consumer groups.

The findings highlight that new attitudes and motivations related to energy are emerging within Hungarian society, which can be observed in the following consumer segments:

1. **Green consumers:** These individuals are primarily motivated by the desire to actively contribute to the reduction of greenhouse gases responsible for global warming and to minimize harmful impacts on the planet. They are leaders in replacing fossil fuels with alternative resources, viewing renewable energy sources as the future. Their consumption habits indicate a keen interest in innovation, technology, and renewable energy content, keeping them highly informed on the subject. Their respect and care for the environment further enhance their sensitivity towards it (Cheng et al., 2015). According to the survey results, **23.2% of respondents identified**

environmental protection as their primary motivation for adopting renewable energy, confirming that this group's mindset is strongly value-driven.

2. **Energy efficiency-oriented consumers:** Driven mainly by economic interests, this active consumer group focuses on reducing energy-related costs, with their primary goal being to minimize or entirely eliminate these expenses (thus becoming independent of energy providers). Some have already installed renewable energy sources to mitigate the uncertainties and financial issues caused by the energy crisis. Their consumer decisions are significantly influenced by the opinions and experiences of individuals or groups they consider authoritative. Their attitude towards renewable energy sources is significantly influenced by the availability and monetary value of EU or state subsidies. The database reveals that **26.8% of respondents adopted renewable energy mainly for financial savings**, and an additional **24.4% cited rising energy prices** as their key driver, illustrating the strong dominance of cost-related motivations in this group.
3. **Energy-conscious consumers:** These individuals are mindful of their energy use in their daily lives, avoid waste, monitor their energy consumption and related habits, and are willing to change established practices if it leads to an improved quality of life (financial return is secondary to them). They have adopted a fundamental energy-conscious mindset and typically use renewable energy sources to meet their energy needs. If they do not have access to alternative resources, they remain open and interested in the topic. Should their financial situation or current living conditions permit, they would transition to renewable energy. They set an example for their children, emphasizing the importance of educating the next generation on energy awareness. Supporting this profile, survey participants rated their own **energy awareness at an average of 6.65 on a self-assessment scale**, and only **1% indicated that they make no attempt to live energy-consciously**, highlighting a broad, albeit uneven, commitment to conscious energy use.
4. **Open and receptive consumers seeking energy awareness:** They are interested in the topic and follow developments and innovations in the energy sector in some way. Their openness is evident in their media consumption habits, as they consume relevant content across various platforms and follow different energy providers. Their main areas of interest include content focused on minimizing energy waste and energy consumption tips. When asked about their preferences for educational materials, **45% of respondents expressed clear interest in content from energy providers, 35% showed conditional openness ("maybe"), and 13% reported that they already consume such content**, with only **5% declaring no interest**. These findings emphasize that this group can be reached effectively through targeted communication strategies.
5. **Environmentally conscious consumers:** They are familiar with basic environmental definitions and aware of current issues related to the topic. Therefore, they are committed to both their lifestyle and actions, believing that their efforts contribute to change. Their lifestyle, habits, and behavior reflect this commitment. The research data supports this characterization: **12.6% of respondents stated that the energy crisis directly increased their interest in renewables, 18.4% reported that the crisis has driven more households toward renewable energy**, and a large majority, **64.1% perceived a general increase in openness to renewable energy in society**. These percentages show that environmental concerns and collective responsibility are increasingly relevant motivators.
6. **Passive, indifferent social group:** They are not particularly interested in renewable energy and remain indifferent towards it. They are either unable or unwilling to change their lifestyle, or both conditions may apply. They only alter their entrenched habits if these habits negatively impact their lives and financial situation. For this group, barriers represent the most significant explanation for inactivity: **33.6% reported that the high initial cost of renewable installations prevents them from investing, 18% cited the lack of adequate financial support schemes, and 16.6%**

pointed to excessively long payback periods. A smaller proportion, **10.1% believed that renewables are not worthwhile under current Hungarian conditions,** while only **1.8% described such investments as too risky due to uncertainties associated with the energy crisis.** These results illustrate the structural constraints and psychological reservations that characterize this disengaged segment.

This typology underscores the heterogeneous ways in which Hungarian consumers have responded to the energy crisis. While some groups – particularly green consumers and energy-conscious households – demonstrate proactive, value-driven behavior, others are primarily guided by economic considerations, and a notable portion of society remains resistant to change. The coexistence of these diverse attitudes reveals both opportunities and obstacles for policymakers, energy providers, and educators. On the one hand, proactive groups provide a solid foundation for the diffusion of sustainable practices; on the other, economically motivated and passive groups highlight the necessity of differentiated policy measures and targeted communication strategies.

The results therefore suggest that energy awareness in Hungary is far from homogeneous. Instead, it is shaped by a complex interplay of financial incentives, ecological values, lifestyle factors, and social influence. Recognizing this diversity is essential: policy interventions must address acute vulnerabilities in energy-poor households, provide incentives for financially secure but reluctant consumers, and strengthen educational and communication campaigns that can further mobilize the open and environmentally conscious groups. In this sense, the energy crisis has acted not only as a disruptive shock but also as a formative force, accelerating the crystallization of new consumer typologies that reflect the multifaceted nature of energy awareness in contemporary Hungary.

2. Materials and Methods

The primary focus of this research was on understanding respondent's perspectives, specifically in relation to how the energy crisis has influenced the Hungarian population's views on renewable energy (1), the impact of recent events on the public's perception of renewable energy (2), the preliminary knowledge of individuals participating in the online survey (3), the level of awareness among the surveyed consumers (4), and the external and internal motivations (5) that have affected or could affect their purchasing decisions or would affect them if they had the opportunity to transition to alternative energy sources.

To achieve this, we employed a user-friendly online questionnaire administered through the Surveyplanet platform. The questionnaire was organized into four principal sections: an assessment of knowledge related to renewable energy (1), an exploration of consumer attitudes towards renewable energy, interest in renewable energy sources and preconceptions (2), an examination of experiences among individuals using renewable energy and the factors influencing their decisions (3), and demographic questions (4). The survey was completed by over 400 participants, primarily private individuals who either already utilize renewable energy sources or are open to them and possess some knowledge about alternative energy.

3. Results

The energy crisis and its effects, such as rhapsodically fluctuating prices, have disrupted the daily operations of all energy stakeholders. Therefore, it was deemed essential to examine how participants perceive the impact of the energy crisis as an external event on their interest in and openness towards renewable energy. Moreover, this study aims to determine whether the energy crisis can be considered an influencing factor in the willingness to adopt renewable energy sources, changes in consumer behavior, and the dissemination of an energy-conscious mindset.

3.1. Consumer openness

A substantial proportion of respondents believe that consumers have become more receptive to renewable energy sources, with 18.7% asserting that the crisis has actually increased the number of individuals interested in renewable energy. In contrast, 4.8% of respondents stated that residents would have invested in renewable energy sources regardless of the crisis, suggesting that the latter did not exert a significant influence. Although the number of green movements and individuals actively engaged in environmental initiatives has grown in recent years, environmental protection has not yet mobilized the wider population.

70% of respondents indicated that their decisions had been directly affected by rising energy prices and expenditures, whereas 24.4% reported no impact. This demonstrates that a considerable portion of the population has been adversely influenced by the energy crisis, which necessitated adjustments in existing consumption habits while still attempting to preserve the quality and quantity of their preferred comfort levels. The survey further explored which communication channels respondents consider most effective for disseminating information on renewable energy. Television programs (70% rated 4 or 5) and social media advertising (69%) were identified as the most influential formats, followed by online advertising (64%) and advertising films (62%). By contrast, only 26% regarded print materials (brochures, flyers, press advertisements) as effective, while newsletters achieved similarly low levels of support (28%). Approximately half of the participants valued professional articles on the websites of energy providers (48%) and mobile applications (47%). These findings underline that receptiveness to renewable energy is closely connected to media preferences, with younger cohorts tending to favor digital platforms and older groups relying more strongly on television.

3.2. Internal and external consumer motivations

Beyond the overall level of energy consumption, it is equally important to emphasize the transformation of consumption habits. The ongoing technological revolution has altered consumer behavior, exemplified by the increasing prevalence of online shopping. These behavioral changes have introduced new attitudes, motivations, and concerns into decision-making processes. Consumers are now striving for more deliberate and conscious practices in multiple areas of life, shaped by global disruptions such as the Russian–Ukrainian conflict and the climate crisis (Graczyk et al., 2023). These events have underscored the vulnerability of energy systems, forcing governments to develop alternative strategies and encouraging individuals to reconsider their energy use at a personal level (Rausser et al., 2023). This heightened awareness enables more effective responses to unexpected circumstances rather than passive adaptation.

The identification of external and internal motivational factors is critical for understanding consumers' decision-making mechanisms, as well as their beliefs, habits, and concerns. On this basis, the current level of energy awareness can be evaluated, its determinants mapped, and the new habits and attitudes shaped by the crisis better interpreted. A more precise understanding of consumer segments supports targeted educational initiatives and fosters the development of content that is practical, accessible, and relevant. Contemporary consumers tend to reject superficial messages and instead demand reliable, information-rich, and applicable knowledge. The surge in consumer interest and the heightened demand for credible information observed during the energy crisis serve as clear evidence of this shift.

The survey identified five key internal and external motivational factors among the Hungarian population: (1) financial considerations, (2) rising energy prices, (3) environmental awareness, (4) the desire for independence from providers, and (5) the energy crisis. The distribution of these motivators is illustrated in Figure 1. The most decisive factor proved to be financial pressure, with 26.8% of respondents indicating that they selected renewable energy solutions primarily to reduce utility costs. Rising energy prices were cited as an external motivator by 24.4% of respondents, while 23.2% reported environmental considerations as

their main reason for adopting alternative energy. Furthermore, 13.4% emphasized the aspiration to achieve full independence from providers, and 6.1% identified the energy crisis as a direct driver of their decision.

In addition to financial, environmental and independence-related factors, the analysis revealed the growing significance of educational incentives. The willingness of consumers to engage in energy-conscious behavior appears to be closely linked to the accessibility, clarity and credibility of the information they receive. Nearly seven out of ten respondents rated mass-reach digital and television communication as effective channels for promoting renewable energy awareness, highlighting that the reliability of the message and the medium constitutes a decisive influence alongside economic and ecological considerations.

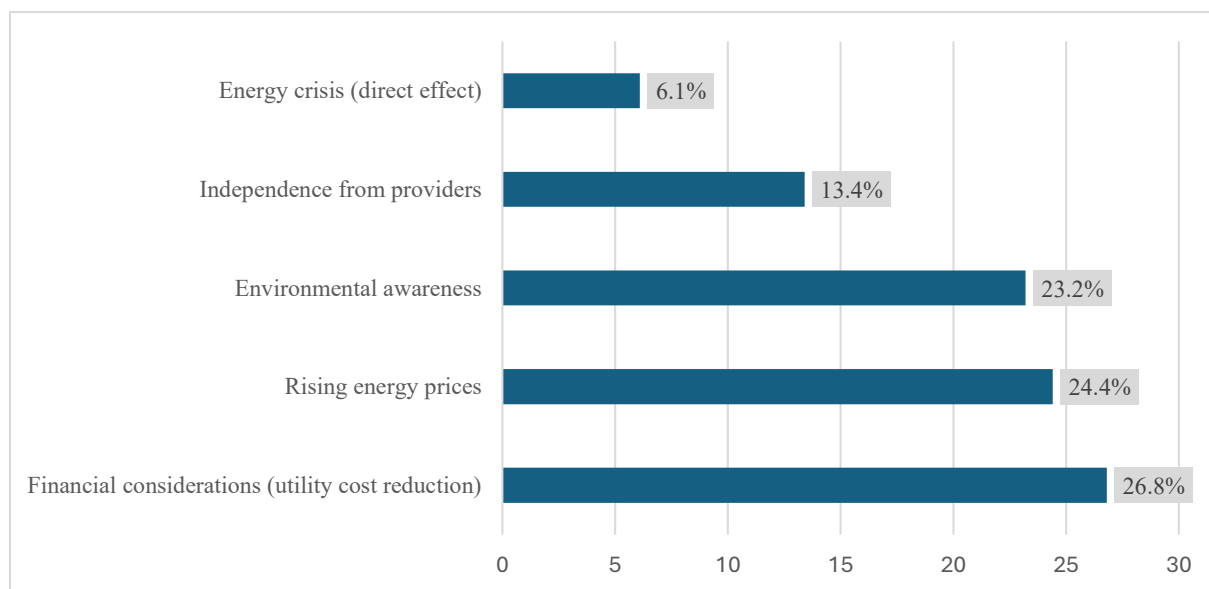


Fig. 1 Motivational factors for adopting renewable energy

Source: own editing

As illustrated in Figure 1, the energy crisis emerges as a decisive factor shaping consumer attitudes toward renewable energy. On the one hand, the crisis itself functions as a direct trigger for considering alternative energy sources; on the other, its negative consequence – namely rising energy prices – acts as an additional catalyst for adoption. Taken together, these findings confirm that the energy crisis constitutes a significant external driver influencing the decisions of Hungarian consumers. Beyond the individual categories shown in the figure, the distribution can also be grouped into three broader motivational domains. Financial drivers dominate, with more than half of respondents (51.2%) citing either offsetting utility costs (26.8%) or rising energy prices (24.4%) as their primary rationale. Value-based considerations, such as environmental protection (23.2%) and the aspiration for independence from providers (13.4%), together account for 36.6%. By contrast, a smaller proportion (6.1%) reported that the energy crisis itself directly triggered their decision. This distribution suggests that the crisis exerted its greatest influence indirectly, through economic pressures, while intrinsic values and security-related considerations continue to play a secondary but non-negligible role. Financial considerations, particularly the objective of reducing utility expenses, therefore remain the most decisive motivators. Yet, environmental protection also appears as a prominent internal driver, encouraging respondents to participate more actively in addressing global warming and the climate crisis. This internal concern fosters a willingness to assume responsibility for personal energy consumption and to minimize unnecessary waste. Externally, the combined impact of escalating energy prices and the broader energy crisis exerts considerable pressure on households (Smith & Johnson, 2021). Under such circumstances, personal economic interests increasingly converge with ecological concerns, reinforcing both the importance of energy awareness and the attractiveness of transitioning toward renewable energy sources.

The significance of these motivators, however, is not uniform across the population. Younger cohorts tend to emphasize environmental protection and long-term sustainability, whereas older respondents are more responsive to immediate financial considerations. Regional and socio-economic differences are also evident, with households in less affluent areas being disproportionately sensitive to price increases. These variations suggest that tailored policy measures and differentiated communication strategies are essential to address the diverse drivers of energy awareness. It is also noteworthy that only a small proportion of respondents (6.1%) explicitly identified the crisis itself as their primary motivator. These findings underline that the energy crisis influenced behavior mainly in an indirect manner, through rising prices and heightened economic uncertainty, rather than through the immediate perception of crisis. The observed patterns have clear policy and institutional implications. They highlight the importance of designing interventions that simultaneously address short-term financial concerns and reinforce long-term environmental values. Energy providers and policymakers are therefore expected to act not only as regulators of costs but also as facilitators of lasting behavioral change through credible education and effective communication.

Finally, the convergence of economic and ecological concerns suggests a potential trajectory for future consumer behavior. Once financial pressures ease, intrinsic values related to environmental protection may gain further prominence, providing a stable foundation for the long-term development of energy awareness. This dynamic illustrates how the crisis, despite being primarily an external shock, may ultimately foster deeper and more enduring shifts in consumer attitudes.

3.3. Financial considerations

The Hungarian population is highly sensitive to price fluctuations, striving for predictability, security, and stability. As a result, the energy crisis and its consequences have profoundly affected consumer behavior. In the aftermath of the crisis, a financially conscious segment has emerged that is particularly proactive in acquiring information and preparing for anticipated risks. Many within this group have opted for renewable energy sources, as these provide a sense of self-sufficiency and control, offering both emotional and financial

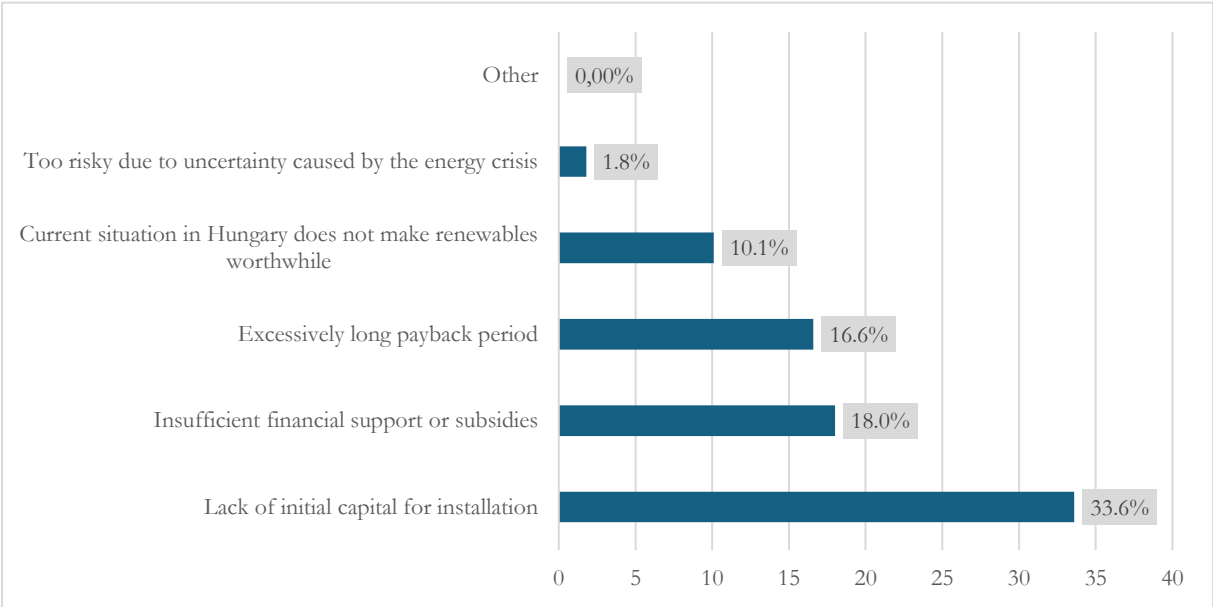


Fig 2. Barriers to renewable energy adoption among Hungarian consumers
Source: own editing

security in the event of another sharp increase in energy prices. Notably, 13.8% of respondents view renewable energy systems as a pathway to self-sufficiency and regard them as a worthwhile investment prompted by the crisis. Despite this growing interest, significant barriers continue to constrain the wider

diffusion of renewable energy systems. The most frequently cited obstacles are presented in Figure 2, which illustrates the relative weight of financial and contextual factors discouraging adoption.

As shown in the figure, the lack of initial capital represents the most significant barrier, with 33.6% of respondents indicating that they cannot afford the upfront costs of installation. A further 18.0% pointed to insufficient financial support schemes, while 16.6% considered the excessively long payback period a major deterrent. Additionally, 10.1% believed that under current conditions in Hungary renewable investments are not worthwhile, and a smaller share (1.8%) perceived such investments as too risky due to uncertainty associated with the energy crisis. These results clearly demonstrate that, even for financially motivated households, decisions are shaped by careful risk-benefit calculations, and that state support mechanisms play a decisive role in facilitating broader adoption.

3.4. Rising energy prices

The energy crisis-induced increase in energy prices has elicited diverse responses from Hungarian consumers, which can be grouped into four distinct categories:

1. **Economically Constrained Households:** These households immediately adopted energy-saving practices, substantially reducing their consumption, in some cases making drastic adjustments to their daily routines (Azizi et al., 2019). Where finances permitted, they invested in renewable energy systems or undertook smaller efficiency measures, such as insulation or window replacement.
4. **Fuel-Poverty Affected Segment:** In areas characterized by energy poverty, respondents reported even more substantial reductions in energy use. Where alternative fuels were available, residents increasingly relied on fossil resources to satisfy basic energy needs.
5. **Knowledge-Oriented Consumers:** This group actively sought knowledge and guidance to stabilize their situation. They invested time and resources in learning about conservation methods, adjusted their consumption to align with their budgets, and adopted practical measures to reduce energy expenses.
6. **Comfort-Oriented Consumers:** By contrast, households that were not financially constrained by higher prices maintained their existing levels of consumption and comfort, continuing their previous energy practices without major adjustments (Slupik et al., 2021).

These consumer types and their main characteristics are summarized in **Table 1**.

Table 1. Consumer responses to rising energy prices during the energy crisis

Consumer type	Main reaction	Typical behavior	Illustrative examples
Economically Constrained Households	Immediate consumption reduction	Adopt energy-saving habits, reduce daily activities, invest if affordable	Installing insulation, window replacement
Fuel-Poverty Affected Segment	Substantial reductions, reliance on cheaper sources	Cut energy use drastically, switch to cheaper or traditional fuels	Increased use of fossil fuels (wood, coal)
Knowledge-Oriented Consumers	Proactive adaptation through knowledge	Research energy-saving tips, adjust consumption	Monitoring bills, adopting practical measures

		to budget, apply conservation methods	
Comfort-Oriented Consumers	Continuation of prior consumption	Unaffected by rising prices, maintain comfort and service levels	Keeping same heating/cooling, unchanged use of devices

Source: own edited

This typology illustrates the heterogeneous nature of consumer responses to the energy crisis: while some groups adopted significant restrictions or proactive measures, others remained largely unaffected, highlighting the uneven social and economic impacts of rising energy costs (Várgedő, 2022). As shown in Table 1, price-sensitive residents were the quickest to adopt energy-saving practices, reducing their consumption and, where possible, investing in smaller-scale efficiency improvements. By contrast, households in energy-poor regions reported even more drastic reductions, often relying on cheaper fossil fuels such as wood or coal. Information-seeking consumers adopted a proactive approach, dedicating time and resources to researching and applying conservation strategies. Meanwhile, consumer hedonists remained largely unaffected by price increases, maintaining their previous levels of comfort and consumption. The distribution presented in Table 1 therefore underlines the necessity of differentiated policy approaches and communication strategies: measures aimed at energy-poor households must address acute vulnerability, whereas financially secure groups may require targeted incentives to shift their consumption habits. At the same time, the proactive behavior of information-seeking consumers demonstrates the potential of education and awareness-raising campaigns, suggesting that knowledge transfer can serve as an effective tool to foster more sustainable energy practices across different segments of society.

3.5. Environmental awareness and energy crisis

Individuals strongly motivated by environmental protection, reducing their ecological footprint, and prioritizing their children's future were already striving for energy and environmental consciousness before the energy crisis (Jaciow et al., 2022; Radácsi & Szigeti, 2024). Some participants in the research had installed renewable energy sources years earlier to actively contribute to mitigating global warming. Their commitment is evidenced by the time invested in learning about renewable technologies and their willingness to pay more for environmentally friendly solutions if these contribute to the preservation of the planet (Ul-Mulk & Reynaud, 2018). In recent decades, there has been a growing tendency to adopt renewable energy sources primarily to achieve household-level energy autonomy. Such investments not only improve financial stability and living standards but also stem from an intrinsic drive to reduce dependence on external providers and to limit vulnerability to fluctuating energy costs. The energy crisis further reinforced this pattern, as many respondents believed that alternative energy could provide greater autonomy and security, counterbalancing the uncertainty and distrust associated with conventional suppliers.

Survey data confirm these perceptions. The results show that 12.6% of participants reported that the crisis directly increased their personal interest in renewable energy, 18.4% perceived that the crisis has led more households to turn to renewables, and 64.1% observed a general increase in societal openness toward renewable energy. These findings highlight that the crisis did not only stimulate economic rationality but also strengthened collective awareness and receptiveness. Savings from energy efficiency measures offer additional advantages, allowing households to reinvest in further improvements as needed (Farghali et al., 2023). Consequently, individuals who have become more receptive to energy-conscious perspectives due to the crisis represent a more accessible target group for future educational and awareness-raising initiatives.

3.6. Responsibility

In examining the issue of responsibility, the survey results indicate that participants believe all individuals share responsibility for adopting an energy-conscious lifestyle and regard mindful energy use as a common societal interest. This perception reflects a relatively high level of awareness and willingness to assume responsibility among a significant portion of the population. Respondents nevertheless assign greater responsibility to the state than to energy providers, particularly in the context of communicating the opportunities offered by renewable energy sources. Energy providers, however, cannot be exempted from responsibility: many participants emphasized that promoting energy-conscious living and educating the public about renewable energy should also be considered part of their mandate (Kozma & Bosnyák-Simon, 2022c). Consumers with a strong sense of personal responsibility are more likely to become active participants in both energy consciousness and environmental protection. Their heightened sensitivity leads them not only to adopt energy-conscious behavior but also to expect a similar commitment from energy providers towards sustainability (Kollmuss & Agyeman, 2002).

Survey data further clarify these expectations. When asked about their interest in educational content prepared by energy providers, approximately 45% of respondents expressed strong interest, 35% indicated conditional openness (“maybe”), and 13% reported that they already consume similar content, while only 5% were not interested. This distribution demonstrates a strong societal expectation for energy providers to act not merely as suppliers but also as reliable sources of knowledge, thereby complementing the state’s efforts to foster energy awareness. At the same time, respondents consistently assigned the greatest responsibility to the state, particularly with regard to regulating the market and communicating the benefits of renewables. Nevertheless, a substantial share also highlighted that energy providers bear responsibility for raising awareness and promoting sustainable practices, while individuals themselves were seen as accountable through everyday energy-saving behaviors. Taken together, these findings reinforce the view that energy awareness is a shared societal task, requiring coordinated contributions from the state, providers, and consumers alike (Szeberényi et al., 2022).

3.7. Consumer energy awareness

Although an energy-conscious mindset has developed within certain consumer groups, the real breakthrough was prompted by the energy crisis and its negative consequences, which jolted the entire population out of its apathy towards energy issues. Recent events have made consumers aware that their current lifestyles are unsustainable both economically and environmentally, necessitating a reconsideration and modification of their energy consumption. The energy crisis has compelled not only businesses but also households to take urgent measures, with rising energy prices prompting consumers to become more conscious about their energy use. In the study, 54.6% of participants consider the transition to renewable energy to be extremely important. Although Hungarian residents are often perceived as not being particularly energy-conscious, individuals rate their own energy awareness at 6.65 on a self-assessment scale. They are committed to an energy-conscious lifestyle, actively striving to live according to this principle, only 1% not attempting to practice energy-conscious living (see Figure 3).

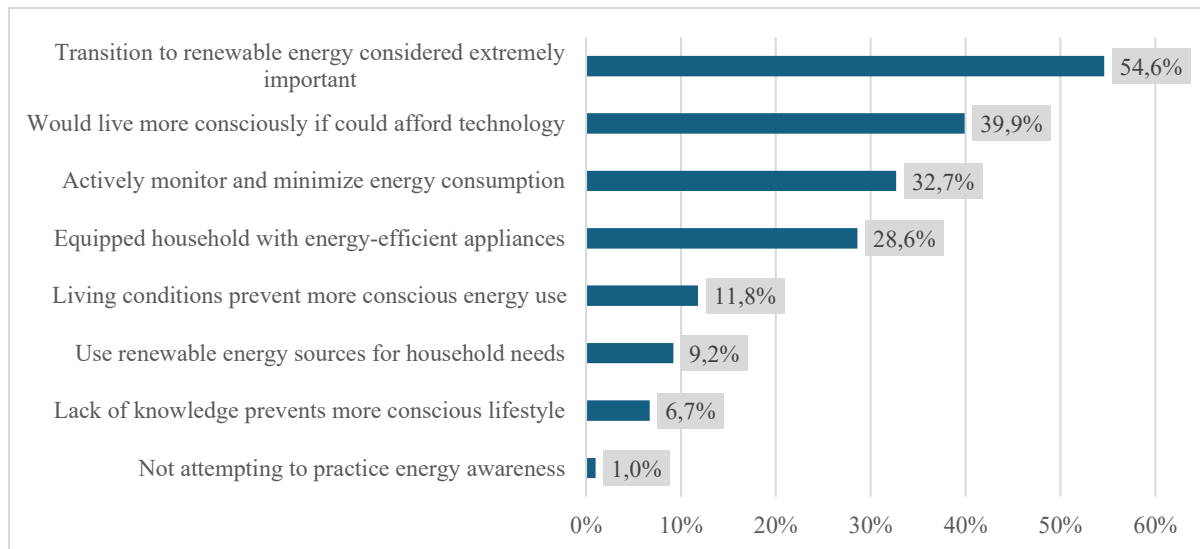


Fig. 3 Indicators and barriers of energy awareness among respondents

Source: own edited

Figure 3 clearly illustrates the implementation of energy awareness in the respondents' lives. Specifically, 28.6% have equipped their households with energy-efficient appliances, while 32.7% actively monitor and strive to minimize their energy consumption. Additionally, 9.2% of the respondents use renewable energy sources to meet their energy needs. These examples effectively demonstrate their commitment to an energy-conscious approach.

Beyond behavioral indicators, the survey also explored which factors most strongly influenced openness to renewable energy. The results highlight the energy crisis and soaring energy prices as the most decisive external drivers, while climate change and environmental concerns emerged as key internal motivators. Furthermore, the desire for independence from providers and the availability of subsidies and state or EU support schemes were also significant. These findings confirm that energy awareness is shaped not only by individual household practices but also by global challenges and institutional frameworks, underscoring the interplay of economic, ecological and policy-related factors. Energy awareness is commonly defined by respondents as being conscious of energy consumption, minimizing energy waste and employing responsible energy practices. It is also linked to concepts such as energy conservation and efficiency. Additionally, the adoption of renewable energy sources, the abandonment of wasteful energy consumption habits, and the optimization of energy use through understanding and adjusting consumption patterns are frequently mentioned. The overarching goal is to transform daily life to achieve minimal energy usage.

Despite the variety of expressions used by respondents to describe energy awareness, the consensus is that it is primarily perceived as attentiveness and mindfulness regarding energy use, aimed at avoiding waste and unnecessary consumption. Among the respondents, 39.9% would live more energy-consciously if they could financially afford the technology, 11.8% cited their living conditions as a reason for their inability to use energy sources more consciously, and 6.7% lacked sufficient knowledge to develop an energy-conscious lifestyle.

4. Conclusions

As a consequence of the energy crisis, attention has increasingly turned to energy consumption habits and, by extension, to energy awareness. A growing number of consumers have redefined what this concept means for them personally and how their existing practices can be adjusted to ensure both economic and environmental sustainability. Financial considerations, however, continue to exert a decisive influence: when behavioral change is not perceived as economically advantageous, the willingness to adopt more conscious habits remains limited. In the absence of such willingness, meaningful engagement in energy awareness cannot be achieved. This tension between positive attitudes and the practical realities of financial constraints reflects a broader dilemma that is common in transitional societies, where aspirations often exceed the resources available to implement them.

The results nevertheless point to a gradual shift toward more conscious consumption patterns. A considerable share of respondents indicated that they would adopt renewable energy sources, provided that their financial situation and living conditions allow it. At present, energy awareness manifests predominantly in the form of conservation efforts, such as the reduction of wasteful habits and the monitoring of consumption. Yet these relatively modest practices still represent a solid foundation for the transformation of consumer attitudes. Over time, they can help nurture future generations for whom energy awareness will likely evolve into an integral element of daily life and mindset (Sárvári, 2022a). Furthermore, respondents with limited knowledge of the subject demonstrated notable openness to additional information, underlining the importance of educational initiatives, transparent communication, and the availability of reliable resources in shaping long-term awareness and motivation.

In summary, these findings reveal that while financial and infrastructural limitations continue to determine the extent of energy-conscious behavior, the social foundations for greater awareness are already in place. The crisis has acted as a catalyst that not only altered daily routines but also redefined expectations regarding sustainable living. In this sense, the energy crisis can be regarded as both a disruptive shock and a developmental opportunity: disruptive because it forced households to reconsider deeply ingrained consumption habits, and developmental because it accelerated the spread of attitudes and practices that can support a sustainable energy future (Kozma, 2018). The conclusion is therefore clear: by reinforcing existing tendencies through education, policy support, and technological accessibility, Hungary can foster an energy-conscious society that is better prepared to face both economic uncertainties and environmental challenges in the decades to come (Bozsik et al., 2024).

Conflict of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- Azizi, Z. M., Mokhtar Azizi, N. S., Abidin, N. Z., & Mannakkara, S. (2019). Making Sense of Energy-Saving Behaviour: A Theoretical Framework on Strategies for Behaviour Change Intervention. *Procedia Computer Science*, 158, 725–734. <https://doi.org/10.1016/j.procs.2019.09.108>
- Baranyai, E., & Banai, Á. (2022). Feeling the heat: Mortgage lending and central bank options. *Financial and Economic Review*, 21(1), 5–31. <https://doi.org/10.33893/fer.21.1.5>
- Bozsik, N., Tánczos, T., & Bozsik, N. (2024). Az Európai Unió megújuló energiaforrásainak szerepe a széndioxid-kibocsátás és az energiafüggőség csökkentésében. *Külügyi Szemle*, 23(2), 3-27. https://doi.org/10.47707/Kulugyi_Szemle.2024.2.1
- Cheng, T.-M., & Wu, H. C. (2014). How do environmental knowledge, environmental sensitivity, and place attachment affect environmentally responsible behavior? An integrated approach for sustainable island tourism. *Journal of Sustainable Tourism*, 23(4), 557–576. <https://doi.org/10.1080/09669582.2014.965177>
- Farghali, M., Osman, A. I., Mohamed, I. M. A., Chen, Z., Chen, L., Ihara, I., Yap, P.-S., & Rooney, D. W. (2023). Strategies to save Energy in the Context of the Energy crisis: a Review. *Environmental Chemistry Letters*, 21. <https://doi.org/10.1007/s10311-023-01591-5>
- Gadenne, D., Sharma, B., Kerr, D., & Smith, T. (2011). The influence of consumers' environmental beliefs and attitudes on energy saving behaviours. *Energy Policy*, 39(12), 7684–7694. <https://doi.org/10.1016/j.enpol.2011.09.002>
- Gajdzik, B., Wolniak, R., Nagaj, R., Żuromskaitė-Nagaj, B., & Grebski, W. W. (2024). The Influence of the Global Energy Crisis on Energy Efficiency: A Comprehensive Analysis. *Energies*, 17(4), 947. <https://doi.org/10.3390/en17040947>
- Gârdan, I. P., Micu, A., Paștiu, C. A., Micu, A. E., & Gârdan, D. A. (2023). Consumers' Attitude towards Renewable Energy in the Context of the Energy Crisis. *Energies*, 16(2), 676. <https://doi.org/10.3390/en16020676>
- Hassan, M. G., Hirst, R., Siemieniuch, C., & Zobaa, A. F. (2009). The impact of energy awareness on energy efficiency. *International Journal of Sustainable Engineering*, 2(4), 284–297. <https://doi.org/10.1080/19397030903121968>
- Jaciow, M., Rudawska, E., Sagan, A., Tkaczyk, J., & Wolny, R. (2022). The Influence of Environmental Awareness on Responsible Energy Consumption—The Case of Households in Poland. *Energies*, 15(15), 5339. <https://doi.org/10.3390/en15155339>
- Kollmuss, A., & Agyeman, J. (2002). Mind the Gap: Why Do People Act Environmentally and What Are the Barriers to pro-environmental behavior? *Environmental Education Research*, 8(3), 239–260. <https://doi.org/10.1080/13504620220145401>
- Kolozsi, P. P., Ladányi, S., & Straubinger, A. (2022). Measuring the Climate Risk Exposure of Financial Assets: Methodological Challenges and Central Bank Practices. *Financial and Economic Review*, 21(1), 113–140. <https://doi.org/10.33893/fer.21.1.113>
- Kolozsi, P. P. (2023). Új közgazdaságtan a fenntarthatóságért. *Pénzügyi Szemle = Public Finance Quarterly*, 69(1), 115–119. https://doi.org/10.35551/psz_2023_1_8

- Kozma, D. E., & Bosnyák-Simon, N. (2022c). A fenntarthatóság környezeti elemeinek megjelenése a hazai nagyvállalatok gyakorlatában. In Soproni Egyetem Kiadó eBooks (149–164). https://doi.org/10.35511/978-963-334-411-8_s3_kozma_bosnyak-simon
- Kozma, D. E. (2018). A Fenntartható Fejlődési Célok (SDGs) és a GDP közötti kapcsolat vizsgálata. *Gazdaság és Társadalom*, 3-4, 67–89. <https://doi.org/10.21637/gt.2018.3-4.05>
- Mansor, R., & Sheau-Tingi, L. (2019). The psychological determinants of energy saving behavior. *IOP Conference Series: Materials Science and Engineering*, 620, 012006. <https://doi.org/10.1088/1757-899x/620/1/012006>
- Meyer, N., Magda, R., & Bozsik, N. (2021). The role of renewable energies in the new EU member states. *Journal of Eastern European and Central Asian Research (JEECAR)*, 8(1), 18–25. <https://doi.org/10.15549/jeecar.v8i1.536>
- Radácsi, L., & Szigeti, C. (2024). The illusion of the Holy Grail of decoupling: Are there countries with relatively high SDGI and moderately low ecological footprint? *Environmental and Sustainability Indicators*, 22, 100379. <https://doi.org/10.1016/j.indic.2024.100379>
- Rausser, G., Strielkowski, W., & Mentel, G. (2023). Consumer Attitudes toward Energy Reduction and Changing Energy Consumption Behaviors. *Energies*, 16(3), 1478. <https://doi.org/10.3390/en16031478>
- Sárvári, B. (2022). A zöld pénzügyi kapacitásfejlesztés trendjei és dilemmái. *Hitelintézeti Szemle*, 21(4), 207–218. o.
- Slupik, S., Kos-Łabędowicz, J., & Trzęsiok, J. (2021). An Innovative Approach to Energy Consumer Segmentation—A Behavioural Perspective. The Case of the Eco-Bot Project. *Energies*, 14(12), 3556. <https://doi.org/10.3390/en14123556>
- Smith, J., & Johnson, L. (2021). Consumer Attitudes Towards Energy Efficiency and Renewable Energy Sources: A Comparative Study. *Journal of Sustainable Energy and Environment*, 12(3), 45–60.
- Szakály, Z., Balogh, P., Kontor, E., Gabnai, Z., & Bai, A. (2020). Attitude toward and Awareness of Renewable Energy Sources: Hungarian Experience and Special Features. *Energies*, 14(1), 22. <https://doi.org/10.3390/en14010022>
- Szeberényi, A., Rokicki, T., & Papp-Váry, Á. (2022). Examining the relationship between renewable energy and environmental awareness. *Energies*, 15(19), 7082. <https://doi.org/10.3390/en15197082>
- Ul-Mulk, R., & Reynaud, E. (2018). Sustainable attitudes and behavioural intentions towards renewable energy: a comparative analysis of developed and developing countries. *Recherches En Sciences de Gestion*, 129, 151-178. <https://doi.org/10.3917/resg.129.0151>
- Várgedő, B. (2022): Klímakockázati stresszteszt: a karbonár-sokk csődvalószínűsége kifejtett hatása a magyar bankrendszerben. *Hitelintézeti Szemle*, 21(4), 57–82. <https://doi.org/10.33893/FER.21.4.57>
- Wall, W. P., Khalid, B., Urbański, M., & Kot, M. (2021). Factors Influencing Consumer's Adoption of Renewable Energy. *Energies*, 14(17), 5420. <https://doi.org/10.3390/en14175420>
- Zhao, S., Song, Q., & Wang, C. (2019). Characterizing the Energy-Saving Behaviors, Attitudes and Awareness of University Students in Macau. *Sustainability*, 11(22), 6341. <https://doi.org/10.3390/su11226341>



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VOLUME 1

AI, Sustainability and Digital Transformation: Shaping the Future of Business and Society

The Economical, Social, Political and Environmental Impacts of the CATL Battery Factory Regarding the City of Debrecen and its Region

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Abstract: In recent years, the Hungarian economy has increasingly concentrated on the automotive industry, particularly on battery production. This study examines the implications of CATL battery plant investment in Debrecen, focusing on residents' attitudes, city administration plans, and expert projections. The central question is whether factory construction will exacerbate existing economic, environmental, and socio-political issues in the region. These findings indicate that lithium-ion battery production poses significant environmental risks in the absence of stringent regulations. The semi-arid climate of Debrecen presents a challenge to the city's ability to manage its water resources effectively, particularly in light of the assurances provided by local authorities regarding the availability of water. The findings of researches conducted in the city indicate a lack of confidence in the efficacy of local environmental monitoring efforts and a significant level of opposition (over 60%) among residents who prefer factory relocation; from an economic perspective, the factory could potentially boost tax revenues (Skrydstrup et al., 2020). However, the low return on investment and substantial environmental damage anticipated, especially **during** the initial phase with lenient regulations, raises concerns about the long-term sustainability of the project. From a social perspective, the project offers limited benefits, with plans to employ lower-paid foreign workers because of a domestic labor shortage. Overall, investment is expected to impose significant political and social burdens on Debrecen, with potentially severe environmental consequences and insufficient economic returns to offset the damage (Debrecen City Governance, 2023).

Keywords: Battery Industry, Environmental Impact, Foreign Direct Investment (FDI), Hungarian CATL, Regional Development

JEL Codes: R11, O18, Q56, L52.

1. Introduction

One of the most pivotal roles in the ongoing struggle for environmental sustainability is to advocate for the increased utilization of electric transportation (International Energy Agency, 2022a). Over the past decade, the number of electric vehicles has increased exponentially; while there were almost no such vehicles in 2010, by 2021 their number had increased to 16.5 million globally (International Energy Agency, 2022a). The imperative to decarbonize is expected to reinforce this trend, which will significantly increase the demand for batteries for electric cars (Hungarian Government, 2022; Hawkins, 2024; Polyák, 2024). The significance of the region is reflected in the fact that, in the global context of 2021, Hungary had become the third largest producer of batteries, with a production capacity of 28 gigawatt hours, after China and the United States (Yu-Sumangil, 2021; Samsung SDI, 2019). This capacity is set to be augmented by the Chinese Contemporary Amperex Technology Co., Limited (CATL) in 2025, with an investment of 7.34 billion euros in Debrecen to create 100 gigawatt-hours of capacity (Szabó et al., 2022).

This study examines the question of whether battery production in the Hungarian economy, with significant government support, will serve Hungary's long-term economic catch-up. Four specific areas require further investigation. The initial area of focus is the economic aspect. Secondly, it is necessary to consider the social influence on local communities and the lives of the people of Debrecen. Thirdly, it is inevitable to examine the potential impact of the factory on the local environment, including the soil, water, air, and other natural resources. Finally, it is crucial to comprehend the political conflicts surrounding the construction of the battery factory, as well as the perspectives and prevailing sentiments of non-governmental organizations and political parties.

The research is guided by the following question: How does the establishment of the CATL battery factory in Debrecen affect the region's economic development and environmental sustainability, what are the related social implications, how does it contribute to political polarization and public mistrust, and what are the perceived long-term consequences for local stakeholders?

2. Literature Review

To ensure clarity and consistency throughout this manuscript, the following key concepts are defined at the outset of this literature review:

2.1. Political Legitimacy

Political legitimacy is defined as a virtue of political institutions and the decisions made within them, encompassing laws, policies, and candidates for political office. It can be understood descriptively, referring to people's beliefs about political authority, or normatively, concerning the justification of political power or authority and the associated obligations (Peter, 2017). A **legitimacy deficit** would therefore imply a shortfall in this virtue, indicating a lack of justification or acceptance of political power or authority.

2.2. Legitimacy Deficit

A **legitimacy deficit** refers to a situation where a political entity, such as a state, lacks sufficient justification or acceptance of its authority and actions by its constituents. This can manifest in various forms, including failures in **input legitimacy** (lack of mechanisms for authorization considered legitimate by the people), **output legitimacy** (failure to provide effective governance or deliver public goods), and **identity-based legitimacy** (challenges arising from the role of identity in shaping alternative visions and grievances against the state) (Lindberg, 2021).

2.3. Social License to Operate (SLO)

Social License to Operate (SLO) refers to the ongoing acceptance of a company or industry's standard business practices and operating procedures by its stakeholders and the general public. It is an informal contract that signifies a community's approval and broad acceptance of an operation. More specifically, SLO can be understood as a community's ongoing acceptance of operations in cases where that community holds a **moral authority** over those operations, meaning their acceptance is a necessary condition for the operations' overall moral legitimacy (Thomson & Boutilier, 2011).

2.4. Public Trust

Public trust refers to the confidence and belief that citizens have in their government institutions and officials to act in the best interests of the public. This concept is crucial as it underpins the legitimacy of governmental authority, influences public opinion, and affects the overall stability of democratic systems. High levels of public trust generally lead to greater civic engagement and compliance with laws and regulations (OECD, 2017).

2.5. CORIS Framework (Challenge-Oriented Regional Innovation Systems)

The **Challenge-Oriented Regional Innovation Systems (CORIS)** framework is an approach that re-evaluates the traditional Regional Innovation System (RIS) concept. While conventional RIS focuses on technological and business innovation for competitiveness and economic growth, CORIS addresses persistent environmental and social challenges (e.g., climate change, aging, inequalities). This framework embraces a more critical view of innovation, emphasizes the directionality of change, incorporates new innovation actors across different territorial scales, and prioritizes the application and upscaling of innovation within and beyond the region (Tödtling et al., 2022).

This literature review establishes the theoretical and empirical context for analyzing the CATL battery factory investment in Debrecen. It critically examines key academic debates and relevant studies across several domains: regional innovation systems, particularly the challenge-oriented approach; mission-oriented innovation policies; the environmental impacts of lithium-ion battery production; and the regulatory, policy, and local development contexts in Hungary.

2.5.1. Regional Innovation Systems and the Challenge-Oriented Approach

While traditional regional innovation systems (RIS) focus on technological growth, CORIS emphasizes mission-driven innovation to address complex societal challenges. This framework is particularly relevant to the **Political Dimension** sub-question, which examines how power dynamics and governance structures influence public trust and polarization in the context of large-scale foreign investments.

CORIS addresses these limitations by emphasizing mission-driven innovation aimed at specific regional challenges (Isaksen et al., 2022; Tödtling et al., 2021). It promotes collaboration among diverse stakeholders—including government, businesses, research institutions, and civil society—to foster an innovation ecosystem that generates and implements new solutions (Tödtling et al., 2021; Trippel et al., 2022). Unlike the often-decentralized governance of traditional RIS, CORIS advocates for more centralized coordination to tackle complex, multi-sectoral problems (Tödtling et al., 2021).

However, a critical analysis of CORIS reveals potential limitations, particularly in the context of post-socialist countries like Hungary. The framework may present an idealized view of institutional influence and harmony between government and regional decision-makers, often overlooking significant power imbalances between local governments and multinational investors (Purdy, 2016). Furthermore, its technological optimism might not adequately address fundamental environmental challenges inherent in industries like battery manufacturing, especially when communication on environmental protection mismatches actual production impacts. These limitations necessitate adapting the framework to account for the substantial power differences prevalent in such contexts. While Trippel et al. (2021) examine automotive regions in transition, their analysis often overlooks the distinct environmental and skill-related demands of a shift to battery manufacturing. This subsection, therefore, sets the stage for a critical application of the CORIS framework, adapted to the specific political and institutional realities of the Debrecen case.

2.5.2. Challenge-Oriented Innovation Policies

Building on the CORIS framework, this section examines **mission-oriented innovation policies**, as conceptualized by Mazzucato (2018). This theoretical lens is essential for addressing the **Economic Viability** sub-question, as it provides a framework for assessing whether state-provided resources and public subsidies for the CATL factory align with broader societal goals, such as sustainable economic growth and decarbonization.

However, applying Mazzucato's theory to Hungary's investment-driven growth model reveals contradictions. The theory assumes significant state autonomy and bargaining power, which may not hold true in Hungary, where competition for foreign investment can lead to deregulation and weaker environmental controls. Moreover, Mazzucato's 'entrepreneurial state' framework may not fully account for the relational networks in former socialist countries, where investment decisions might serve individual interests over strategic development. Voszka's (2019) research provides valuable context on national industrial policies in a global environment, highlighting challenges governments face in balancing political autonomy with attracting foreign investment, a dynamic clearly evident in the CATL case. This critical perspective is crucial for evaluating the true economic costs and benefits of the CATL investment, moving beyond simplistic job creation metrics.

2.5.3. Environmental Impacts of Lithium-Ion Battery Manufacturing

The following review of the literature on raw material extraction, manufacturing processes, and waste management provides the scientific basis for assessing the quantifiable environmental risks posed by the CATL factory in Debrecen.

The environmental implications of lithium-ion battery production are central to this study. Li et al. (2018) provides a comprehensive overview of battery developments, including environmental impacts from raw material extraction and manufacturing. These processes are associated with significant environmental impacts, including habitat destruction, water pollution, and resource depletion, often raising ethical concerns regarding sourcing (Li et al., 2018; Philippot et al., 2019). Improper disposal can lead to the leakage of hazardous chemicals, soil and groundwater contamination, and the loss of valuable materials (Toshiba 2024; Manthiram, 2017).

However, critical analysis highlights methodological limitations in some literature, such as Li et al.'s primary focus on technical aspects with limited analysis of social impacts or comprehensive life cycle assessments, particularly concerning water use and toxic waste management. Philippot et al. (2019) specifically examine the water footprint of battery production, a crucial aspect for water-scarce regions like Debrecen. Yet, their methodology, while robust for direct process water accounting, may overlook broader hydrological impacts (e.g., watershed integrity, groundwater resources) critical in diverse geographical settings. This raises the fundamental question of whether large-scale battery production can be truly sustainable in arid areas. Yang et al. (2023) offer a more holistic view on sustainable battery production through digital economic developments, while Wu's (2024) research on the acceptance of Chinese battery manufacturers in Hungary provides important context on local power relations and social acceptance.

2.5.4. Regulatory and Policy Context

Understanding the interplay between EU regulations, national strategies, and local governance is crucial for evaluating the effectiveness of the existing frameworks in mitigating risks and ensuring sustainable outcomes.

European Commission regulations provide the supranational framework for environmental and sustainability compliance, though their implementation can present nuances, sometimes diverting attention from direct manufacturing impacts or supporting problematic developments (European Commission, 2023).

At the national level, the Hungarian Investment Promotion Agency (HIPA) website and the Hungarian Government's (2022) "National Battery Industry Strategy 2030" outline the policy framework. HIPA's reports, while providing data on investment scale, often rely on optimistic economic forecasts and uncritically assume sustainable development, necessitating critical evaluation. The National Battery Strategy itself, while outlining policy, has analytical shortcomings, including reliance on general assumptions for environmental impact assessments and a focus on manufacturing that risks dependent development rather than innovation. This suggests a more political than comprehensive development plan, requiring rethinking for balanced regional development.

2.5.5. Regional and Local Development Context

By examining existing research on local economic development, labor issues, and regional disparities in Hungary, this section provides the necessary background for understanding the community's perceptions and the potential social impacts of the CATL factory.

Bajmócy (2011) provides a theoretical framework for local economic development, though its applicability can be limited by overestimating local government bargaining power against large international firms and lacking specific tools for environmental impact assessment. Bodnár's articles (2021, 2022, 2023) offer empirically valuable case studies on environmental violations and labor issues, despite methodological scrutiny due to their journalistic format. Gyórfy (2021) examines regional economic disparities, highlighting how weak institutional quality can hinder development benefits, though its macro-level analysis may overlook crucial regional and local differences. Nagy et al. (2019) explore reindustrialization in Central and Eastern Europe, with implications for foreign worker employment, but their framework may oversimplify regional nuances and predate significant global disruptions.

2.6. Conclusion of the Literature Review

This comprehensive review of the literature has established the theoretical and empirical context for analyzing the CATL battery factory investment in Debrecen. While each domain offers valuable insights, several critical gaps and areas for further investigation have emerged, which this study aims to address.

Firstly, existing frameworks such as the Challenge-Oriented Regional Innovation System (CORIS) and mission-oriented innovation policies, while powerful, often present an idealized view that may not fully account for the complex power dynamics and institutional realities prevalent in post-socialist economies like Hungary. The literature reveals a need for more nuanced applications of these theories, particularly in understanding how they interact with foreign direct investment (FDI) pressures and local governance structures. This study contributes by critically adapting these frameworks to analyze the specific case of the CATL investment, thereby enriching the understanding of their applicability in contexts marked by significant power asymmetries.

Secondly, despite extensive research on the environmental impacts of lithium-ion battery production, there remains a critical need for context-specific assessments, especially concerning water-scarce regions and the broader hydrological impacts beyond direct process water accounting. The current literature emphasizes technological solutions but less frequently addresses the systemic environmental challenges inherent in large-scale manufacturing in vulnerable ecosystems. The research addresses this gap by scrutinizing the environmental sustainability of the CATL factory within Debrecen's semi-arid climate, focusing on water

consumption, hazardous waste management, and soil contamination, and evaluating the adequacy of local regulatory frameworks.

Thirdly, the literature highlights a limited understanding of how regional innovation systems can effectively transform economic development with broader environmental and social goals, particularly in the context of rapid industrial transformation in Central and Eastern European regions. There is a scarcity of research that comprehensively integrates economic, environmental, social, and political dimensions to provide a holistic view of such mega-projects. This study bridges this gap by offering a multidimensional analysis, examining the interplay between industrial development, environmental health, social stability, and political trust. By doing so, it provides a robust case study for advancing theoretical and empirical knowledge on sustainable regional development in similar contexts.

In synthesizing these insights, this literature review underscores the necessity of a holistic and critically informed approach to evaluating large-scale industrial investments. The identified gaps directly inform the sub-questions guiding this research, ensuring that the study contributes meaningfully to academic discourse and provides practical insights for policymakers and local stakeholders grappling with the complex trade-offs of economic development and sustainability.

3. Research question/objectives

The global transition to electric mobility has positioned Hungary as a key hub for battery manufacturing, highlighted by the €7.34 billion investment from Contemporary Amperex Technology Co., Limited (CATL) to build a massive battery factory in Debrecen. While promoted as a landmark project for economic growth, the investment has ignited significant public controversy and political debate. This research provides a multidimensional analysis of the project's anticipated impacts, moving beyond simple economic metrics to explore the complex interplay between industrial development, environmental health, and social stability.

The central research question guiding this study is: How does the establishment of the CATL battery factory in Debrecen affect the region's economic development and environmental sustainability, what are the related social implications, how does it contribute to political polarization and public mistrust, and what are the perceived long-term consequences for local stakeholders?

To address the multifaceted nature of the central research question, this study will be guided by the following four sub-questions, each aligned with a key analytical dimension:

1. **The Economic Viability Question:** To what extent does the CATL factory investment contribute to sustainable regional development, and how do the economic benefits (e.g., job creation, tax revenue) weigh against the costs (e.g., public subsidies, reliance on foreign labor, risk of dependency)?
2. **The Environmental Sustainability Question:** What are the quantifiable environmental risks posed by the factory—particularly concerning water consumption, hazardous waste management, and soil contamination—and are the existing regulatory and monitoring frameworks sufficient to mitigate these risks effectively?
3. **The Social Acceptance Question:** How does the local community in Debrecen perceive the social impacts of the factory, including the effects of a large expatriate workforce on social cohesion, public services, and quality of life, and what factors shape their 'social license to operate'?
4. **The Governance and Political Trust Question:** In what ways has the decision-making process surrounding the CATL investment influenced political polarization and public trust, and how do the power dynamics between the national government, local authorities, and the multinational corporation align with the principles of a Challenge-Oriented Regional Innovation System?

(CORIS)? The research delves into the political conflict and governance failures surrounding the investment. It seeks to understand the roots of widespread public mistrust, the exclusion of local communities from the decision-making process, and the power imbalances between the national government, the multinational corporation, and local authorities.

This study employs a mixed-methods approach within a Challenge-Oriented Regional Innovation System (CORIS) framework. By focusing on these interconnected economic, environmental, social, and political dimensions, the research aims to provide a holistic understanding of the CATL investment, offering crucial insights for ensuring that future industrial projects align with principles of sustainable and equitable development.

4. Methodology

The study employs a mixed-methods research design to provide a comprehensive analysis of the economic, environmental, social, and political impacts of the CATL battery factory investment in Debrecen. The methodology is structured around the Challenge-Oriented Regional Innovation System (CORIS) framework, which guides data collection and analysis by focusing on how the region responds to the multifaceted challenges posed by the investment.

The research is built on two pillars: primary and secondary data collection. Secondary research involved a systematic review of academic literature, government reports, policy documents, and media sources to establish a foundational context (Boncz, 2015; Stewart & Kamins, 1993). However, due to the politically sensitive nature of the topic and the early stage of the investment, much of the necessary data was unavailable or biased, necessitating a strong focus on primary data collection (Boncz, 2015).

The primary research consists of three distinct methods:

1. **Qualitative In-depth Interviews:** Eight semi-structured interviews were conducted with key stakeholders, including senior city government officials, opposition representatives, and members of non-governmental organizations (NGOs). Snowball sampling technique was used to access these hard-to-reach individuals (Patton, 2015; Bryman, 2016; Noy, 2008). The interviews were designed to capture nuanced perspectives on the investment's preparation, perceived impacts, and the surrounding political controversies. Data was manually transcribed, anonymized, and thematically coded using the CORIS framework to identify key regional challenges, actor roles, and collaborative networks.
2. **Qualitative Survey with an Observational Phase:** A survey of 150 individuals was conducted at Debrecen's main railway station using a quota sampling method to ensure demographic diversity across age and gender (Babbie, 2020). This method combined two elements: participants were asked for their immediate word association with the "Debrecen battery factory," while an observer simultaneously documented their non-verbal emotional reactions (facial expressions and body language). This innovative approach captured both conscious attitudes and subconscious, pre-reflective responses, providing deeper insight into public sentiment (Davidson et al., 2016).
3. **Quantitative Attitude Survey:** A quick, single-question online survey was distributed via social media to gauge public opinion. The question, "How do you feel about the battery factory investment near Debrecen?", garnered 112 responses, which were analysed to provide a broad quantitative measure of positive, negative, and neutral sentiments toward the project.

By integrating these qualitative and quantitative findings, the methodology facilitates a robust, multi-dimensional analysis. The in-depth interviews provide expert context and detail, the observational survey

captures raw public perception and emotion, and the attitude survey offers a snapshot of overall public opinion. This triangulation of data ensures a more valid and holistic understanding of the complex impacts of the CATL investment on the Debrecen region (Creswell, 2017).

5. Results

The results of this multifaceted investigation into the CATL battery factory investment in Debrecen reveal a deeply polarized landscape, where official narratives of economic progress clash with significant public apprehension and documented risks. Analysed through the Challenge-Oriented Regional Innovation System (CORIS) framework, the findings indicate a regional system under strain, struggling to balance externally imposed industrial ambitions with local environmental, social, and political realities.

5.1. Stakeholder Perspectives and Governance Failures

The in-depth interviews exposed a fundamental schism between government officials and local stakeholders. City administration representatives framed the investment as a strategic necessity for economic development, attributing public opposition to politically motivated misinformation spread by opposition parties. They emphasized the robustness of official environmental monitoring systems, asserting that all operations would comply with legal standards.

In stark contrast, opposition representatives and non-governmental organizations (NGOs) painted a picture of a top-down, non-transparent process that has actively marginalized the local community. They cited the repeated rejection of local referendums and the government's use of a "priority investment" designation as proof that democratic principles and the public's right to consultation under the Aarhus Convention were bypassed. These stakeholders expressed profound mistrust in the official environmental impact assessments, which they described as superficial and tailored to facilitate, rather than scrutinize, the investment. This governance failure has created a significant legitimacy deficit, undermining social acceptance crucial for sustainable development.

5.2. Public Perception and Emotional Response

The quantitative and qualitative surveys confirmed that this legitimacy deficit is widespread among the public. The online attitude survey revealed that a clear majority of respondents (65%) hold a negative view of the investment, with only 20% expressing positive sentiment.

The observational survey provided deeper insight into these attitudes. While "economic development" and "job creation" were mentioned as positive associations, they were largely accompanied by negative terms like "pollution," "environmental degradation," "wastewater," and "insecurity." A striking finding was the disconnect between verbal responses and emotional reactions. A significant majority of participants (67%) displayed neutral or unreadable facial expressions, even when voicing an opinion. However, when emotions were visible, negative expressions were far more common and strongly correlated with negative verbal associations. This suggests that while many may be undecided or disengaged, those who are engaged are predominantly concerned.

Generational differences were also notable. Younger generations (Z and Y) were more likely to mention both technological innovation and environmental pollution, reflecting a dual awareness of promise and peril. Older generations (X and Baby Boomers) focused more on economic risks and social instability (Twenge and Campbell, 2009). This divergence highlights that the community is not a monolith; different demographics perceive the challenges and opportunities of the investment in distinct ways.

5.3. Economic Impacts: A High-Risk Venture

The study's analysis of the economic dimension reveals that the CATL factory represents a high-risk, state-driven venture rather than a market-led development. While the projected GDP contribution is substantial, the reliance on massive state subsidies (with payback periods estimated between 7.5 and 17 years) raises serious questions about its long-term viability, especially given the rapid pace of technological change in the battery sector (Járdi, 2023; Szabó, 2022a).

Furthermore, the promise of local job creation appears tenuous. The reliance on imported labor from countries like the Philippines, often at lower effective wages and under precarious leasing arrangements, means the primary economic benefits may not flow to the local community (Spirk, 2023). Instead of fostering endogenous innovation and building local skills, this model risks creating a dependent "low-value manufacturing" enclave, locking Debrecen into a vulnerable position within the global supply chain without significant knowledge transfer or local economic integration (Tödtling et al., 2021).

5.4. Environmental Harm: A Significant Challenge

The environmental findings present the most concerning findings. The factory's immense water demand poses a direct threat to Debrecen's semi-arid climate and already strained water resources. Independent analysis suggests water consumption could be significantly higher than officially disclosed figures and promises to use treated greywater remain vague and unenforceable (Hancz, 2024; Philippot et al., 2019).

The risk of chemical contamination from heavy metals and other toxic substances is a primary concern, amplified by a regulatory environment that interviewees described as deliberately weakened to attract foreign investment (Bodnár, 2023; Hungarian Government Office, 2023b). The lack of a robust, independent environmental monitoring system and the authorities' perceived leniency towards existing polluters have eroded public confidence that safety standards will be enforced (Czirfusz, 2022; Degen & Schütte, 2022). The potential for Hungary to become a destination for toxic electronic waste under future EU recycling mandates further compounds these fears.

6. Discussion

While the project is framed as a catalyst for economic modernization, it simultaneously exposes deep-seated tensions between national industrial policy, regional sustainability, and democratic governance. This discussion interprets the results through the lens of the Challenge-Oriented Regional Innovation System (CORIS) framework, highlighting the systemic failures and potential pathways forward.

6.1. The CORIS Framework in a Post-Socialist Context: A Mismatch of Theory and Reality

The CORIS framework, with its emphasis on mission-driven collaboration and multi-stakeholder engagement, provides a useful ideal for assessing the Debrecen case. However, the reality on the ground reveals a significant mismatch. Instead of a collaborative ecosystem, the findings point to a top-down, state-led model where the national government and a multinational corporation dictate terms, largely excluding local government, civil society, and the public from meaningful participation. This aligns with critiques of the CORIS framework that question its applicability in contexts with high power asymmetries and weak institutional capacity (Purdy, 2016).

The Debrecen case suggests that in post-socialist countries like Hungary, where centralized power and a reliance on foreign direct investment are dominant features of the political economy, the CORIS model may be more aspirational than descriptive. The "challenge" being addressed appears to be less about regional

sustainability and more about fulfilling a national industrial strategy, even at the expense of local well-being. This raises a critical question for both theory and practice: How can the principles of challenge-oriented innovation be adapted to function effectively in environments where democratic institutions are under pressure and state-corporate power is concentrated?

6.2. The Illusion of Economic Modernization: Dependency and the Low-Value Trap

The economic analysis reveals that the CATL investment, while significant in scale, may not deliver the promised benefits of sustainable regional development. The reliance on substantial public subsidies, coupled with the importation of a low-wage foreign workforce, suggests a model of dependent development rather than genuine economic upgrading. This approach risks locking Debrecen into a “low-value manufacturing” trap, where the region provides cheap labor and resources without capturing the higher-value aspects of the innovation chain, such as research and development or strategic management (Tödtling et al., 2021).

This finding challenges the prevailing narrative of FDI-led growth in Hungary, suggesting that not all investment is equally beneficial. Without strong institutional frameworks to ensure knowledge transfer, local sourcing, and fair labor practices, such mega-projects can exacerbate existing inequalities and create a dual economy, with a high-tech, foreign-owned enclave disconnected from the local economic fabric. This underscores the need for a more discerning and strategic approach to industrial policy, one that prioritizes long-term regional resilience over short-term GDP growth.

6.3. Environmental Risks and the Erosion of Public Trust

The environmental findings are perhaps the most stark, highlighting the tangible risks of locating a water-intensive and potentially polluting industry in a semi-arid region. The lack of transparent and credible environmental impact assessments, coupled with a history of regulatory leniency, has created a deep-seated public mistrust that cannot be dismissed as mere misinformation. This erosion of trust is a critical failure of governance, as it undermines the social license to operate and fuels political polarization.

The Debrecen case serves as a powerful reminder that environmental sustainability is not a technical problem to be solved by engineering solutions alone; it is fundamentally a political and social issue. Without robust, independent, and transparent environmental governance, even the most technologically advanced projects will face legitimate public opposition. This highlights the urgent need for a paradigm shift in how environmental risks are assessed and communicated, moving from a compliance-based approach to one that prioritizes public participation, precaution, and long-term ecological stewardship.

6.4. The Social Dimension: A Community Divided

The social impacts of the CATL investment are complex and multifaceted. While some residents see the potential for economic opportunity, a significant portion of the community is deeply concerned about the erosion of their quality of life, the strain on public services, and the potential for social friction arising from a large influx of foreign workers. These concerns are not simply a matter of xenophobia; they reflect a legitimate anxiety about the capacity of the local community to absorb such a rapid and large-scale transformation.

The generational divide in perceptions is particularly revealing. Younger generations’ simultaneous awareness of technological promise and environmental peril suggests a more nuanced and perhaps more realistic understanding of the trade-offs involved. Older generations’ focus on economic and social stability reflects a deep-seated concern for the preservation of their community’s character and way of life. These

divergent perspectives underscore the need for a more inclusive and participatory approach to development, one that acknowledges and addresses the diverse concerns of all community members.

7. Conclusion

The study has provided a multidimensional analysis of the CATL battery factory investment in Debrecen, revealing a complex and often contradictory landscape of economic ambition, environmental risk, and social tension. The findings challenge the simplistic narrative of foreign direct investment as a panacea for regional development, highlighting the critical importance of robust governance, environmental stewardship, and public trust in ensuring sustainable and equitable outcomes.

The central conclusion of this research is that the CATL investment, in its current form, represents a significant gamble for the Debrecen region. While the potential economic benefits are substantial, they are accompanied by equally significant risks, including environmental degradation, social disruption, and the erosion of democratic accountability. The study's analysis through the Challenge-Oriented Regional Innovation System (CORIS) framework reveals a system that is failing to effectively balance these competing interests, with a top-down, state-led approach that has marginalized local stakeholders and fueled public mistrust.

The implications of these findings are far-reaching. For policymakers, the study underscores the need for a more strategic and discerning approach to industrial policy, one that prioritizes long-term regional resilience over short-term economic gains. It highlights the urgent need for stronger environmental regulations, more transparent and participatory decision-making processes, and a greater emphasis on building local innovation capacity. For local communities, this research provides a framework for understanding and articulating the complex trade-offs involved in large-scale industrial projects, empowering them to advocate for their interests and hold decision-makers accountable.

This study also contributes to the academic literature on regional innovation systems, mission-oriented innovation policies, and the political economy of post-socialist development. It demonstrates the need for a more critical and context-sensitive application of these theoretical frameworks, particularly in environments characterized by high power asymmetries and weak institutional capacity. By providing a rich, empirically grounded case study, this research offers valuable insights for scholars seeking to understand the complex interplay of economic, environmental, social, and political forces shaping regional development in the 21st century.

Looking ahead, further research is needed to monitor the long-term impacts of the CATL investment as it moves from construction to operation. Longitudinal studies will be crucial for tracking the actual economic benefits, environmental consequences, and social changes over time. Comparative research with other battery factory investments in Europe and beyond would also provide valuable context and help to identify best practices for ensuring that the transition to a green economy is both just and sustainable.

In conclusion, the case of the CATL battery factory in Debrecen serves as a powerful cautionary tale. It reminds us that the path to a sustainable future is not simply a matter of technological innovation; it is a complex and often contentious process that requires careful navigation of competing interests, a deep commitment to democratic principles, and a steadfast focus on the well-being of both people and the planet.

Conflict of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- Bajmócy, Z. (2011). Bevezetés a helyi gazdaságfejlesztésbe [Introduction to local economic development]. *Tér és Társadalom, 25*(4), 170–174. <https://doi.org/10.17649/tet.25.4.2015>
- Bodnár, Z. (2023, January 12). *Pert nyertünk és kiderült: Betemették a kutat, ami megmutatná, mérgezi-e a talajvizet a gödi akkumulátorgyár* [We won a lawsuit, and it was revealed: The well that could show whether the Göd battery factory is contaminating the groundwater was filled in]. atlatszo.hu. <https://atlatszo.hu/kornyezet/2023/01/12/pert-nyertunk-es-kiderult-betemettek-a-kutat-ami-megmutatna-mergezi-e-a-talajvizet-a-godi-akkumulatorgyar/>
- Bours, S., Wanzenböck, I., & Frenken, K. (2021). Small wins for grand challenges. A bottom-up governance approach to regional innovation policy. *European Planning Studies, 30*(11), 2245–2272. <https://doi.org/10.1080/09654313.2021.1980502>
- Chen, Y. (2024). Overseas strategic communication strategies of new energy enterprises: Media image analysis of BYD and CATL in Hungary. *Advances in Education, Humanities and Social Science Research, 11*(1), 341. <https://doi.org/10.56028/achssr.11.1.341.2024>
- Creswell, J. W. (2017). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). Sage Publications.
- Czirfusz, M. (2022). *The electronics industry in Hungary, Regional risk assessment: The electronics industry in Hungary*. Electronics Watch. <https://electronicswatch.org/regional-risk-assessment-electronics-industry-hungary-november-2022> 2615914.pdf
- Debrecen City Governance. (2023). *Debrecen fenntartható városfejlesztési stratégiája (FVS) 2021-2027* [Sustainable urban development strategy 2021-2027 of the County City of Debrecen]. debrecen.hu. <https://www.debrecen.hu/hu/debreceni/cikkek/debrecen-fenntarthato-varosfejlesztési-strategiája-fvs-2021-2027>
- European Commission. (2023). *New regulation on batteries and waste batteries. Regulation - 2023/1542*. EUR-lex. <https://eur-lex.europa.eu/eli/reg/2023/1542/oj/eng>
- Győrfy, D. (2021). Felzárkózási pályák Kelet-Közép-Európában két válság között [Convergence paths in Central and Eastern Europe between two crises]. *Közgazdasági Szemle, 68*(5), 499-524. <https://doi.org/10.18414/KSZ.2021.5.499>
- Hancz, G. (2024). A debreceni CATL akkumulátorgyár vízgazdálkodása szakmai szemmel [Water management of the CATL battery factory in Debrecen from a professional perspective]. *Debreceni Szemle, 31*(3), 256–266. <https://doi.org/10.59424/debreceniszemle/2023/31/3/256-266>
- Hungarian Government. (2022). *Nemzeti akkumulátor iparági stratégia 2030* [Hungarian national battery industry strategy 2030]. Magyarország Kormánya. <https://kormany.hu/dokumentumtar/nemzeti-akkumulator-iparagi-strategia-2030>
- International Energy Agency. (2022a). *Global EV Outlook 2022*. IEA. <https://www.iea.org/reports/global-ev-outlook-2022>
- Isaksen, A., Trippel, M., & Mayer, H. (2022). Regional innovation systems in an era of grand societal challenges: reorientation versus transformation. *European Planning Studies, 30*(11), 2125–2138. <https://doi.org/10.1080/09654313.2022.2084226>
- Li, M., Lu, J., Chen, Z., & Amine, K. (2018). 30 years of lithium-ion batteries. *Advanced Materials, 30*(33), 1800561. <https://doi.org/10.1002/adma.201800561>

- Manthiram, A. (2017) 'An outlook on lithium-ion battery technology', *ACS Central Science*, 3(10), pp. 1063-1069. <https://doi.org/10.1021/acscentsci.7b00288>.
- Mazzucato, M. (2018). Mission-oriented innovation policies: Challenges and opportunities. *Industrial and Corporate Change*, 27*(5), 803–815. <https://doi.org/10.1093/icc/dty034>
- Nagy, B., Udvari, B., & Lengyel, I. (2019). Újraiparosodás Kelet-Közép-Európában: újraéledő centrum-periféria munkamegosztás? [Reindustrialization in Central and Eastern Europe: reviving center-periphery division of labor?]. *Közgazdasági Szemle*, 66*(2), 163–184. <https://doi.org/10.18414/ksz.2019.2.163>
- Patton, M. Q. (2015). *Qualitative research & evaluation methods: Integrating theory and practice** (4th ed.). Sage Publications.
- Philippot, M., Ayerbe, E., Hoedemaekers, E., Van Mierlo, J., & Messagie, M. (2019). **Water footprint of the manufacturing of a traction lithium-ion battery pack**. Vrije Universiteit Brussel. https://cris.vub.be/ws/portalfiles/portal/49452020/EVS32_FullPaper_V1.pdf
- Polyák, P. (2024, January 25). Battery supremacy. **Phenomenal World**. <https://www.phenomenalworld.org/analysis/battery-supremacy/>
- Purdy, J. M. (2016). The role of power in collaborative governance. In **The challenges of collaboration in environmental governance** (pp. 246-264). Edward Elgar Publishing.
- Skrydstrup, J., Madsen, H. M., Löwe, R., Gregersen, I. B., Pedersen, A. N., & Arnbjerg-Nielsen, K. (2020). Incorporating objectives of stakeholders in strategic planning of urban water management. *Urban Water Journal*, 17(2), 87–99. <https://doi.org/10.1080/1573062x.2020.1748204>
- Trippl, M., Baumgartinger-Seiringer, S., & Kastrup, J. (2024). Challenge-oriented regional innovation systems. **Investigaciones Regionales - Journal of Regional Research*, 60*, 105–116. <https://doi.org/10.38191/iirr-jorr.24.026>
- Toshiba (2024) *How lithium-ion batteries work?*, *global.toshiba*. Available at: <https://www.global.toshiba/ww/products-solutions/battery/scib/product/module/sip/download/batteryschool/episode1.html>
- Tödtling, F., Trippl, M., & Desch, V. (2021). New directions for RIS studies and policies in the face of grand societal challenges. **European Planning Studies*, 30*(11), 2139–2156. <https://doi.org/10.1080/09654313.2021.1951177>
- Tödtling, F., Trippl, M., & Desch, V. (2022). New directions for RIS studies and policies in the face of grand societal challenges. *European Planning Studies*, 30(11), 2139–2156. <https://doi.org/10.1080/09654313.2021.1951177>
- Voszka, É. (2019). Iparpolitika határok nélkül [Industrial policy without borders]. **Külgazdaság*, 63*(1–2), 82–115. <https://doi.org/10.47630/kulg.2019.63.1-2.82>
- Wu, Q. M. (2024). The embrace and resistance of Chinese battery investments in Hungary: The case of CATL. **Asia Europe Journal*, 22*(2), 201–223. <https://doi.org/10.1007/s10308-024-00699-9>
- Yang, X., Xu, Y., Razzak, A., Wu, D., Cao, J., & Ran, Q. (2023). Roadmap to achieving sustainable development: Does digital economy matter in industrial green transformation?. **Sustainable Development*, 32*(3), 2583–2599. <https://doi.org/10.1002/sd.2781>



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Part II - Digital and Sustainable Industrial Systems



VOLUME 1

AI, Sustainability and Digital Transformation: Shaping the Future of Business and Society

Freight transport decarbonisation and strategic procurement: a comparative analysis across Europe, China, and North America

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Abstract: Freight transportation is one of the most important contributors to global greenhouse gas (GHG) emissions. This study analyzes and compares how sustainability targets and practices are being implemented in road freight across three key regions: Europe, China, and North America. The aim is to evaluate the challenges, opportunities, and lessons learnt. Multiple approaches were applied: (1) a comprehensive literature review of sustainability regulations and technological trends; (2) secondary data collection from sustainability reports in the automotive industry; and (3) a primary survey distributed to international forwarders and service providers.

The results indicate that Europe is mainly driven by regulatory decarbonization with strong commitments to electrification and intermodal freight, though infrastructure gaps remain. China demonstrates fast and strong progress in electrification and digital logistics platforms but faces challenges in implementation across regions. North America shows slower regulatory adoption but strong industry-driven initiatives in efficiency and alternative fuels. Results from the questionnaire indicate that cost pressures, **service** reliability, and infrastructure readiness are the most well-known challenges, while collaboration and digital transparency tools are seen as key points toward sustainability.

The study outlines a potential strategic route that can give direction to political decision-makers and to industry leaders for creating strong procurement strategies and a stable base for creating and implementing sustainable solutions within the local and global supply chains. It is confirmed within the study that even though each region takes a different path, the key drivers of success are similar: using new technologies, working together across industries, and keeping government rules in line with market needs.

Keywords: Carbon neutrality, CO₂ reduction, Cross region study, Decarbonization, Freight transport, Road freight, Sustainability

JEL Classification: Q55, L92, L22

1. Introduction

The global freight transport sector is under increasing pressure to reduce its environmental impact (Jing et al., 2025) while continuing to meet the growing demand for goods across regions. Road, ocean, and air transport are essential for supply chains and these transport systems are representing the core of the modern society (Engström, 2016), and these transport systems are the largest contributors to greenhouse gas (GHG) emissions worldwide (International Energy Agency, 2021). Road freight, as part of this global systems, is representing a fundamental part of it. (Engström, 2016; Eurostat, n.d.). In Europe, heavy goods vehicles (HGVs) reached their peak in 2023 (IEA, 2023; Smart Freight Centre, 2024; Reuters, 2024) representing 25.3% of road transport emissions, equal to 1807 billion tonne-km (Kliuyeva, 2022; Eurostat, n.d.; Regulation (EU) 2023/1804 of the European Parliament and of the Council of 13 September 2023 on the Deployment of Alternative Fuels Infrastructure, and Repealing Directive 2014/94/EU (Text with EEA

Relevance), 2023) and overall global logistics freight transport represents approx. 8-10% of global emissions (Smart Freight Centre, 2024). This contribution is expected to rise if no major changes happen, as per expectations the share of road freight might raise to 40% by 2030, and by 80% by 2050 (European Commission, n.d.). Due to this potential high increase of the market share of road freight transport compared to other transport modes, it is essential to put a focus and identify how this aligned in reaching the global sustainability goals by 2030, and reaching full climate neutrality by 2050. To reach the global sustainability goals, a full operational mindset change is needed which supports the goals while bringing the freight transport into a more sustainable approach (Kumar et al., 2019).

Governments, industry players, and logistics service providers are now facing a dual challenge: ensuring efficient and reliable (Kumar Dadsena et al., 2019) delivery of goods, but also meeting ambitious sustainability targets, led by governments, on the regional and global level as well. The regional landscape of targets gives a very different base. As an example, the revised EU regulations under the Fit-for-55 package (Council of the European Union, 2023) sets a clear and challenging roadmap to reduce transport emissions of heavy-duty vehicles by 45% by 2030, 65% by 2035, 90% by 2040 (Regulation (EU) 2023/1804 of the European Parliament and of the Council of 13 September 2023 on the Deployment of Alternative Fuels Infrastructure, and Repealing Directive 2014/94/EU (Text with EEA Relevance), 2023; Reuters, 2024). China has targeted to achieve carbon neutrality by 2060, supported by investments in low-emission logistics infrastructure (Li et al., 2025; Xie et al., 2025; Zhang et al., 2025; Zheng et al., 2025). Meanwhile, in North America, the U.S. Inflation Reduction Act (Inflation Reduction Act of 2022, 2022) and California's climate policies are creating new incentives for cleaner freight operations (*Current California GHG Emission Inventory Data | California Air Resources Board*, n.d.; Tostes et al., 2025).

Despite regional differences, the logistics and transport sector shares many common challenges: increasing fuel costs, the slow change to alternative fuels, and the need for digital systems that can increase efficiency. At the same time, there are opportunities in electrification, low-carbon fuels, and cross-industry collaboration. Several studies highlight that procurement decisions, starting with carrier selection, packaging strategies, and warehouse management, play an important role in reducing emissions (Balcombe et al., 2019; McKinnon, n.d.)

The study investigates the answers to the following main questions:

- How do the sustainability goals and implementation strategies of road freight transport differ in Europe, China, and North America?
- What are the main drivers and barriers on the route of decarbonization?
- How can strategic sourcing and procurement practices be leveraged to expedite the adoption of low-carbon transport solutions for road freight?

The study links the academic perspective with practical insights from the automotive industry, including the author's own experience in procurement within the mentioned sector. By combining theory and practice, the Authors identify key challenges, highlight best practices, and suggest ways for making transport and logistics procurement more sustainable in each region.

2. Theoretical background and literature review

Transportation and freight procurement are increasingly recognized as a main area for emission reduction, not only because of the high contribution to global emission output, but also because of a high potential for technological and operational improvements. This literature review section focuses on policy frameworks, industry strategies, and comparative trends across regions without repeating the same figures mentioned above.

2.1. Decarbonization and political environment

From a global perspective, the Paris Agreement states warming limits to 1.5°C, which initiates transport decarbonization in energy and industrial sectors (United Nations Framework Convention on Climate Change, 2015), emphasizing the importance of reducing emissions. International alliances such as Drive to Zero and CALSTART (a non-profit clean transportation organization) initiated the Global MoU (Memorandum of Understanding) (Weber, 2024) on Zero-Emission Trucks. This official agreement between governments, cities, and industry leaders aims to support the global targets to reach zero-emission freight vehicles by 2030-2040 (Middlebrooks, n.d.) These Coalitions can give a framework and targets for companies, which can help to set procurement targets for low-carbon transport solutions. Research also highlights the importance of integrating digital logistics platforms, route and load optimization, and transport type combinations (intermodal) as policy-aligned solutions (European Court of Auditors., 2023).

2.2. Technology and green logistics

The European Green Deal (The European Green Deal - European Commission, n.d.) and other supporting regulations not only set emission reduction goals but also aim to improve infrastructure readiness and operational changes. For example, AFIR (Regulation (EU) 2023/1804 of the European Parliament and of the Council of 13 September 2023 on the Deployment of Alternative Fuels Infrastructure, and Repealing Directive 2014/94/EU (Text with EEA Relevance), 2023) requires the EU to develop common charging networks and refuel stations to support a smoother acceptance of electric and hydrogen trucks (The European Green Deal - European Commission, n.d.). The EU member states have already implemented several pilot cases of low-emission freight corridors, combining electrified trucking, rail, and intermodal solutions, hydrogen and biofuel trucks as trials between key logistics routes (*Current California GHG Emission Inventory Data | California Air Resources Board*, n.d.): Trans-European Transport, Core Network.

In North America, adapting a common policy is uneven but improving. California's Advanced Clean Trucks (*Current California GHG Emission Inventory Data | California Air Resources Board*, n.d.) (ACT) Rule requires that all new sales of medium- and heavy-duty vehicles should be with zero emissions by 2035 in California, following the purpose of the state-level regulation called California Air Resources Board (*Current California GHG Emission Inventory Data | California Air Resources Board*, n.d.) (CARB). The U.S. federal Clean Trucks Plan is aligned with this to support battery-electric and hydrogen-powered trucks, supporting fleet modernization and using emissions-tracking systems (Balcombe et al., 2019).

China's approach is different than Europe or North America; it combines policy-driven fleet transformation with digital logistics, and is mainly driven by local, national reasons, not global ones. National-level plans, including the 14th Five-Year-Plan for Low-emission Transport (*The 14th Five-Year Comprehensive Work Plan on Energy Conservation and Emission Reduction – Policies*, 2025), highlight a shift in transport modes, investing in charging and fueling stations, and emphasize public-private collaboration to accelerate the adoption of low-carbon solutions in freight forwarding. (Ministry of Transport of the People's Republic of China, n.d.).

2.3. Barriers of implementation

The above-mentioned European green corridor trials are helping governments to assess feasibility, technological readiness, and operational effectiveness before these solutions are scaled for other areas. Reports and the pilot programs suggest that route optimization and cross-border harmonization of infrastructure will be crucial for achieving full compliance (Regulation (EU) 2023/1804 of the European Parliament and of the Council of 13 September 2023 on the Deployment of Alternative Fuels Infrastructure, and Repealing Directive 2014/94/EU (Text with EEA Relevance), 2023).

In North America, unlike Europe, infrastructure scaling remains a key challenge due to significant geographical distances. Stronger government incentives and a more structured focus are also essential to be able to scale, which has not been seen yet.

In China, the major roadblock to implementing sustainable transport solutions is the strong cost pressure and customers' preference to choose cheaper solutions over sustainable options. Infrastructural gaps are also slowing down the acceleration, however several pilot programs are running in cities like Shenzhen that demonstrate how electrification of urban freight fleets can reduce emissions and operational costs (Jing et al., 2025; Teng et al., 2024).

2.4. Role of strategic procurement and supply chain

Across regions, companies are increasingly focusing on freight procurement and supply chain decisions, considering sustainability strategies ("What Drives Sustainable Procurement?," 2025). Academic studies and industry case studies show that combining technology solutions (electric/hydrogen trucks), operational efficiency (load factors, route optimization), and collaboration between suppliers, customers, and industry members (Zheng et al., 2025) drives the most significant reductions to reach better sustainability (European Court of Auditors., 2023). Including Scope 3 emissions in corporate reporting also strengthens the role of procurement as a key leverage for decarbonization.

Procurement, as a key leader of change, is able to implement sustainability criteria into contracts, which is already starting to be in place, pushing carriers to have more transparency in emissions, optimize packaging, and reinforce industry collaborations for low-carbon corridors. As the Author's experience, companies such as Yanfeng have also publicly documented efforts (Partner Code of Conduct, RSCI membership, recycled resin/upcycled seat innovations, downstream and upstream transportation ESG surveys) illustrate how Tier-1 procurement can create a path to sustainable logistics transitions.

3. Methodology and case study

The study combines primer and secondary analysis. The methodology of this study consists of eight steps:

- Formulation of the search question and choice of keywords,
- definition of inclusion and extrusion criteria,
- search in databases,
- papers selection, discussion and analysis of the results,
- identifying participants for the survey, introducing the survey, summarizing the survey, clearing up the incorrect feedback,
- conducting an analysis of the survey responses,
- reporting of the results in combination and reference to relevant literature.

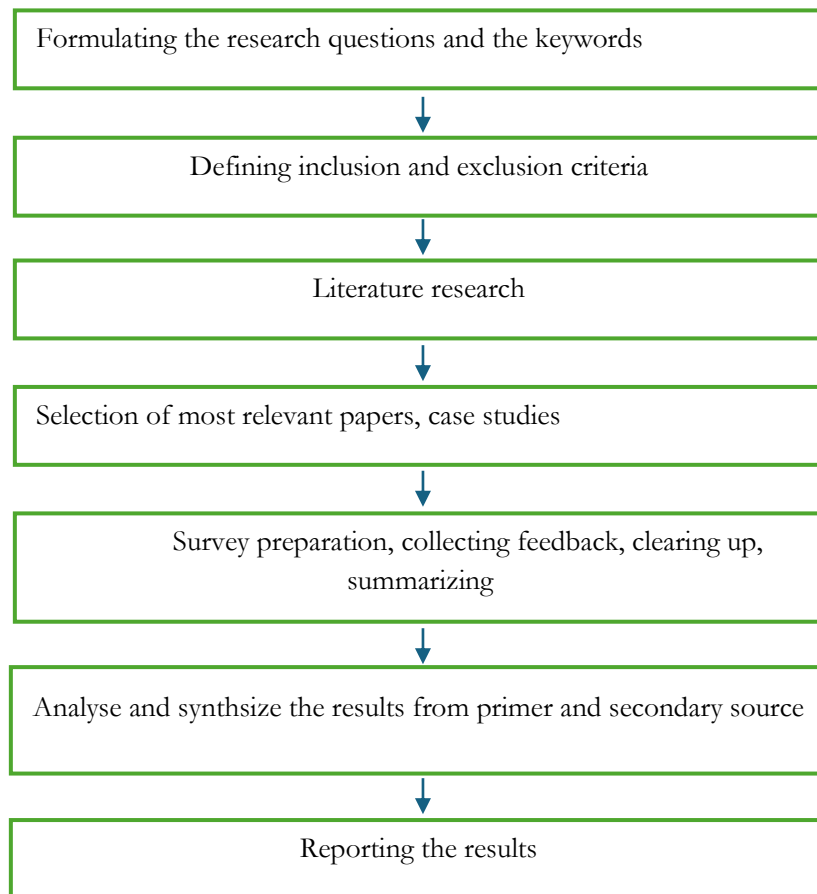


Fig 1: Methodology steps
Source: own editing

3.1. Research purpose and approach

This research aims to identify sustainability challenges and opportunities in freight transport, focusing on road transport in Europe, North America, and China, comparing their practices and identifying potential roadblocks and opportunities. The study combines secondary data analysis from government policies, published reports, academic literature, and primary data from a sustainability framework collected via a questionnaire of logistics service providers and freight forwarders, approaching procurement professionals in the automotive industry.

The study prefers this two-methods analysis, in order to capture both macro-level policy trends and micro-level operational insights.

3.2. Case study context

The Authors' experience is based on an automotive EMEA operations covering the interior, seating, and safety systems divisions, and the study targeted the related providers of the Author, focusing on freight forwarders and logistics service providers. While the Author is not responsible for resin and material procurement, however, this is a main contributor to sustainability, but transportation, packaging and contract logistics; therefore, the study is focusing on upstream and downstream logistics emissions for the context.

This context allows the study to:

- Examine how procurement decisions influence freight decarbonization emissions.(Johnsen et al., 2022; “What Drives Sustainable Procurement?,” 2025)
- Identify difficulties and opportunities to low-carbon logistics solutions
- Compare regional differences in sustainability regulations, infrastructure, and supplier readiness.

3.3. Primary data collection

To confirm or refute literature insights, a short survey was prepared by the Author for freight service providers and sent to 60 companies, between the period of 20th August to 25th August 2025.

40 responses have been received and taken into consideration. This represents a 66.7% completion ratio.

Main objectives of the survey:

- a) Identify how significant sustainability is in their strategy
- b) Identify current sustainability practices (e.g., use of electric/hydrogen trucks, load optimization, digital tracking solutions).
- c) Understand difficulties in adopting low-carbon solutions (infrastructure, cost, regulation).
- d) Collect region-specific challenges and opportunities for sustainable freight.
- e) Identify best practices across regions

Design of the survey is as follows:

- 9 short, structured questions (mix of multiple choice, Likert scale, open questions, matrix questions)
- Questions were prepared in bilingual (English/Hungarian), reaching higher participants
- Some questions were split into regional sections to identify the differences between North America, Europe, and China.

This survey provides quantitative and qualitative insights that can be combined with the literature review to help understand procurement decisions and future opportunities.

3.4. Secondary data analysis

Secondary data was collected from:

- a) Industry reports
- b) Policy documents
- c) Academic literature: Studies on decarbonization strategies, fleet electrification, and freight emissions

The study focuses on articles published in the last one and two decades, from 2006 to 2026. The study excluded rail, ocean freight, and air transport and papers related to ecological sustainability. The study focused on road freight and automotive industry. The main database considered for the study was Scopus as it is considered the world’s largest database of abstracts and citations.

The search was conducted in July and August 2025. The search strings have to demonstrate repeatability (“Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of

Systematic Review | Request PDF,” 2025), with the identified keywords and its variations. Studies were categorized and sorted with thematic coding, while excluding duplication, excluding the not relevant papers. Coding units were being used (Mayring, 2014), and within a thematic analysis the major themes were identified as a., load and route optimization, digitalization, b., operative difficulties and infrastructure, c., governmental and industrial policies and regulations, d., procurement decisions in strategical planning. This analysis allows us to combine the findings and ensure consistency between regulatory expectations, industry trends, and real-life operational feedback.

3.5. Data analysis method

The survey data will be analyzed in a quantitative (percentages, trends) and qualitative way (open text responses). The qualitative answers were evaluated by the Authors within a thematic analysis, followed the method was used for secondary data analysis.

Regional comparisons highlight differences in potential barriers, opportunities, and country/supplier/industry readiness.

Using the same method for coding and thematic analysis, the findings are linked back to policy frameworks and corporate sustainability strategies, particularly in the context of the procurement role in influencing low-carbon logistics in transportation, focusing on road transport, as the main scope of this study.

4. Results

40 responses were received in the period from 20th August to 25th August 2025, representing a 66,7% completion rate.

4.1. Geographic operations

As per Table 1, the majority of the participants indicated that their primary operating region is Europe (58%), followed by global operation footprint who has active presence in all compared three regions (30%), North America focused companies (10%), exclusively China dominant company 2%.

Table 1: Regional distribution of participants

China	North America	Europe	Global (all 3 regions)
2%	10%	58%	30%

Source: own editing

4.2. Importance of sustainability

The rate of importance of sustainability, shown in Table 2 and Table 3, was evaluated in the respondents’ transport strategy (on a 1–5 scale, 5 being the most important, 1 being not important).

Table 2: Importance of sustainability in company’s strategy I.

Europe	N	Valid	23
		Missing	0
	Median		4,00
	Mode		4

North America	N	Valid	4
		Missing	0
	Median		4,50
	Mode		5
China	N	Valid	1
		Missing	0
	Median		4,00
	Mode		4
Global	N	Valid	12
		Missing	0
	Median		5,00
	Mode		5

Source: own editing via SPSS program

Table 3: Importance of sustainability in company's strategy II.

Region			Frequency	Percent	Valid Percent	Cumulative Percent
Europe	Valid	important	1	4,3	4,3	4,3
		more important	12	52,2	52,2	56,5
		very important	10	43,5	43,5	100,0
		Total	23	100,0	100,0	
North America	Valid	important	1	25,0	25,0	25,0
		more important	1	25,0	25,0	50,0
		very important	2	50,0	50,0	100,0
		Total	4	100,0	100,0	
China	Valid	more important	1	100,0	100,0	100,0
Global	Valid	more important	2	16,7	16,7	16,7
		very important	10	83,3	83,3	100,0
		Total	12	100,0	100,0	

Source: own editing via SPSS program

4.3. Challenges in reducing CO₂

Regional differences were questioned by the respondents to understand the potential barriers, as future risks and challenges, the regional split is shown in Figure 2.

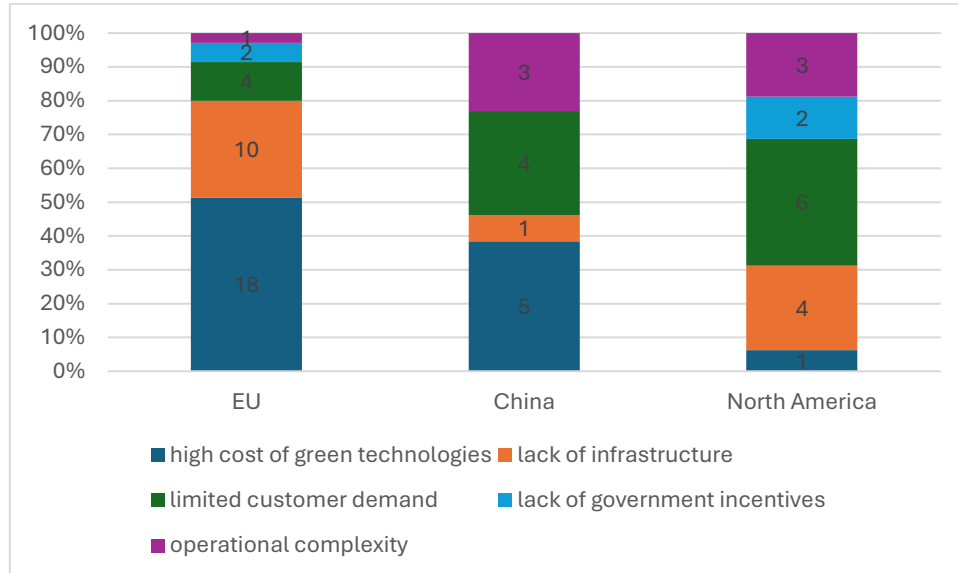


Fig. 2: Regional differences in recognized challenges

Source: own editing

4.4. Sustainable Solutions Implemented or Planned

During the survey, the Authors' goal was to identify the potential opportunities based on best practices of each region. The results shown in Figure 3:

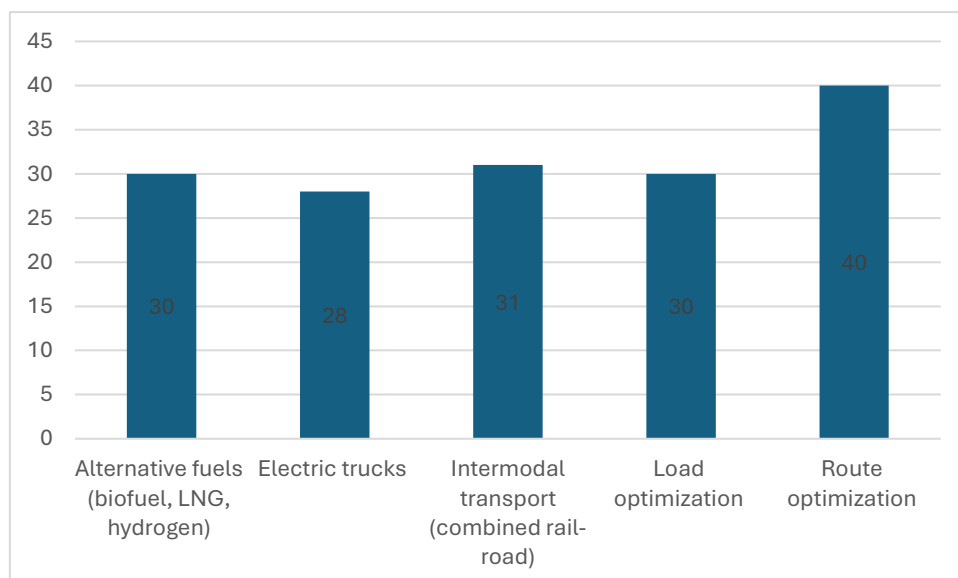


Fig. 3: Sustainable solutions implemented vs planned

Source: own editing

4.5. Fleet structure (Low-emission vehicles)

The survey collected an overview of available low-emission vehicles in the respondents' fleet versus available standard equipment, split by different regions, as per Table 4.

Table 4: Share of low-emission fleet by region

	0-10%	11-25%	26-50%	51-76%	76-100%
China	7	3	3	0	0
North America	11	3	2	0	0
Europe	23	6	5	0	1

Source: own editing

5. Discussion

5.1. Theoretical implications

The added value of this study lies in demonstrating that political decisions and directions represent a much stronger influence on the adoption of green solutions than previously estimated. Clear and stable rules set by policymakers, such as reduction targets, carbon pricing mechanisms, and long-term regulatory frameworks which are essential to provide companies with predictability, and to shape their sustainability strategies (Kannan, 2021; Kollmuss & Agyeman, 2002; “What Drives Sustainable Procurement?,” 2025). Without clear goals, companies may end up with short-term and fragmented actions instead of real long-term change.

The findings also highlight the importance of behavioral and organizational factors. The behavioral intention of the companies is significantly influenced by individual attitudes, capabilities, and awareness of consequences, as well as recognized corporate social responsibility engagement (Khan et al., 2023; Kollmuss & Agyeman, 2002). This aligns with earlier research showing that sustainability strategies are not only shaped by external pressures but also by internal commitment, and managerial leadership approach (Kollmuss & Agyeman, 2002; “What Drives Sustainable Procurement?,” 2025). In the automotive sector, for example, willingness and commitment toward sustainable solutions differ across regions and supply chain levels (Brammer & Walker, 2011). Sustainability is represented stronger in OEMs' strategies compared to other level in the supply chain. Within going down the supply chain, the weight of importance of sustainability often reduces, mostly due to cost involvement and resource constraints.

The analysis of the relationship between regions and the importance of sustainability strategy developed as follows: the survey results represent a strongly asymmetric pattern, so a comparative statistical test is not justified; however, descriptive analysis is recommended. In Europe, sustainability has been strongly considered as a strategic element, with the large majority of respondents categorizing it as “more important” or “very important.” North American responses indicate a strong strategic commitment on sustainability, but due to the low sample size, the results are preliminary. The Chinese sub-sample is not suitable for evaluation and should be treated only as individual observations. Among global forwarders with active footprint in all analysed regions, sustainability is a particularly strong strategic priority, reflecting international regulatory expectations and pressures of prestige.

All these insights confirm that sustainability strategies are not uniform but strongly shaped by political, economic, and social aspects. The theoretical implication is that sustainability in logistics and supply chains cannot be understood as a global and universal way; but it must be analysed through the lens of regional governance structures, market dynamics, and organizational behavior. This reinforces the need for comparative and context-sensitive approaches in sustainability research, acknowledging that the drivers,

barriers, and strategic priorities vary significantly across different regions and also in different levels of supply chain members.

5.2. Practical implications

From a practical view, the study confirms that financial incentives are essential to overcome the high upfront costs of investments and to accelerate the speed of the green transition (Kannan, 2021; Kollmuss & Agyeman, 2002; “What Drives Sustainable Procurement?,” 2025). Governments must invest in green infrastructure together with companies in order to accelerate the progress in an efficient way. This includes charging networks for electric trucks, intermodal hubs to support modal shifts, and renewable energy grids to help the acceleration of the decarbonization of logistics operations. Without such infrastructure, companies remain constrained by cost sensitivity and uneven regional conditions, which limit the speed of the implementation of sustainable solutions.

Majority of the respondents confirmed that they focused first on operational efficiency improvements (Figure 4), such as route optimization, load optimization, and packaging optimization, as for the companies this is a reachable achievement, since it brings immediate results, and it represents low-cost compared to high investment required developments. These digital, optimization tools creates for the companies reduced fuel consumption, and reduced emissions in a short and quick way, providing low-barrier entry points and ability to demonstrate to their customers a willingness to implement sustainable solutions (Ahmad et al., 2022; Ballot & Fontane, 2010; Nataraj et al., 2019; Pan et al., 2013; Teng et al., 2024; Zhang et al., 2025; Zheng et al., 2025). However, these digital optimization tools are only a short-term focus solutions, and can create a false sense when we are talking about sustainability achievements. Companies are looking for integrated solutions, offered by logistics service providers (LSPs) who are able to use a collaboration mechanism collecting different companies in one system and to design increasingly efficient logistics networks, while minimizing operating cost, and reduce traffic burden. These actions are low-cost, but in return, are able to deliver immediate efficiency results (Wang et al., 2017, 2020) to the companies, but these are not bringing long term and structural progress, which are required by governments, such as fleet electrification, using renewable fuels, or hydrogen adoption (Bhattacharjee, D. & Rittstiege, M., n.d.; Kannan, 2021; Smart Freight Centre, 2024).

The survey results also highlight significant pressures and different level of readiness in supply chains. Automotive OEMs are increasingly request low-emission solutions in transportation, yet they often attempt to eliminate cost-sharing, pushing the financial burden onto logistics providers and suppliers (Kannan, 2021; Smart Freight Centre, 2024). This imbalance not only limits the speed of acceleration of green solution but also creates tensions in global supply chains, particularly for smaller providers who are lack of resources to invest in high-cost technologies. This approach of the OEMs were highlighted in each region, no big difference is visible between the regions since the OEMs are the same usually. Unless new partnership models are introduced where OEMs share knowledge within their supply chains, invest tot he green solutions together with their Tier-1, Tier-2 suppliers jointly, and mentor their suppliers, the green transition risks being slowed by uneven structural conditions. Awareness of the environmental, social, and economic impacts of procurement decisions must be raised, since it is critical to create a more balanced and sustainable collaboration (Kollmuss & Agyeman, 2002).

Majority of the respondents highlighted clearly that the infrastructure is not ready in any region, except in China. Based on the survey result the availability of the required infrastructure is the less prepared in Europe between the analysed regions. The adoption of sustainable solutions and a smooth green transition are highly depending on the existing infrastructure, the available government incentives, and collaboration between the market leaders, and as well as on procurement strategies. Procurement plays a significant role in creating a resilient, low-carbon global freight system, but procurement is not enough to accelerate the transition, as

the global company mindset is required on top of it. The strategic procurement function within companies is shaped by corporate strategy, and the management commitment strongly influences individuals' approach and willingness to commit to sustainability (Khan et al., 2023). The role of procurement is also tied to the willingness of companies to pay for sustainability (Kollmuss & Agyeman, 2002; "What Drives Sustainable Procurement?," 2025). There is an existing trend that companies started checking green solutions within the standard freight tenders, however when the decision needs to be done, the usual way is considered staying with standard solutions and not investing into the more expensive, but environmentally friendly solutions due to the significant cost barrier.

In summary, the practical implications emphasize that while companies are making progress through digital optimization and efficiency measures, the structural decarbonization of fleets remains rare due to high upfront costs and lack of government incentives. Strong government support, coherent infrastructure, and collaborative supply chain models are essentials to accelerate the adoption of green solutions and to ensure that sustainability commitments also represents long-term solutions and not only short term actions.

6. Conclusion

This study confirms that freight forwarder companies across Europe, China, and North America increasingly recognize the strategic importance of sustainability, however the practical implementation of green solutions remain behind the ambitious targets of government and also of companies. (Kannan, 2021; Kollmuss & Agyeman, 2002; "What Drives Sustainable Procurement?," 2025). Road freight decarbonisation is a daily and actual topic, and already considered in global strategies of majority of the companies, but in parallel it is still a complex challenge shaped by regional governance structures, infrastructural difficulties, market dynamics, and supply chain behaviors.

Europe has a strong regulatory framework and policy, but cost barriers and infrastructure gaps remain significant obstacles for the companies. China has an advantage of significant government incentives, and they are in advance with quick implementation of green solutions under central planning and government-driven support, being market leaders in electrification and digital logistics, though uneven implementation across regions exists. North America, by contrast, relies more strongly on market-driven innovation and industry initiatives, progressing in a slower way compared to Europe and China. In regulatory, North America is fragmented, there are certain regions in advance compared to other states. In both North America, China and Europe, the demand-driven approaches, infrastructure readiness, and government incentives are critical accelerators of sustainable freight transitions.

The survey results highlight that operational efficiency improvements, such as route- and load optimization systems, and digital tools are widely implemented as less cost intensive but short-term solutions. The fleet decarbonization remains ambitious goals for many of the companies, and rarely implemented at this stage among the respondents, mostly due to the high investment cost upfront, and lack of government and OEM incentives. Stronger financial support toward mostly the smaller market players and stronger technological investments are essential to accelerate the road freight decarbonisation.

The survey findings also identified difficulties within supply chains. OEMs and some Tier-1 suppliers are showing increasing demand within their own supply chains for finding low-emission transport opportunities, but they mostly face with the difficulties of implementing green solutions due to their significant financial burden, since the lower level of supply chains cannot bear the additional cost alone, without receiving any support from OEMs nor government. This imbalanced situation are slowing down the transition unless new partnership models and collaborations within the market players are introduced, where the cost of investment but also the knowledge can be shared within the supply chains.

Ultimately, the adoption of sustainable freight solutions and the achievement of a smooth green transition depend on four pillars: infrastructure readiness, government incentives, collaboration among market players

including all levels of supply chain starting from OEM level, and procurement strategies. Strategic procurement is a key role for the future, and not only in designing the contracts having focus on sustainable solutions, but also it starts from supplier selection till cost contribution. Management commitment, personal attitudes, and corporate social responsibility engagement (Khan et al., 2023) are significantly influencing the willingness to invest in sustainability, but procurement alone is not able to lead the green transition, the global mindset of management is essential. Evidence from the automotive sector also confirms that sustainability priorities are strongest at the OEM level but already visible in Tier-1, Tier.2 level as well, however with less practical progress (Brammer & Walker, 2011).

In conclusion, while regional approaches differ, the success factors are the same in each regions: clear regulatory frameworks, shared financial responsibility, technological innovation, and procurement-led collaboration. Without these, the global freight sector risks fragmented progress and delaying the real green transition. With them, however, a resilient, low-carbon freight system can be built, which aligns on economic efficiency with environmental responsibility, and secures the long-term sustainability of global supply chains.

7. Limitations and future research

- Survey responses may be limited by the company's willingness to share sensitive operational data.
- Regional comparisons are constrained by differences in data availability and reporting standards.
- The study focuses on road transport, not covering all upstream supply chain emissions.
- A larger-scale survey should include domestic Chinese logistics companies to test whether adoption rates differ from those that participated in the current survey.
- Comparative analysis between OEM sustainability requirements and actual cost-sharing practices could provide insight into systemic bottlenecks.
- Research within a longer time frame on the impact of environmental tolls and green corridors in Europe could help to understand the cost impact on supply chains.
- Case studies of leaders (e.g., DHL's GoGreen strategy, Kuehne+Nagel's Net Zero Carbon program) could help identify best practices and future opportunities.

Conflict of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- Ahmad, S., Sarwo Utomo, D., Dadhich, P., & Greening, P. (2022). Packaging design, fill rate and road freight decarbonisation: A literature review and a future research agenda. *Cleaner Logistics and Supply Chain*, 4, 100066. <https://doi.org/10.1016/j.clscn.2022.100066>
- Balcombe, P., Brierley, J., Lewis, C., Skatvedt, L., Speirs, J., Hawkes, A., & Staffell, I. (2019). How to decarbonise international shipping: Options for fuels, technologies and policies. *Energy Conversion and Management*, 182, 72–88. <https://doi.org/10.1016/j.enconman.2018.12.080>
- Ballot, E., & Fontane, F. (2010). Reducing transportation CO₂ emissions through pooling of supply networks: Perspectives from a case study in French retail chains. *Production Planning & Control*, 21(6), 640–650. <https://doi.org/10.1080/09537287.2010.489276>
- Bhattacharjee, D., & Rittstiege, M. (n.d.). *Boosting zero-emission truck adoption*. McKinsey & Company. <https://www.mckinsey.com/industries/logistics/our-insights/can-zero-emission-trucks-become-viable-and-what-will-it-take-to-boost-adoption>
- Brammer, S., & Walker, H. (2011). Sustainable procurement in the public sector: An international comparative study. *International Journal of Operations & Production Management*, 31(4), 452–476. <https://doi.org/10.1108/01443571111119551>
- Council of the European Union. (2023). “Fit for 55”: Council adopts key pieces of legislation delivering on 2030 climate targets. Consilium. <https://www.consilium.europa.eu/en/press/press-releases/2023/04/25/fit-for-55-council-adopts-key-pieces-of-legislation-delivering-on-2030-climate-targets/>
- California Air Resources Board. (n.d.). *Current California GHG emission inventory data*. Retrieved December 7, 2025, from <https://ww2.arb.ca.gov/ghg-inventory-data>
- Engström, R. (2016). The roads’ role in the freight transport system. *Transportation Research Procedia*, 14, 1443–1452. <https://doi.org/10.1016/j.trpro.2016.05.217>
- European Commission. (n.d.). *Multimodal and combined transport—Mobility and transport*. Retrieved December 7, 2025, from https://transport.ec.europa.eu/transport-themes/logistics-and-multimodal-transport/multimodal-and-combined-transport_en
- European Court of Auditors. (2023). *Intermodal freight transport: EU still far from getting freight off the road* (Special report 08/2023). Publications Office of the European Union. <https://data.europa.eu/doi/10.2865/86233>
- Eurostat. (n.d.). *Freight transport statistics—Modal split*. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Freight_transport_statistics_-_modal_split
- International Energy Agency. (2023, September 26). *Road transport – Analysis*. <https://www.iea.org/reports/road-transport>
- Inflation Reduction Act of 2022. (2022). *Inflation Reduction Act of 2022*. Energy.gov. <https://www.energy.gov/lpo/inflation-reduction-act-2022>
- International Energy Agency. (2021). *Global EV outlook 2021 – Analysis*. <https://www.iea.org/reports/global-ev-outlook-2021/policies-to-promote-electric-vehicle-deployment>
- Jing, H., Chen, Y., Ma, M., Feng, W., & Xiang, X. (2025). Unlocking global freight transport decarbonization potential: Role of modal shifts. *Transportation Research Part D: Transport and Environment*, 148, 105025. <https://doi.org/10.1016/j.trd.2025.105025>
- Johnsen, T. E., Caniato, F., Meqdadi, O., & Miandar, T. (2022). Swimming against the tide: Supplier bridging roles in diffusing sustainability upstream and downstream in supply networks. *International Journal of Operations & Production Management*, 42(10), 1605–1629. <https://doi.org/10.1108/IJOPM-02-2022-0110>

- Kannan, D. (2021). Sustainable procurement drivers for extended multi-tier context: A multi-theoretical perspective in the Danish supply chain. *Transportation Research Part E: Logistics and Transportation Review*, 146, 102092. <https://doi.org/10.1016/j.tre.2020.102092>
- Khan, O., Bellini, N., Daddi, T., & Iraldo, F. (2023). Effects of behavioral intention and dynamic capabilities on circular economy adoption and performance of tourism SMEs. *Journal of Sustainable Tourism*, 31(8), 1777–1796. <https://doi.org/10.1080/09669582.2022.2066683>
- Kliuyeva, K. (2022, June 14). *European Environment Agency: Analysis on road transport gas emissions*. European Shippers' Council. <https://europeanshippers.eu/european-environment-agency-analysis-on-road-transport-gas-emissions/>
- Kollmuss, A., & Agyeman, J. (2002). Mind the gap: Why do people act environmentally and what are the barriers to pro-environmental behavior? *Environmental Education Research*, 8(3), 239–260. <https://doi.org/10.1080/13504620220145401>
- Kumar, A., Calzavara, M., Velaga, N. R., Choudhary, A., & Shankar, R. (2019). Modelling and analysis of sustainable freight transportation. *International Journal of Production Research*. <https://www.tandfonline.com/doi/abs/10.1080/00207543.2019.1642689>
- Kumar Dadsena, K., Sarmah, S. P., & Naikan, V. N. A. (2019). Risk evaluation and mitigation of sustainable road freight transport operation: A case of trucking industry. *International Journal of Production Research*, 57(19), 6223–6245. <https://doi.org/10.1080/00207543.2019.1578429>
- Li, X., He, L., Cui, Q., & Chen, H. (2025). Environmental and economic impact of modal shift policy in China's freight transportation. *Transportation Research Part D: Transport and Environment*, 140, 104617. <https://doi.org/10.1016/j.trd.2025.104617>
- Mayring, P. (2014). *Qualitative content analysis*. <https://www.scribd.com/document/342254401/Mayring-2014-QualitativeContentAnalysis>
- Middlebrooks, G. (n.d.). *CALSTART*. Retrieved December 7, 2025, from <https://calstart.org/>
- Ministry of Transport of the People's Republic of China. (n.d.). *Ministry of Transport of the People's Republic of China*. <https://www.mot.gov.cn/>
- Nataraj, S., Ferone, D., Quintero-Araujo, C., Juan, A. A., & Festa, P. (2019). Consolidation centers in city logistics: A cooperative approach based on the location routing problem. *International Journal of Industrial Engineering Computations*, 393–404. <https://doi.org/10.5267/j.ijiec.2019.1.001>
- Pan, S., Ballot, E., & Fontane, F. (2013). The reduction of greenhouse gas emissions from freight transport by pooling supply chains. *International Journal of Production Economics*, 143(1), 86–94. <https://doi.org/10.1016/j.ijpe.2010.10.023>
- Regulation (EU) 2023/1804 of the European Parliament and of the Council of 13 September 2023 on the deployment of alternative fuels infrastructure and repealing Directive 2014/94/EU. (2023). *Official Journal of the European Union*. <http://data.europa.eu/eli/reg/2023/1804/oj>
- Reuters. (2024). Emissions-free truck prices need to drop by 50% to compete with diesel, study says. <https://www.reuters.com/sustainability/emissions-free-truck-prices-need-drop-by-50-compete-with-diesel-study-says-2024-09-11/>
- Smart Freight Centre. (2024). *Annual report 2024*. <https://www.smartfreightcentre.org/en/about-sfc/annual-report-2024/>
- Teng, F., Zhang, Q., Chen, S., Wang, G., Huang, Z., & Wang, L. (2024). Comprehensive effects of policy mixes on the diffusion of heavy-duty hydrogen fuel cell electric trucks in China considering technology learning. *Energy Policy*, 185, 113961. <https://doi.org/10.1016/j.enpol.2023.113961>

International Energy Agency. (2025). *The 14th five-year comprehensive work plan on energy conservation and emission reduction*. <https://www.iea.org/policies/14799-the-14th-five-year-comprehensive-work-plan-on-energy-conservation-and-emission-reduction>

European Commission. (n.d.). *The European Green Deal*. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

Tostes, B., Henriques, S. T., Heun, M. K., Brockway, P. E., & Sousa, T. (2025). Global transport emissions 1850–2020: Historical drivers and lessons for transport decarbonization. *Transportation Research Part D: Transport and Environment*, 148, 104998. <https://doi.org/10.1016/j.trd.2025.104998>

United Nations Framework Convention on Climate Change. (2015). *Paris agreement*. <https://unfccc.int/process/conferences/pastconferences/paris-climate-change-conference-november-2015/paris-agreement>

Wang, Y., Ma, X., Li, Z., Liu, Y., Xu, M., & Wang, Y. (2017). Profit distribution in collaborative multiple centers vehicle routing problem. *Journal of Cleaner Production*, 144, 203–219. <https://doi.org/10.1016/j.jclepro.2017.01.001>

Wang, Y., Zhang, S., Guan, X., Peng, S., Wang, H., Liu, Y., & Xu, M. (2020). Collaborative multi-depot logistics network design with time window assignment. *Expert Systems with Applications*, 140, 112910. <https://doi.org/10.1016/j.eswa.2019.112910>

Weber, C. (2024, May 22). CALSTART's Global Drive to Zero program announces new global MOU endorsers at the International Transport Forum. CALSTART. <https://calstart.org/new-global-endorsers-announced-at-itf-2024/>

What drives sustainable procurement? Insights from the theory of planned behavior. (2025). *International Journal of Operations & Production Management*, 45(13), 28–52. <https://doi.org/10.1108/IJOPM-02-2024-0164>

Xie, Q., Wu, Y., & Zhang, R. (2025). The effects of transportation structural adjustment policy on carbon emission: Evidence from China. *Journal of Cleaner Production*, 522, 146213. <https://doi.org/10.1016/j.jclepro.2025.146213>

Zhang, F., Gallagher, K. S., Deng, M., Liu, H., Orvis, R., & Xuan, X. (2025). Assessing the policy gaps for achieving China's carbon neutrality target. *Environmental Science & Technology*. <https://doi.org/10.1021/acs.est.4c12478>

Zheng, Q., Liu, S., & Tan, J. (2025). Stable networks, responsible firms? The differential effects of supplier and customer network stability on CSR performance. *International Journal of Operations & Production Management*. <https://doi.org/10.1108/IJOPM-04-2025-0273>



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VOLUME 1

AI, Sustainability and Digital Transformation: Shaping the Future of Business and Society

Societal and Industrial Expectations for the Future of Road Freight Transport Vehicles

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Abstract: Road freight transport continues to play a key role in the functioning of global and regional supply chains, but both industry and society are placing increasingly high demands on future vehicle technologies. In addition to increasing economic efficiency, there is an increasingly urgent need to reduce environmental impact, improve safety, and integrate digitalization and automation into road freight transport. The aim of this study is to map and systematize the expectations of industrial and social actors regarding future road freight vehicles, with a particular focus on sustainability, technological development, and regulatory trends. This study identifies and models the fundamental tensions between societal expectations and industrial realities as one of the main obstacles to the sustainable transition of road freight transport. The thesis is based on a review of the literature and an analysis of current policy documents, and provides a structured discussion of the expected impacts of technological trends such as electric and hydrogen-powered vehicles, autonomous systems, and smart logistics networks. The study also looks at how social preferences are changing and what responses are required from decision-makers, manufacturers, and logistics providers. The findings of the research can provide guidance for both industrial developments and transport policy measures aimed at creating sustainable and competitive road freight transport.

Keywords: Alternative Fuels, Industrial Needs, Road Freight Transport, Societal Expectations, Sustainability, Automation, Transport Innovation

JEL Classification: Q55, L92, L22

1. Introduction

Road freight transport has been a key element of global, regional, and local logistics systems for decades. The ability to move goods quickly, flexibly, and reliably has made road transport crucial to the functioning of national economies and maintaining their competitiveness. At the same time, in the 21st century, this sector faces complex challenges that require new approaches and innovative solutions. Industry players, society, and government and regulatory bodies are all setting increasingly stringent requirements for road freight vehicles. These expectations go beyond mere economic performance and increasingly take into account environmental sustainability, transport safety, and technological and social integration.

The aim of this study is to explore and systematize the industrial and social expectations that are being formulated for the road freight vehicles of the future. To achieve this goal, the research is primarily based on an analysis of literature and policy documents, while also taking into account the directions indicated by technological innovations and regulatory trends. One of the starting points of the study is that the road freight transport sector does not operate as an isolated entity, but is part of a complex ecosystem that is closely linked to industrial production, supply chains, urban planning, and various segments of social life.

From an industry perspective, key requirements include increasing the efficiency and reliability of transport processes, reducing costs, and integrating digital technologies such as data analytics, artificial intelligence, and automation into freight and logistics systems. In addition, there is a growing focus on environmentally

friendly technologies such as electric and hydrogen-powered vehicles, which enable the sector to contribute to reducing greenhouse gas emissions.

At the societal level, expectations are also diverse. The public and civil society organizations are increasingly sensitive to the environmental and health impacts of road transport, such as noise and air pollution, traffic congestion, and the risk of accidents. In addition, people expect road freight transport to fit into the concept of sustainable urban mobility and not to compromise the livability of public spaces.

At the same time, there is a strange contradiction: people support green, smart transport in theory – less pollution, safer roads, etc. – but when it comes to actually implementing it, suddenly everyone protests. For example, they don't want solar charging stations in their neighborhood, they don't trust self-driving cars, and they don't like that everything will become more expensive. People are afraid of the risks, they don't want to pay more, and many say, "Okay, let there be change, just not in my backyard."

The freight vehicles of the future must therefore meet not only economic and technological requirements, but also social and environmental expectations.

The complexity outlined in the introduction justifies the multidisciplinary approach of the study, taking into account the intertwining of technological development, economic rationality, environmental policy guidelines, and social demands. The following chapters discuss in detail the expectations of industrial and social actors, presenting current trends, future directions, and the challenges the sector may face in the coming decades.

The original contributions of the study are:

- (a) technological development,
- (b) environmental sustainability,
- (c) regulatory trends, and
- (d) social acceptance.

2. Literature review: Practical examples and policy developments

This chapter reviews key international developments that shape the evolution of autonomous road freight transport. It summarizes relevant literature while highlighting concrete market deployments and policy actions that demonstrate how technological progress is translated into practice. By presenting both operational examples and regulatory trends, the chapter delineates the conditions under which autonomous driving technologies are currently emerging.

2.1. Autonomous driving in practice – technologies and market introduction

This section examines the practical implementation of autonomous driving in the heavy-duty vehicle sector. Through selected industry cases, it outlines the leading actors, the technological solutions they deploy, and the environments in which early commercial operations are taking place. These examples provide a concise overview of the technology's current maturity and the factors influencing its market introduction.

2.1.1. Aurora Innovation (USA, Texas)

Aurora launched its first fully autonomous trucks on the Dallas–Houston route in 2025, without human drivers, although some vehicles initially still had safety drivers on board.

According to a Wall Street Journal report, the Lidar-based system, which can detect objects up to three football fields away, reacts nearly 11 seconds faster than a human.

Aurora plans to expand its operations to include nighttime and inclement weather driving in the second half of 2025 and to open new routes, such as to El Paso and Phoenix (*Aurora*, n.d.).

2.1.2. Waymo Via (USA)

Waymo's robot test plans include Class 8 autonomous trucks, currently being tested in Texas, Arizona, New Mexico, and California; their partner is Daimler Freightliner Cascadia vehicles.

2.1.3. Plus (international)

Plus.ai, which develops Level 4 self-driving technology, is partnering with Scania/MAN/Navistar, with testing underway in Texas and Sweden. A hydrogen-powered Level 4 autonomous truck was also unveiled (*Plus and NVIDIA Collaborate to Advance AI for Level 4 Autonomous Trucks With Large-Scale World Models*, n.d.).

2.1.4. Kodiak Robotics (USA)

At the end of 2024, Kodiak Robotics pioneered the launch of its first commercial driverless truck routes along leased roads in West Texas (*Kodiak Catalyst*, n.d.).

2.1.5. Gatik (USA, Canada)

Operates in the middle-mile transport sector: in 2019, they launched pilot projects with Walmart and Loblaw in Canada, and in 2025, they will also operate driverless vehicles in partnership with Kroger and Tyson Foods.

The above-mentioned projects clearly indicate that the technology is ripe for commercial application under limited conditions (highway driving, specified routes). The main obstacle at present is not technology, but regulation, trust building, and economic scaling.

2.2. Green innovations and infrastructure development

This chapter reviews key green innovations and related infrastructure developments that support the decarbonisation of road freight transport. By examining recent industry initiatives, it highlights how alternative energy solutions, energy-efficient vehicle technologies, and dedicated charging or refuelling networks are beginning to shape more sustainable freight operations.

2.2.1. TIP Group – solar-powered refrigerated trucks

SolarEdge and Mitsubishi Heavy Industries have collaborated to develop electric trailers powered by solar panels and energy storage systems.

2.2.2. Scania – Sweden's longest electric truck route

Scania, SKU, and LOTS Group have formed a consortium to create a 430 km electric route with three fast charging stations to demonstrate long-term operation.

2.2.3. Hyundai XCIENT – hydrogen trucks in Germany

They operate a hydrogen fuel cell truck that can save up to 69,000 kg of CO₂ emissions per year compared to diesel.

2.2.4. Austria – electric vehicle transport truck

In early 2025, Hödlmayr began using the first electric vehicle transport vehicle (Mercedes-Benz eActros 300) between the Magna Steyr factory (Graz) and the vehicle depot, a distance of approximately 4 km.

2.3. Regulatory and policy frameworks

This chapter provides an overview of the policy and regulatory measures that influence the decarbonisation and modernisation of road freight transport. It highlights the most relevant EU-level and national frameworks that affect technology adoption, cost structures, and market dynamics, thereby defining the conditions for the sector's ongoing transition.

2.3.1. European carbon dioxide reduction targets

Between 2024 and 2040, CO₂ emissions from heavy-duty vehicles must be gradually reduced (by 45% by 2030 and 65% by 2035, and by 90% by 2040) at the EU level – the new regulations are already in force following their adoption in May 2024.

2.3.2. Germany: CO₂-based road tolls and support for alternative drive systems

The introduction of CO₂-dependent road tolls and exemptions for zero-emission vehicles (e.g., until 2031) is encouraging the transition, although the latter support may be discontinued after 2025.

2.3.3. German climate programs and government incentives

The 2030 target is for one-third of German truck traffic to be electric. According to industry reports, up to 75% of new trucks could be zero- or low-emission by 2030. Hybrid solutions, HVO100 (hydro-treated vegetable oil), LNG (liquefied natural gas), and hydrogen will also play a role, but infrastructure and costs continue to hinder a rapid transition.

2.3.4. EU: Support for combined transport

The Combined Transport for Europe initiative aims to ensure that intermodal (rail+water+road) transport can deliver up to 90% CO₂ reductions by 2040, in line with the EU's proposed climate law.

2.3.5. EU regulatory barriers for heavy-duty vehicles

ACEA (Association des Constructeurs Européens d'Automobiles) and freight transport organizations are pushing for an update to the EU's vehicle size and weight directive so that heavier electric vehicles (e.g., those with large batteries) can be competitive. They also recommend allowing longer trailers and higher load capacities.

2.3.6. ICCT forecast: road emissions to peak in 2025

According to the ICCT (International Council on Clean Transportation), CO₂ emissions from road transport in the EU could peak as early as 2025 and fall by around 25% by 2035, thanks to recent regulations. (*Clean and Sustainable Mobility*, n.d.)

2.3.7. Impact of toll and ETS systems on logistics

From 2025, the transport sector will also be affected by the ETS (EU Emissions Trading System) emissions trading system, with companies being required to purchase quotas. According to research, this will increase operating costs while encouraging energy efficiency and alternative modes of transport.

2.4. Practical developments, examples, and policy directions

Not only technological innovations, but also concrete practical implementations and developments in the regulatory environment play a key role in shaping the future of road freight transport. In recent years, several initiatives have been launched worldwide that are not only in the testing phase but are already operating the freight vehicles of the future in real traffic environments, whether they are self-driving, electric, or alternatively powered trucks.

2.4.1. Autonomous trucks: from theory to practice

One of the most significant advances has been in the field of autonomous road freight transport. In 2025, the American company Aurora Innovation launched its first fully self-driving trucks in Texas, without any human presence (*Aurora*, n.d.). During transport between Dallas and Houston, Aurora's lidar-based sensors were able to identify obstacles three football fields away, reacting 11 seconds faster than a human driver (Kekade, n.d.). This development is a milestone in the application of Level 4 autonomous driving technology, especially on long-distance freight routes.

Similar initiatives are also underway at Waymo Via, Kodiak Robotics, and Gatik. Waymo is using Daimler Freightliner Cascadia trucks for testing in Texas and California (*Waymo Via Expands Partnership with UPS to Autonomous Freight Movement with Class 8 Trucks*, n.d.). Gatik's autonomous systems, optimized for middle-mile transportation, are already in commercial operation in the United States and Canada, with partners including Walmart and Kroger ('AI Research', n.d.).

2.4.2. Sustainable powertrains and green innovations

In the interests of environmental sustainability, the logistics sector is rapidly transitioning to alternative powertrain technologies. In 2025, Swedish companies Scania, SKU, and LOTS Group launched Sweden's longest electric truck route to date, covering 430 kilometers and supported by three fast-charging stations (Kumar et al., 2025). The aim of the demonstration was to prove the viability of long-distance electric freight transport, not only technologically but also economically.

Hyundai's XCIENT hydrogen-powered trucks are already in service in Germany. A single vehicle saves up to 69,000 kilograms of carbon dioxide emissions per year compared to conventional diesel-powered versions (Bayerlein et al., 2025). In addition, Mercedes-Benz eActros 300 electric vehicle transport trucks operate daily between Graz and Hödlmayr in Austria (Williams, 2025).

Solar-powered refrigerated trucks, such as those presented by TIP Group and Mitsubishi Heavy Industries, also represent an innovative approach. In these solutions, solar panels mounted on the vehicle's trailer provide energy for the cooling system, significantly reducing fuel consumption (Segreteria, 2023).

2.5. Policy directions and regulatory environment

Industrial developments are closely followed by EU and Member State regulations aimed at achieving climate targets and promoting sustainable freight transport. Under the regulatory package adopted by the European Union in 2024, carbon dioxide emissions from heavy-duty vehicles must be gradually reduced: –45% by 2030, –65% by 2035, and –90% by 2040 (*Clean and Sustainable Mobility*, n.d.). The regulation applies to newly sold vehicles and encourages manufacturers to develop new technologies.

Germany is playing a pioneering role in policy incentives. Following the introduction of a CO₂-based road toll system in 2024, zero-emission vehicles will be exempt from these charges until 2031, although this exemption may be modified after 2025 (*Electric Trucks to Remain Exempt from Tolls in Germany until 2031 - Electrive.Com*, 2025). In addition, according to the German transport strategy, at least 75% of new trucks put into service by 2030 must be low- or zero-emission vehicles (Guhlke, 2025). In practice, this will result in the emergence of an increasingly wide range of alternative technologies, such as electric, hydrogen, or HVO100-based vehicles.

The EU Emissions Trading System (ETS) is also undergoing a transformation: from 2025, road transport will be included in the quota system, making it mandatory for transport companies to purchase carbon dioxide quotas, which will directly affect operating costs (Pahle et al., 2025).

Also worth mentioning is the EU's policy of promoting combined transport, which aims to increase the share of intermodal transport (rail + road + waterway) by 2040, offering up to 90% CO₂ reduction potential, according to UIRR (Union internationale pour le transport combiné Rail-Route).

2.6. Market challenges and regulatory barriers

Although progress has been significant, market players face a number of obstacles. The current weight of electric trucks exceeds that of conventional vehicles, mainly due to the batteries. Vehicle weight and size limits, therefore, often put alternative-fuel vehicles at a competitive disadvantage, as they can carry less cargo. Several professional organizations, such as ACEA, are pushing for an update to the directives, particularly with regard to allowing longer trailers and higher axle loads ('European Manufacturers and Operators Urge EU Member States to Finalise Weights and Dimensions Revision', 2025).

3. Methodology

The aim of the study is to explore the expectations of industry and society regarding future road freight vehicles, with a particular focus on sustainability, technological development, and the regulatory environment. The research uses a qualitative approach based on secondary data, supplemented by thematic content analysis.

3.1. Research approach

The study is exploratory, qualitative research based on an analysis of relevant literature, policy documents, and practical examples. As the topic also has a strong future-oriented dimension (e.g., technological forecasts, transport policy objectives), the methodology is synthetic in nature and based on a combination of several types of sources.

3.2. Analysis method

The research used thematic content analysis based on the following main topics:

- Technological developments (e.g., autonomous driving, electric and hydrogen propulsion, logistics digitalization)
- Sustainability expectations (e.g., zero emissions, energy efficiency, circular economy)
- Policy and regulatory directions (e.g., CO₂ targets, ETS, road tolls, infrastructure support)
- Social and economic considerations (e.g., labor replacement, road safety, acceptance)

The structure of the individual subsections of the analysis was also based on these topics, allowing for the exploration of the relationships between the expectations.

3.3. Data sources

The study relies primarily on secondary sources, which can be classified into the following categories:

Scientific articles and literature reviews, in particular regular literature reviews on the future of road freight transport (Ferguson et al., 2025), (Engholm et al., 2025), (Kallionpää et al., 2023), (Jungblut et al., 2024)

Recent news sources and case studies from leading international media outlets (e.g., The Verge, Reuters, FT) reporting on the practical introduction of autonomous and electric trucks

European and national policy documents, such as EU CO₂ regulations, ETS guidelines, combined transport strategy, or Germany's sustainability incentive packages

Industry analyses and forecasts, such as publications by DSV, ICCT, ACEA, and UIRR

When selecting sources, the researcher took into account current, reliable, and relevant materials from after 2020.

3.4. Scope and limitations of the analysis

The research does not include primary empirical data collection (e.g., questionnaire surveys or interviews), so the generalizability of the results is limited. The aim was rather to explore trends, identify scientific and industrial discourses, and synthesize the expectations of different actors (industry, regulators, society).

Some of my sources (media reports) may be overly optimistic about technological breakthroughs, as they are often based on company press releases. Environmental groups, on the other hand, may be overly pessimistic. For this reason, my conclusions are cautious.

Another limitation is that the policy environment examined (EU/Germany) cannot necessarily be generalized to other geographical contexts (e.g., the US, Asia), although the study attempts to present examples from several regions.

As a point of interest, let us look at the frequency analysis of keywords ("sustainability," "safety," "autonomy") occurring in policy documents and company press releases over time to see how the emphasis has changed.

2004 – Early focus: Laying the foundations for efficiency and sustainability

Sustainability: The 2001 White Paper (and its 2004 evaluation) already emphasized environmental considerations, particularly in relation to carbon dioxide emissions,

congestion, and the strengthening of multimodal transport (rail, water transport). However, "sustainability" was still more of a background goal than a dominant keyword.

Safety: Road safety was a priority area, with a target of reducing fatal road accidents by 50% by 2010. Attention was paid to the development of passive and active safety technology (e.g., seat belts, ABS, speed limits).

Autonomy: This term did not yet appear in a technological sense during this period. The topic of digital and self-driving vehicles was not yet on the agenda in EU strategic documents.

2014 – The beginning of the digital revolution, security, and green transition

Sustainability: Sustainability was already a key element in the 2011 White Paper (*Plus and NVIDIA Collaborate to Advance AI for Level 4 Autonomous Trucks With Large-Scale World Models*, n.d.), which also defined the policy directions for 2014. The EU's goal was to:

- reduce CO₂ emissions from the transport sector by 60% by 2050,
- increase electromobility and urban public transport.

Safety: Remained a strategic priority. New emphasis was placed on driver assistance systems (ADAS, Advanced driver-assistance systems) and the development of transport culture (e.g., training, prevention). The development of TEN-T (Trans-European Transport Network) networks was also a goal in order to achieve safer infrastructure.

Autonomy: As a result of technological developments, self-driving vehicles were mentioned, mainly in the context of research and innovation programs (e.g., Horizon 2020). Autonomous mobility was not yet a widespread strategic goal, but was rather treated as a potential.

2024 – Intelligent and autonomous systems, green mobility in the spotlight

Sustainability: The 2020 European Green Deal and the 2020–2024 Sustainable and Smart Mobility Strategy have radically reinforced the role of sustainability:

Target: 90% reduction in emissions from the transport sector by 2050

Regulations on electric vehicles, zero-emission fleets, active mobility (walking, cycling)

Safety: The Vision Zero concept (zero fatalities) has become increasingly integrated into policies. On the regulatory side, ADAS (e.g., automatic emergency braking) has become mandatory, as have EU-supported C-ITS systems (cooperative intelligent transport systems).

Autonomy: By 2024, autonomous vehicles will have already appeared as a specific policy objective. The following topics have come to the fore:

Testing of SAE Level 3–4 autonomous systems within the EU,

Development of an ethical and legal framework (liability, data management),

Development of digital infrastructure to support autonomous transport (e.g., 5G, sensor networks).

Table 1: Summary: evolution of concepts over time

Year	Sustainability	Safety	Autonomy
2004	Secondary objective	High priority (fatality reduction)	Not included
2014	Strategic goal (Green Transport)	Advanced systems and safety culture	Appeared at the research level
2024	Central EU climate objective	System-level regulation	Strategic goal, testing, and legal frameworks

Source: own editing

4. Findings

Based on the thematic content analysis, the expectations identified by industry and society can be classified into four main categories: (1) technological expectations, (2) environmental and sustainability expectations, (3) regulatory and infrastructure-related requirements, and (4) social and economic considerations.

4.1. Technological expectations

Industry clearly expects future trucks to feature a high level of automation, intelligent systems, and connected digital solutions. Based on the rapid development of advanced driver assistance systems (ADAS), self-driving functions, and machine learning-based navigation systems, the industry's goal is to reduce costs and human resource dependency.

Practical examples, such as the Aurora and Waymo tests, are already on the verge of commercializing Level 4 autonomy. At the same time, there is also an increased demand for safety from society – the expectation that artificial intelligence should operate at least as safely as a human driver (*Waymo Via Expands Partnership with UPS to Autonomous Freight Movement with Class 8 Trucks*, n.d.).

4.2. Environmental and sustainability expectations

Social and political pressure is increasingly pushing the industry towards zero-emission technologies. Sustainability expectations focus on electric drives, hydrogen fuel cells, and renewable energy-powered devices.

Projects by Scania (Bayerlein et al., 2025), Hyundai, and the TIP Group show that the industry is capable of adapting, but the transition is costly and slow. Social expectations, on the other hand, demand a faster transition, especially in light of climate protection goals (e.g., the EU Green Deal). These contradictions also present challenges for industrial decision-makers.

4.3. Regulatory and infrastructure requirements

There is a strong demand from industry players for a predictable, incentivizing, and technology-friendly regulatory environment. Measures such as toll exemptions for zero-emission vehicles or infrastructure support (e.g., charging network development) have a stimulating effect. In contrast, several regulatory barriers, such as vehicle weight limits, currently hinder the widespread adoption of alternative powertrains.

Social expectations also point towards regulation, namely in the form of active state support for the spread of climate-friendly technologies, for example, through subsidies and quotas.

4.4. Social and economic aspects

Society has two expectations: on the one hand, environmentally friendly, sustainable freight transport, and on the other, job protection and a people-centered approach to technological change. Digitalization and automation may replace jobs in the transport sector, which is why there is a growing social demand for managing the social transition, for example, through retraining programs and new employment models.

Here we must highlight the tensions:

Time pressure: Society and regulators expect immediate CO₂ reductions, but unfortunately, this is not a quick process.

Cost pressure: Green technologies are expensive and place a burden on industry, but ultimately, society also feels the pinch as everything inevitably becomes more expensive.

Technological tension: The promise of autonomous vehicles (fewer drivers, lower costs) is offset by the loss of jobs.

We should also mention Tesla Semi's replaceable battery concept and "Truck-as-a-Service" models as possible solutions to economic barriers and cost tensions.

4.5. Cross-cutting insights and emerging tensions

The analysis reveals several cross-cutting patterns that extend beyond the four thematic categories. A key finding is the growing mismatch between societal expectations for rapid decarbonisation and the industry's ability to implement technological and infrastructural change at the required pace. While companies invest in autonomous, electric, and hydrogen technologies, deployment is constrained by infrastructure gaps, regulatory uncertainty, supply chain limitations, and high capital costs.

Risks and uncertainties—such as the technological maturity of autonomous systems, cybersecurity challenges, and fluctuating support schemes—further shape stakeholder expectations and slow adoption. At the same time, the perspectives of industry, regulators, and society diverge: efficiency and cost reduction remain central to industry, whereas policymakers prioritise climate targets, and society emphasizes both sustainability and social protection. These interacting pressures underscore the need for coordinated public–private strategies to strike a balance among innovation, affordability, and societal acceptance.

Table 2: Summary of cross-cutting insights and stakeholder tensions

Dimension	Key Insight	Main Stakeholder Tension
Technology readiness	Rapid progress in autonomy, electrification, and hydrogen, but uneven maturity and reliability	High expectations vs. limited large-scale deployability
Infrastructure	Charging and hydrogen networks remain insufficient; digital infrastructure varies regionally	Need for rapid expansion vs. high investment costs
Regulation	Strong climate ambition, but evolving rules (ETS, tolls, weight limits) create uncertainty	Predictability for industry vs. policy pressure for accelerated transition
Economics	Transition increases CAPEX/TCO; emerging models (TaaS, battery-swapping) only partly mitigate costs	Demand for affordability vs. rising operational costs
Labour and society	Automation promises efficiency but raises concerns about job displacement and acceptance	Technological optimisation vs. social protection expectations
Risk factors	Cybersecurity, supply chain constraints, and volatile support schemes	Need for innovation vs. risk aversion in adoption decisions

Source: own editing

5. Discussion

Based on the results of the research, it has become clear that the expectations of industry and society are aligned in many respects—particularly in the areas of sustainability, safety, and digitalization—but that there are conflicts between stakeholders regarding the speed of implementation and costs.

5.1. The issue of technology acceptance and social trust

From a technological point of view, developments have already reached a level where commercial application is realistic. Autonomous vehicles, for example, are already capable of safe transportation in certain environments. However, society is still skeptical in many cases: a lack of trust and technophobia can slow down acceptance. This challenge can only be overcome through transparent, regulated operation and strong communication.

5.2. The economic reality of environmentally friendly powertrains

Although there is strong pressure from society towards sustainability, alternative powertrains (e.g., electric, hydrogen) currently involve high investment and operating costs. A large-scale transition is therefore not

realistic without government incentives and infrastructure support. However, long-term sustainability can only be ensured if industry and government work closely together.

5.3. Regulatory tensions and barriers to innovation

In many cases, existing legal frameworks are not keeping pace with technological developments. Overly strict or outdated regulations—such as weight limits and vehicle dimensions—restrict competitiveness. This is particularly true for heavy electric vehicles, where the weight of the battery reduces the useful load capacity. The regulation of future vehicles, therefore, requires a more flexible, technology-friendly approach. Consequently, we recommend relaxing axle load restrictions exclusively for zero-emission vehicles to compensate for the weight of the batteries, while respecting the physical load limits of the road infrastructure.

5.4. The role of the human factor

Although technological advances are significant, the future of road freight transport continues to depend on the human factor: social acceptance, labor market flexibility, and the adaptability of the education system. Retraining programs, the development of new professions, and a human-centered approach play a key role in a successful transition.

5.5. Integrated interpretation and strategic implications

The discussion highlights that the transformation of road freight transport is driven by mutually reinforcing technological, economic, regulatory, and social factors. Although industry and society share long-term objectives—decarbonisation, higher safety, and digital efficiency—the transition is slowed by structural constraints: infrastructure gaps, cost burdens, regulatory rigidity, and uneven social acceptance. These factors create a fragmented innovation landscape in which technological feasibility does not automatically translate into large-scale adoption.

A critical insight is that no single stakeholder group can independently overcome the barriers identified. Industry requires regulatory predictability and infrastructure investment; policymakers need credible technological pathways to meet climate targets; and society expects both environmental improvement and economic fairness. Coordinated action—public–private partnerships, harmonised regulation, risk-sharing mechanisms, and inclusive labor transition strategies—emerges as a necessary condition for a viable transformation. Without such alignment, the pace of implementation will continue to lag behind expectations despite rapid technological progress.

Table 3: Cross-cutting insights and strategic implications for stakeholders

Challenge Area	Core Tension Identified in Discussion	Strategic Implication
Technology acceptance	High technical maturity vs. low social trust	Transparent safety validation, regulated pilot zones, communication strategies
Economic burden of green technologies	Sustainability expectations vs. high CAPEX/TCO	Targeted incentives, public co-investment, scalable business models (e.g., TaaS)
Regulatory rigidity	Fast tech evolution vs. slow rulemaking	Adaptive regulation, weight/dimension revisions,

		innovation-friendly frameworks
Human factor	Automation benefits vs. employment risks	Reskilling programs, new job profiles, socially responsible transition planning
Infrastructure readiness	Market demand for zero-emission vehicles vs. insufficient charging/hydrogen networks	Accelerated infrastructure development, coordinated standards, corridor-based deployment
System-level coordination	Shared goals vs. fragmented stakeholder actions	Public–private partnerships, long-term roadmaps, risk-sharing mechanisms

Source: own editing

6. Conclusions and Recommendations

6.1. Conclusions

This study aimed to explore the industrial and societal expectations for future road freight vehicles, with a particular focus on technological, environmental, regulatory, and societal factors. Based on the analysis of literature and case studies, the following main conclusions can be drawn:

From a technological perspective, the key expectations for future trucks are automation, digitalization, and connectivity. The practical implementation of autonomous vehicles is already underway, particularly in the North American market.

From a sustainability perspective, there is a growing demand from society for zero-emission freight transport. The industry is moving in this direction, but the transition is facing economic and technological constraints.

At the regulatory level, the EU and some Member States (e.g., Germany) are seeking to encourage technological change through active climate policy measures. At the same time, the current legal and infrastructural environment does not always support a rapid transition.

From a societal perspective, accepting technological change, maintaining transport safety, and preserving jobs are key expectations. The human factor continues to be decisive in the acceptance of vehicles and the functioning of the transport system.

These expectations often point in the same direction, but in some areas — particularly with regard to implementation time and costs — tensions can be observed between industry, society, and decision-makers.

Overall, the findings indicate that the future of road freight transport will depend on the sector's ability to align technological feasibility, regulatory frameworks, economic realities, and societal expectations into a coherent and jointly supported transition pathway.

6.2. Recommendations

6.2.1. Encouraging technological developments and ensuring transparency

It is important for developers that technologies not only work, but are also understood and accepted by society. Therefore, transparent testing, public demonstrations, and communication campaigns are recommended for autonomous and alternative-fuel vehicles.

The development of open data formats and common industry standards can promote interoperability and faster technological diffusion.

Strengthening societal trust through transparent testing and shared standards is essential to accelerate the acceptance and diffusion of emerging vehicle technologies.

6.2.2. Expanding economic incentives and targeted subsidies

In order to promote the uptake of zero-emission trucks, it is recommended that purchase subsidies, tax and toll discounts be maintained and extended, particularly for small and medium-sized enterprises.

Expanding the charging and fuel infrastructure is essential: fast chargers must be installed along logistics hubs and major transport routes (e.g. TEN corridors) in accordance with mandatory coordinated EU guidelines, possibly with the involvement of private capital (e.g. IONITY).

A sustained and well-targeted incentive framework remains a prerequisite for lowering adoption barriers and enabling zero-emission technologies to reach commercial scale.

6.2.3. Creating a more flexible regulatory environment

Regulations must adapt to technological change. To this end, it is recommended that vehicle weight and size limits be handled more flexibly in the case of alternative-fuel vehicles.

Legal frameworks for transport safety should be designed in such a way that they do not hinder the development of autonomous systems, while ensuring controllability, rules of responsibility, and citizens' sense of security.

Regulatory adaptability will be decisive in ensuring that legal frameworks evolve in step with innovation rather than restricting its practical implementation.

6.2.4. Supporting people-centered transition and education programs

Jobs lost due to digitization and automation must be offset by retraining and vocational training programs. The aim of these is to enable transport and logistics workers to continue their work in new roles (e.g., vehicle monitoring, system maintenance).

Educational campaigns that present the future of transport in a clear and accessible way can help society adapt to technological change.

Human-centered transition strategies are critical to maintaining social acceptance and ensuring that workforce capabilities develop in parallel with technological change.

6.3. Concluding remarks

The future of road freight transport has already begun. The technology is there, climate protection is urgent, and social expectations are becoming increasingly clear. However, development alone is not enough for a successful transition: coordinated industrial, governmental, and social cooperation is needed to ensure that the vehicles of the future are not only technologically acceptable but also socially acceptable and sustainable.

The transition will succeed only if technological ambition, policy commitment, and societal acceptance advance together and reinforce one another in practice.

Conflict of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- AI Research. (n.d.). *Gatik*. Retrieved 10 December 2025, from <https://gatik.ai/ai-research-team/>
- Aurora: Self-driving freight is here*. (n.d.). Retrieved 9 December 2025, from <https://aurora.tech/>
- Bayerlein, M., Hausmann, J., Heimes, H., & Kampker, A. (2025). A comprehensive techno-economic evaluation of fuel cell electric trucks. *Transportation Research Interdisciplinary Perspectives*, 32, 101548. <https://doi.org/10.1016/j.trip.2025.101548>
- Clean and sustainable mobility*. (n.d.). Consilium. Retrieved 10 December 2025, from <https://www.consilium.europa.eu/en/policies/clean-and-sustainable-mobility/>
- Electric trucks to remain exempt from tolls in Germany until 2031—Electrify.com*. (2025, November 14). <https://www.electrify.com/2025/11/14/electric-trucks-to-remain-exempt-from-tolls-in-germany-until-2031/>
- Engholm, A., Frölander, S., Johansson, M., Kristofersson, F., & Kristoffersson, I. (2025). Impacts of electric and driverless heavy-duty trucks on the future decarbonized freight transport system: Analyzing techno-economic uncertainty using exploratory modeling and analysis. *Transportation Research Part A: Policy and Practice*, 199, 104576. <https://doi.org/10.1016/j.tra.2025.104576>
- European manufacturers and operators urge EU member states to finalise weights and dimensions revision. (2025, July 18). *ACEA - European Automobile Manufacturers' Association*. <https://www.acea.auto/news/european-manufacturers-and-operators-urge-eu-member-states-to-finalise-weights-and-dimensions-revision/>
- Ferguson, M. M., Sharmin, A., Camur, M. C., & Li, X. (2025). *A Review on Intermodal Transportation and Decarbonization: An Operations Research Perspective* (No. arXiv:2503.12322). arXiv. <https://doi.org/10.48550/arXiv.2503.12322>
- Guhlke, J. (2025, July 23). *Decarbonisation of German transport sector ramps up | Latest Market News*. <https://www.argusmedia.com/en/news-and-insights/latest-market-news/2713255-decarbonisation-of-german-transport-sector-ramps-up>
- Jungblut, E., Grube, T., Linßen, J., & Stolten, D. (2024). *Automated and Connected Driving: State-of-the-Art and Implications for Future Scenario Analysis* (No. arXiv:2408.11864). arXiv. <https://doi.org/10.48550/arXiv.2408.11864>
- Kallionpää, E., Nair, S., & Liimatainen, H. (2023). Perspectives of using Electric- and Alternatively Fuelled Freight Transport Vehicles among Road Haulage Companies in Finland. *Transportation Research Procedia*, 72, 1894–1901. <https://doi.org/10.1016/j.trpro.2023.11.668>
- Kekade, M. (n.d.). *Aurora Innovation And Gatik AI Take Key Strides In Scalable Driverless Trucks*. TechDogs. Retrieved 10 December 2025, from <https://www.techdogs.com/tech-news/td-newsdesk/aurora-innovation-and-gatik-ai-take-key-strides-in-scalable-driverless-trucks>
- Kodiak Catalyst: Everything you need to operate a fleet of autonomous trucks – Kodiak AI*. (n.d.). Retrieved 10 December 2025, from <https://kodiak.ai/industry/trucking>
- Kumar, V. B., Collin, A., Sankar, M. G., & Subramanian, K. (2025). Fuel cell technologies in the automotive sector: A focus on proton exchange membrane and Alkaline fuel cells. *Green Technologies and Sustainability*, 3(3), 100218. <https://doi.org/10.1016/j.grets.2025.100218>
- Pahle, M., Quemin, S., Osorio, S., Günther, C., & Pietzcker, R. (2025). The emerging endgame: The EU ETS on the road towards climate neutrality. *Resource and Energy Economics*, 81, 101476. <https://doi.org/10.1016/j.reseneeco.2024.101476>

Plus and NVIDIA Collaborate to Advance AI for Level 4 Autonomous Trucks With Large-Scale World Models. (n.d.). Retrieved 10 December 2025, from <https://plus.ai/news-and-insights/plus-and-nvidia-collaborate-to-advance-ai-for-level-4-autonomous-trucks-with-large-scale-world-models>

Segreteria. (2023, June 22). Refrigerated trailer equipped with solar panels, TIP to start the very first pilot. *Sustainable Truck&Van*. <https://www.sustainabletruckvan.com/refrigerated-trailer-solar-panels-tip/>

Waymo Via expands partnership with UPS to autonomous freight movement with Class 8 trucks. (n.d.). Waymo. Retrieved 10 December 2025, from <https://waymo.com/blog/2021/11/waymo-via-expands-partnership-with-ups>

Williams, M. (2025, January 10). *Hödlmayr using Mercedes-Benz eActros truck to shuttle finished vehicles from Magna plant in Graz.* <https://www.automotive-logistics.media/ev-and-battery/hoedlmayr-using-mercedesbenz-eactros-truck-to-shuttle-finished-vehicles-from-magna-plant-in-graz/198802>



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Factors Influencing the Electric Car Purchases in the Visegrad Countries: Comparative Analysis of the Influencing Key Factors

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Abstract: The climate protection goals and regulatory **mechanisms** of the world's leading economic powers are accelerating the transition towards electric cars. The most important cornerstone of the successful transition to electric based mobility and product sale is that the value expected and the value perceived by the customer are matched. For understanding these values, it's unavoidable to examine that what kind of factors are influencing the decision making process of the potential e-car buyers. This study focuses on the influencing factors examined in the Visegrad (V4) countries with the methodology of the systematic literature review (SLR). The research question is: *"What are the key factors affecting consumers' decisions to purchase electric vehicles in Hungary, Poland, the Czech Republic, and Slovakia?"* Beside of the research question, the following hypothesis is validated: *"The same influencing factors play a role in the electric car purchasing decisions in the Visegrad countries."* The analysis also use the Theory of Planned Behavior (TPB) and the Technology Acceptance Model (TAM) as theoretical lens for analyzing customer decision making process. Based on the research results, it can be concluded that in the Visegrad countries, the electric car purchase process is primarily influenced by the purchase price, the inadequacies of the charging infrastructure and the insufficient range of electric vehicles. Environmental awareness is present in the decision-making process, but it plays only secondary role. Despite the fact that there are numerous differences (e.g. country size, GDP, e-car purchase support policy, purchasing power parity etc.) between the Visegrad countries. As having conclusion, the observations enable us to formulate hypotheses regarding the key influencing factors of electric car purchase decision making process. It also helps us to understand these influencing factors and based on them, all of the stakeholders like car manufacturers and dealers, political decision makers, local governments etc. could modify their strategies and take actions to promote the transition to electric vehicles.

Keywords: customer preferences, electric car adoption, electric car purchases, electromobility, Visegrad countries

JEL Classification: D7, D11, D46, D91, O33, O52

1. Introduction

The world's leading economic powers are increasingly emphasize areas, which are related to climate protection and for ensuring it, they set very ambitious goals to significantly reduce harmful emissions. This is facilitated by various regulatory measurements such as stricter emission standards (e.g.: carbon-dioxide reduction), different support systems (e.g.: for charging infrastructure and e-car purchase) and other greener future investments (e.g.: sun solar system, battery storage). These measures also have a significant impact on the automotive industry, especially in the direction of drive-train technology development. A vehicle with a traditional internal combustion engine will be gradually overshadowed in the coming years as the rise of electric vehicles will accelerate in parallel. Electric cars have become an increasingly important part of the global mobility and car industry (Chan & Wong, 2004, pp. 24-33.). Another study also highlight that the electrification of the vehicle segment has been acknowledged as a crucial part in tackling the challenges of global climate change (Haghani et al., 2023, p.15.). The transition to e-mobility is imminent in global car markets. In 2024, global sales of electric cars have reached 17.1 million units worldwide, which means a 25% increase compared to the previous year (Rho Motions Benchmark Company, 2025). This transition is driven primarily by the ongoing ever-tightening harmful emission limits and the changing climate protection

targets. In the European Union (EU), the transportation sector is the primary “consumer” of different fossil fuels. This segment is responsible for nearly one-quarter of the EU’s total greenhouse gas emissions (Eurostat, 2025). The EU has set particularly ambitious goals to its member states. From 2035, vehicles with conventional internal combustion engines will not be allowed to be put on the car market and by 2050, the EU aims to achieve complete climate neutrality in all areas. One of the key areas of these global efforts is the decarbonization of the transport sector (as the part of the solution), where the electric based transportation and mobility play a key role (European Commission, 2019).

The topic is highly relevant because in order to reach the successful transition to electric based transportation, it’s important that the value expected and the value perceived by the customer are matched during the electric car purchasing process and usage. For better understanding of these values, it can’t be avoided to deeply analyze the influencing factors of the potential e- car buyers in their decision-making process. These are the well-known influencing factors like the price of the e-car, available charging infrastructure, support policy, cheaper fuel costs etc. This study focuses on the influencing factors in the Visegrad countries (V4) including Hungary, Poland, the Czech Republic and Slovakia. As these countries are part of the European Union, the pollution reduction targets, climate protection goals and all of the legal measurements of the EU have an enormous effect on these countries’ operation, including transportation and mobility reforms.

2. Research objectives

The objective of this comparative analysis is to perform a comprehensive and scientifically well-established study that analyses the influencing factors in the decision-making process. The research has basically four closely related objectives. As the primary objective, the study seeks to explore and systematize all relevant scientific studies, publications, surveys that relate to the electric vehicle market, consumer attitudes and social and economic determinants of electromobility in each Visegrad country. This step is necessary in order to create a well-founded picture of the existing scientific discourse and place this empirical study on a reliable basis. As a second objective (based on the earlier studies), the research aims to introduce all of the factors that affect the willingness to purchase electric cars on a country-by-country basis. These factors include economic incentives, environmental attitudes, infrastructural conditions, regulatory frameworks, technological development and social factors as well. The detailed factor analysis allows for a systematic comparison of the similarities and differences between the Visegrad countries. Thirdly, the research aims to test a hypothesis regarding the factors influencing the electric car purchase process in the Visegrad countries. Validating the hypothesis would contribute to deciding whether the Visegrad countries have a similar market and social characteristics in the field of electromobility or whether relevant differences can be observed at the national level. The fourth objective is to formulate proposals for external and internal stakeholders, e.g. charging infrastructure operators, governmental decision makers, car manufacturers and dealers in order to accelerate the spread of the electric based mobility.

3. Research question and hypothesis

In order to understand the key motivators, it’s crucial to understand all of the influencing factors which can be measured. As the base of the study, the central research question is the following:

“What are the key factors affecting consumers’ decisions to purchase electric vehicles in Hungary, Poland, the Czech Republic, and Slovakia?”

The relevance of the question lies on the fact that the Visegrad countries have similar social-economic structures and a common historical background, while all four countries (as part of the European Union) face similar challenges in the issue of “green” transition, sustainable transportation and mobility.

Accordingly, the research aims to explore the factors that show common patterns or even differences behind consumer attitudes and decisions towards electric vehicles. Analyzing these influencing factors as a V4 country-by-country and regional comparison, it makes possible to determine whether the Visegrad region is characterized by a homogeneous consumer decision-making structure or whether there are differences in certain influencing factors. After having a research question, it's important set up a hypothesis:

“The same influencing factors play a key role in the electric car purchasing decisions in the Visegrad countries.”

This assumption is based on the well-known facts listed by the research question. Testing the hypothesis, the research also seeks to answer whether these similarities are sufficient to validate the same purchasing patterns or whether different institutional, costumer's psychological factors dominate the costumer's decision-making process.

4. Methodology

In the past years, lots of studies and opinion pool surveys were executed regarding electric cars, which shows the significance of this topic as well. To compare and analyze these findings from the last few years, the systematic literature review (SLR) has been chosen as methodology. The SLR is a scientific research method that aims to collect, evaluate and synthesize the existing scientific literature, sources related to a specific research question or hypothesis in a comprehensive and objective manner. Basically the SLR follows a strict protocol system. Sources are selected based on predefined search strategies, using inclusion and exclusion criteria and a profound critical appraisal too (Creswell, 2009, pp.98-110.).

During the first stage of SLR, search engines and academic databases were identified. The main sources were Google, Google Scholar, Web of Science, Science Direct. These platforms are well-known standard and academic search platforms, providing a wide range collection of scientific literature. The records was limited to the years between 2020–2025 in order to finding the latest studies. The initial searching process has taken place between 5 January 2025 and 5 May 2025. To ensure a targeted and a comprehensive literature assessment associated with the topic's frameworks, the following keywords have been used: *electric car adoption, electric car purchasing factors, electric car consumer behavior, electromobility customer*. Initial title screening identified altogether 1241 potentially relevant papers, studies, articles.

The second stage of the SRL process has involved a screening process in order to remove all of the potential duplicates. The duplicates were removed from the records, then all of the titles and abstracts were read carefully, resulted in finally identifying 321 potential records. Further screening process was performed based on exclusion criteria. 1.criteria: Studies, papers and surveys, which apply to the Visegrad countries. After this elimination, 89 article remained for further investigation. In order to reduce the number of studies, papers and surveys, a 2. criteria were applied. Records unrelated to electric car purchase influencing factors, customer behavior, electric car adoption were eliminated.

Through this screening process, the records were reduced to the 3 most relevant in each V4 country, altogether 12 records. These 12 records have performed all the given criteria, so these records being included in this systematic review. The stages for preparing the SLR method are presented in Figure 1. The stages can be followed with the PRISMA flow diagram (Page et al., 2021, pp.3-5)

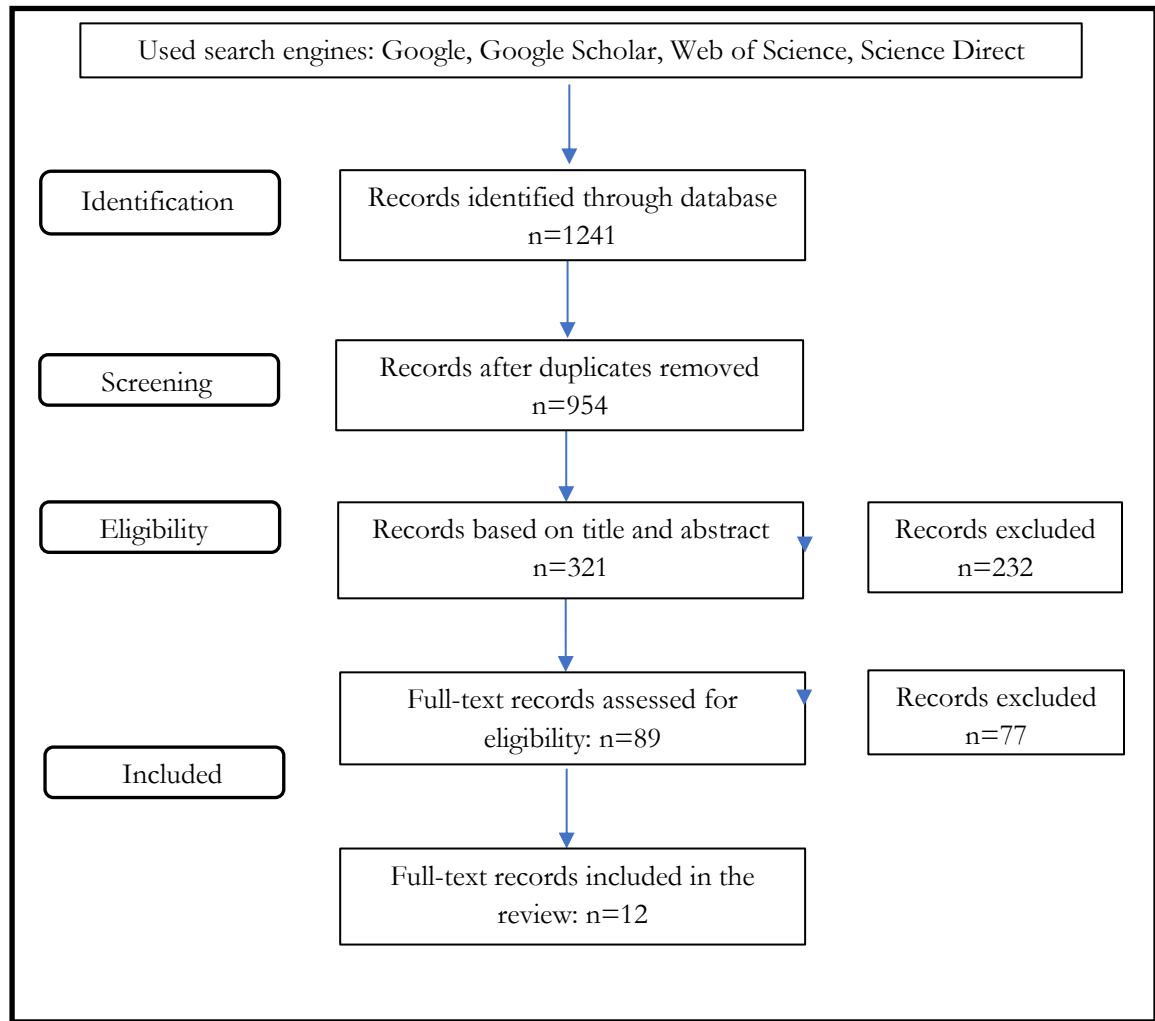


Fig. 1: SLR Prisma diagram

Source: own edition based on Page et al., 2021

5. Theoretical framework and literature review on influencing factors of electric car purchase in the Visegrad countries

As it was indicated, altogether 12 studies, papers, surveys were included in this study. This section introduces the theoretical frameworks and the literature review country by country as selected through the SLR.

5.1. Theoretical frameworks

5.1.1. Positive and negative factors by Secinaro et al. (2022)

According to Secinaro et al. (2022) customer choices regarding electric vehicle purchase process are influenced by 3 positive and 3 negative factors:

Positive factors include:

1. Policy makers' incentives: Government-provided financial incentives, tax allowances or reduction and subsidies aimed to encouraging the adoption of electric vehicles.

2. Environmental (protection) Consciousness: Increasing the general public recognition and knowledge of the environmental advantages by using electric vehicles as a mobility tool.
3. New technology: Advantages of very advanced and innovative technologies of using electric cars.

Negative factors include:

1. Electric car charging issues: General worries regarding the charger accessibility, not appropriate charging speed and overall inconvenience of the e-car charging infrastructure.
2. Price: High initial EV price, especially when it's compared to conventional cars.
3. EV effectiveness and energy efficiency: Customer doubts regarding the efficiency of electric vehicles. (Secinaro et al., 2022, pp. 399–416.)

5.1.2. Further theoretical frameworks: Theory of Planned Behavior (TPB) and the Technology Acceptance Model (TAM)

The further theoretical basis of this research is provided by the integration of the Theory of Planned Behavior (TPB) and the Technology Acceptance Model (TAM). These scientific theories provide eligible explanatory power for examining consumer decisions regarding the electric vehicles purchases in the Visegrad countries.

The TPB model is based on the work by Ajzen (1991). The researcher assumes that behavior is directly determined by behavioral intention, which is based on three basic components. These are the followings: the attitude toward the behavior, the subjective norm and the perceived behavioral control. Attitude refers to an individual's overall positive or negative evaluation of a given behavior. Subjective norm refers to the perceived strength of expectations and social pressure by others like family, friends, professional and altogether the social environment. Perceived behavioral control reflects how easy or difficult an individual finds it to perform a given behavior in light of the available resources and possible constraints to them (Ajzen, 1991, pp.179-211.). In the context of electric car purchase, these components represent consumers' overall view of whether it is "good" or "bad" to buy an electric car (including different considerations like economic, environmental and usage). Furthermore the social expectations associated with electric car ownership (like modern view, prestige, environmental friendly image) and the extent to which consumers feel capable of purchasing and using an electric car in terms of price, income, charging infrastructure, range and other technological aspect, like technological knowledge.

The TAM model is based on Davis's (1989) research, which focuses specifically on the adoption of new technologies. Complementing the TPB, it further emphasizes the influencing role of technology-specific perceived values in the customer's decision-making process. According to the model by Davis (1989), consumer intention to use new technology is primarily influenced by two key factors. The first is the perceived usefulness (PU) and the other one is the perceived ease of use (PEOU). Perceived usefulness expresses the extent to which an individual believes that a given technology improves their performance, efficiency or effectiveness. Beside this, the perceived ease of use refers to the effort amount that is required to use the technology (Davis, 1989, pp. 319-340.). In the case of buying and using an electric vehicle, perceived usefulness (PU) could mean the following: expected "fuel"-cost savings, parking discounts, tax allowances, driving experience, environmental benefits, status significance etc. Perceived ease of use aspect can show us how consumers find the everyday use of the electric cars, including factors like charging convenience, range adequacy, charging time, battery durability, range decrease in winter environment, etc. The TPB and the TAM approaches are particularly suitable for analyzing electric car purchase decision

making process in the Visegrad countries because it's capable for presenting the structural constraints, social influences and technology-specific aspects as well.

5.2. Literature review country by country

For the better illustration, the summaries of the analyzed studies and surveys are structured by country. This section is the base of the comparison presented in the next result and discussion section.

5.2.1. Slovakia

According to the study of Rovňák et al. (2022), the main obstacles to the widespread use of electric vehicles are the high purchase price, the lack of adequate charging infrastructure, range and operational limitations, a lack of information and knowledge about electric cars, concerns about limited electricity and raw material supplies. In the study, respondents think that the biggest obstacles to the wider use of electric vehicles are the high price, the lack of charging stations, the short battery life and low awareness. The key factors - in the purchasing decision process beside of the above mentioned obstacles - are environmental (contributes to environmental protection), economic (e.g., tax incentives) and other technical advantages (Rovňák et al., 2022, pp. 275-277.).

According a survey prepared by Zábajník, S. et al., (2022), the Slovak respondents tend to consider the usual decision-making factors (price, maintenance costs, lack of infrastructure) when purchasing an electric car but environmental considerations do not play an important role in consumer preferences. Based on the study, this can be explained to a certain extent by the disposable income. It's unlikely that environmental considerations such as environmental protection will come to the fore in the decision-making preferences of Slovak consumers. The study emphasizes that environmental protection as a factor will not play a significant role in such decisions for a long time to come. In the same time for the Slovak consumer, the product as the electric car still represents an exceptional image, which could provide a specific status for its owner (Zábajník et al., 2022, pp.132-140.).

Based on the Khalilov & Táborecká (2024) study, the results highlight that two main factors like the price and the income play a significant role in the Slovakian people decision making process. The study confirms that mainly the financial barriers influence the Slovak customer's attitudes when it comes to purchasing an electric cars (Khalilov & Táborecká, 2024, pp. 105-109.).

It can be concluded that in Slovakia, the price of electric vehicles is by far the most important factor in the customer's decision, which is closely followed by the availability of charging infrastructure, then the EV's technological limitations like the short battery life. Environmental considerations are a low priority, while the status symbol associated with owning an electric vehicle plays a significant secondary role.

5.2.2. Czech Republic

According the study from Vins & Kosova (2020), which was conducted among university students. Based on survey, it can be concluded that environmental considerations play a significant role in the process of purchasing electric cars among university students. The conclusion also validate that they would prefer environmentally friendly cars rather than internal combustion engine cars. Their intention to purchase electric car is limited by the insufficient charging infrastructure and range. Interestingly, price is not such an important factor for the young generation (Vins & Kosova, 2020, pp.6-8.).

Based on the study executed by Jaderná et al. (2025), it can be revealed that the most important criterion in the decision-making process for purchasing is the economic aspect. This aspect includes the purchase price as well as the operating and service costs. On the other hand, respondents consider the environmental

criteria for least important factor. Among the user criteria, charging and driving characteristics were rated as the highest. The research results clearly show that economic considerations are the most important factors to Czech consumers (Jaderná et al., 2025, pp.18-21.).

According to the study of Zámečník et al. (2021), the Czech consumers consider electric vehicles to be expensive and less convenient than conventional vehicles due to their range and current inadequate charging infrastructure. According to the survey, the decision-making mechanisms are influenced by price, range, inadequate charging infrastructure, small size of the vehicle, fear of battery degradation and low speed. Interestingly, environmental aspect does not play an important role in Czech consumers' decisions. The study shows that the environmental factors are not a significant factor that would outweigh higher costs and convenience considerations (Zámečník et al., 2021, pp.3-4.).

The influencing factors map is mixed in the Czech Republic. Environmental considerations are important among university students, while price is less important, but economic considerations (including purchase price and operating costs) dominate among the general population. Charging infrastructure and range remain relevant barriers. Environmental criteria are generally less important to the wider public, who also consider other practical factors such as vehicle size and battery degradation.

5.2.3. Poland

According to the study from Bednarz et al. (2023), the survey - involves a large number of respondents (3,170)- clearly shows that the factors influencing Polish consumers' decisions to purchase electric vehicles can be divided into two groups. The first group consists of internal factors (price, range, charging time, price), which are more important than the external factors in the second group (fuel prices, charging network development, social norms). Furthermore, among the internal factors, range is the primary consideration when purchasing electric vehicles in Poland. As the study indicates, this Polish research results are similar to previous research conducted in Germany, where the price and range of electric cars are the two most important factors in the decision-making process. The study also mentions that another commercial opinion polls conducted earlier in Poland, where the price of electric vehicles was the most important factor for consumers, closely followed by range and other operating costs. Other less important factors include the car manufacturer's brand, the use of environmentally friendly solutions and the lower emissions from EVs (Bednarz et al., 2023, pp. 175–192.).

According to the study of Gądek-Hawlena & Bęben (2023), electric cars are considered to be expensive and having insufficient range, which factors are being the main deterrents in the purchasing process. Among those, who intends to buy a new electric car, respondents' spending levels are far below the price range of these cars. According to respondents, the current range of electric cars is between 200 and 300 km, which they think is insufficient. More than 70% of the respondents think that the number of charging stations in Poland are insufficient for providing an uncompromised freedom of movement by car. Polish customer prefers charging at home, but considers the infrastructure available at work, in parking lots and in shopping centers to be just as convenient as charging at home. Other influencing factors include the possibility of using free parking spaces or entering clean traffic zones in Polish cities. Interestingly, respondents think that electric cars are not cheaper to maintain and are no less prone to breakdowns than vehicles with internal combustion engines. Half of participants didn't meet with the state EV incentives and subsidy programs before. But Polish people who heard about them, consider these incentives and subsidies to be extremely important when it comes to buying an e-car (Gądek-Hawlena & Bęben, 2023, pp. 161-180.).

According to the study executed by Bartosik et al. (2025), the following have emerged as the main obstacles to the widespread adoption of electric vehicles: high initial purchase prices, inadequate countrywide charging infrastructure, high concerns about the range and charging time. Besides the obstacles, Polish electric car customers consider numerous factors when establishing their decision-making process. These factors are

the EVs initial price, all of the maintenance costs related to the operations, current availability of charging infrastructure, technological innovations related to electric vehicles and the environmental considerations too. An important finding was made regarding environmental considerations. More than 80% of respondents believe that electric based vehicles (like hybrid and fully electric) have a little effect on the fight effort against climate change. When considering to purchase a new car, Polish consumers generally rank environmental sustainability to be a low priority factor in the decision-making process (Bartosik et al., 2025, pp. 5-14.).

Summarizing the Polish influencing factors, the initial price and range must be highlighted, which are consistently the two most important factors in purchasing decisions for electric vehicles. Charging time and the availability of charging stations also rank highly within the factors among Polish people. Regarding the environmental considerations like air pollution and battery, it remains a low priority factor because many Polish consumer are really skeptical about the role of electric vehicles when it comes to protecting the environment. The car brand reputation, access to clean traffic zones or free parking areas have a weak influence on the decision-making process in Poland.

5.2.4. Hungary

A questionnaire survey executed by Vereckei-Poór & Törőcsik (2022), presented that consumer's opinion regarding electric vehicles for the most part is positive. The majority of the Hungarian respondents find electric cars attractive and do not consider their use to be a limitation on convenient mobility. Furthermore, respondents believe that EVs are no more polluting than conventional vehicles, but rather consider EVs to be environmentally friendly and an integral part of the fight against global warming. This perception is reinforced by the view that sustainability is a top priority among EV users. However, the study highlights the well-known factors that hinder the wider adoption of EV technology, such as the most important one is the high purchase price, which makes these vehicles more accessible to higher-income segments of society. The importance of subsidies is also highlighted, but the charging infrastructure is not addressed in their study (Vereckei-Poór & Törőcsik, 2022, pp.57-66.).

Based on the research results of Németh & Kovács (2022), it can be concluded that a significant proportion of Hungarian respondents are open to purchasing electric vehicles, but only a small part of current car buyers actually decide to purchase them. The primary reasons are the EVs high purchase price and the limited range. Hungarian respondents would like to see an electric vehicle that would allow them to travel at least ten times the average daily distance on a single charge, while also having a lower purchase price and low operating costs. According to the study, the three already known areas remain a significant problem, when it comes to deciding to buy an EV: initial high EV price, charging network is not properly developed and the insufficient range of EVs. With the exception of the high purchase price, Hungarian respondents think that electric cars have more favorable characteristics than traditional internal combustion engine vehicles in many respects, although consumer attitudes continue to be strongly skeptical and averse to the technology. According to the survey participants, electric transportation in its current form contributes only slightly to reducing environmental pollution. The survey results show that respondents are aware of the higher initial purchase cost of electric cars, but are uncertain about the lower operating costs (Németh & Kovács, 2022, pp.7-17.).

Based on a representative public opinion survey from Ipsos Hungary executed in 2021, the following influencing factors were identified: the high price of the electric car, costumer's environmental awareness, financial incentives, the development of the charging infrastructure, openness to the electric based mobility, brand image. Further important factors like consumer perceptions related to vehicle maintenance costs, reliability and safety, lower fuel cost and judgments about future value retention. (Ipsos, 2021).

In Hungary, high purchase prices are once again the most significant obstacle, followed by concerns about the range. Charging infrastructure is mentioned as a limiting factor, but it's not considered as urgent as in Poland or Slovakia. Environmental friendliness is viewed more positively than in other Visegrad countries, especially among supporters of electric vehicles, although many believe that electric vehicles only reduce pollution to a small extent. Other factors, such as brand image, safety and maintenance costs also influence Hungarian consumer's decision-making process, but only slightly.

6. Results and discussion

6.1. Results from the comparative analysis of the influencing factors

The results are similar to the classification of Secinaro et al. (2022), customer choices regarding electric vehicle purchase process are mainly influenced by 3 positive and 3 negative factors in all of the Visegrad countries. Based on the comparative analysis conducted in the Visegrad countries clearly shows that economic and usage-related considerations dominate the decision-making process for purchasing electric vehicles, while environmental and pollutant emission considerations generally remain secondary when it comes to buying EVs.

The most significant common influencing factors in all Visegrad countries are the high purchase prices, inadequate charging infrastructure in terms of quantity and quality and concerns about the range. Subsidies, financial incentives and disposable income levels also play a key role in determining consumer attitudes. The purchase price, operating - service costs and the residual value override environmental considerations in each country. This is consistent with the fact that the income level of the V4 countries still lags behind the Western European average, which makes large investments (like buying an e-car) particularly sensitive. It was surprising that environmental awareness exists, but it's unable to offset financial and infrastructural barriers, so environmental protection is given low priority in decision-making process, except in Hungary. Hungary slightly differs when it comes to environmental considerations, these factors rank higher than in the other V4 countries (Table 1).

Table 1 Comparison of V4 Countries

Most important influencing factors	Slovakia	Czech Republic	Poland	Hungary
High purchase price	.	.	.	.
Charging infrastructure	.	.	.	.
Range limitations	.	.	.	.
Maintenance costs			.	.
Subsidies and financial incentives	.		.	.
Car brand reputation and image			.	.
Environmental considerations (low priority)	.	.	.	

Source: own edited

Also based on the comparative analysis, the research hypothesis was validated. It's true that almost the same influencing factors play a key role in the electric car purchasing decisions, there is no significant difference

in the Visegrad countries in the light of the three most important influencing factors. In the cross-country comparison matrix, the seven most important factors are presented, which factors appear in least two countries.

6.2. Regional summary in the light of the TAM-TPB framework

In the TAM and TPB framework, economic and usage considerations related to electric cars largely determine the content of PU and PEOU. Beside this, income level, available infrastructure, social expectations and norms influence the attitudes, the subjective norms and the perceived behavioural control. In light of these approaches, the empirical results from the four countries show both common regional patterns and clear differences as well.

When examining the four Visegrad countries together, a common regional pattern emerges within the TAM - TPB framework. Among the TAM variables, perceived usefulness (PU) and perceived ease of use (PEOU) are primarily determined by the price, range, charging time and the state of the charging infrastructure. In the consumer decisions, therefore the "value" of EVs is primarily reflected in economic (purchase price, operating costs) and practical (range, charging convenience) dimensions, while environmental benefits are in most cases only a secondary, complementary layer within the PU structure. In Slovakia and Poland, the "environmental PU" is particularly weak as a significant proportion of respondents do not believe that EVs contribute significantly to climate protection. In contrast in Hungary and among Czech university students, the perception of environmental benefits is stronger. Among the TPB components, perceived behavioral control (PBC) is limited in all four countries, which is mainly explained by income level and the development of charging infrastructure. Many consumers not only do not want to buy an EV, but still cannot consider it as a realistic option when taking into account their financial and infrastructural situation. Subjective norms mostly provide only moderate support for electric cars. The social environment does not compel consumers to choose low-emission transportation solutions, that's why electric cars only appear on the horizon as an "interesting alternative" to the conventional internal combustions engines car. Hungary is a partial exception and in a group of Czech university students as well, where environmental sensitivity and social acceptance of EVs are stronger than in the rest of the region. In light of the TAM - TPB models, where the PU and PEOU are low due to high prices, uncertainty due to range and the inadequate charging network. The PBC is also limited, even the relatively positive attitudes or environmental norms are not sufficient to trigger widespread adoption of electric cars. This explains why, despite the declared openness and more favorable attitudes among Hungarian and Czech university students, there remains a persistent gap between intention and actual purchase. In contrast, the Slovak and Polish cases show that if belief in environmental benefits is weak (meaning low environmental PU), the intention to purchase EVs becomes particularly vulnerable. When this is combined with economic and infrastructural barriers, it could lead to that electric vehicles remaining in the background when it comes to the decision-making process.

6.3. Potential socio-economic background factors

One of the most important background factor is the country's energy mix. In Poland, electricity generation remains largely coal-based. In 2025 too, the fossil share of electricity generation was also one of the highest at EU level with the share of solid fossil fuels in the energy balance far exceeding the EU average. (Eurostat, 2025). In this context, the skepticism of Polish consumers seem to be very rational. If electricity is largely generated from "dirty" energy sources, the environmental benefits of electric cars seem less clear. This can be seen in the fact that (as many Polish people believe) electric vehicles only contribute to climate protection very slightly. On the other hand in Hungary, where the government has significantly reduced the role of coal in recent years, while nuclear and solar energy are increasingly important in electricity generation. By 2024 the share of carbon-free electricity generation will be around two-thirds (Eurostat, 2025) This is in line

with the fact that environmental considerations are somewhat stronger in Hungary, while in Poland many consumers question the climate benefits of EVs. In countries where electricity generation is “visibly” still carbon-based, electric cars are more difficult to sell as a clean environmental friendly solution. Where the decarbonization of the energy mix can be seen and very tangible, the environmental narrative of electric cars is more credible.

In the Visegrad countries, the political-economic framing of electromobility follows a similar logic. Due to the post-socialist industrial structure, the strong automotive industry embeddedness and the pressure to catch up electromobility are basically presented as an industrial-technological modernization, rather than as a loss and negative trend of the traditional automotive model. The high level narrative that investments related to electric vehicles (battery factories, supplier capacities and potential R&D centers) serve to strengthen national competitiveness, industrial catch-up and stabilize the export-oriented economy is also emerging. Governments, global OEMs and domestic automotive clusters mostly form a political-economic coalition that connects electromobility not with the mass elimination of jobs, but with new types of jobs and higher technological level.

It's important to note that the emphases of the electromobility narrative slightly differs at the V4 level. While in Hungary the discourse of the “battery superpower” and the electric based car industry is particularly strong, meanwhile in the Czech Republic, Slovakia and Poland due to the dominant role of the automotive industry, uncertainty about structural change is also more present in public discourse. So the fear from decline of the traditional engine and component production is more frequently articulated. In Poland, the issue of the energy mix (carbon dependence) and energy prices is intertwined with the interpretation of electromobility, so the discussion around electric cars here often takes place in the language of energy security, rather than simply environmental protection or industrial development. Despite all this, what is common in the V4 countries is that the social acceptance of electric vehicles is not primarily based on so called “green values”, but on the political-economic message. This change is necessary for adapting to electromobility as the base of the future competitiveness and catching up. Despite high income barriers and limited purchasing power, electric cars are increasingly framed in the region as symbols of a modern, technologically advanced achievements.

Another important explanatory factor is the incentives, regulation and information visibility. All four countries have an EV support and tax incentives system, but their availability, “generosity” and awareness vary country to country. The Hungarian Government was among the first countries round the world who introduced the green license plate for environmental friendly cars. The governmental policies highlight the green license plate benefits (tax breaks, certain free parking options, local toll benefits), subsidies for private and corporate purchases, furthermore targeted programs to expand the charging network in Hungary. These “visible” incentives can also strengthen the positive image (including environmental friendly side) of electric cars. In Poland and Slovakia, relatively large purchase subsidies also available for customers but according to researches, a significant part of the population has not heard of them at all. Corporate and fleet-level incentives are more prominent in the Czech Republic, while subsidies are less transparent or less visible in the residential segment. It can be concluded, where incentives are simple, stable and well communicated (like in Hungary) consumers more easily integrate environmental and long-term cost benefits into their decisions. Where incentives are complicated or poorly communicated (like in Poland, Slovakia), electric cars remain less environmental friendly solutions in the public opinion.

Overall, the results suggest that the similarities between the V4 countries are stronger than the differences. The region's common structural characteristics like the income level, the countries dependence on the automotive industry, the energy mix and the charging infrastructure currently dominate the purchase of electric cars much more than the deep cultural "national characteristics". Where differences can be seen like the Hungarian environmentally friendly narrative, Czech students' green orientation toward sustainability, Slovak focus on car status symbol and the Polish climate skepticism, these differences can be easily traced

back to country specific energy policy, industry, social structure and communication factors, rather than to "mystical" cultural differences.

7. Conclusion and recommendation

Based on the research results, it can be concluded that in the Visegrad countries the electric cars buying process is primarily influenced by the purchase price, the inadequacies of the charging infrastructure and the insufficient range. Environmental awareness is present in the decision-making process, but it plays only secondary role. Based on these findings, a number of recommendations can be made to promote the spread of electromobility in the Visegrad countries.

In order to speed up the pace of electric vehicles sales, it's important to start or continue the widespread government subsidy programs and strengthen tax incentives. These economic incentives have the highest priority as the purchase price remains one of the most significant barriers in consumer decisions process. It's important to note that through mass production, electric cars are becoming even cheaper and cheaper. In the same time, price parity between electric and conventional cars has already been achieved in certain vehicle categories. The price of the used electric cars also falls steadily year by year, but the fears of the fast battery degradation is still hindering faster EVs acceptance (International Energy Agency, 2023). With the above written measures, these could improve the economic dimension of PU and increase PBC of the customers.

The development of the charging infrastructure network also stands out from the governmental reach. The development of rural areas, where the sparse charging network continues to be a significant obstacle to charging e-cars. A whole transparent and reliable fast charging network development could further increase and boost the EV buyer's confidence, especially among those people who are still unfamiliar with the electric based mobility. Furthermore this could reduce the perceived risks-fears associated with range and charging, thereby improving PEOU and PBC.

Different pilot projects regarding EVs should be intensively introduced by the local authorities. For example, local governments should start to use electric vehicles in public services, which could have a demonstration value in communities. These kind of projects can promote the technological transformation in the public and future customer's attitudes towards EVs.

Social awareness campaigns should be started immediately to ease the lack of environmental awareness and financial literacy, which could also contribute to strengthen the social acceptance of electric vehicles.

Car manufacturers also have a key role to introduce more and more affordable models in order to reduce high consumer price sensitivity. As it turned out, purchase price is not the only one, but the strongest factor influencing the purchase decision. It's also essential for stakeholders to clearly inform all of the customers regarding the total cost of ownership - abbreviated TCO -, highlighting the long-term financial benefits of using electric cars. Before deciding to purchase an electric vehicle, it's advisable to examine the above mentioned TCO, meaning that the higher initial costs of electric vehicles are often recouped through lower operating costs even within a few years.

Environmental awareness is not an important factor in the decision-making process, but does play a role, so setting a social example can also help increase willingness to buy an EV. In addition to this, it's also important to consciously strengthening the pro-environmental subjective norms with education, media discourse, corporate and municipal role models, which shift environmental PU and attitudes towards EVs in a favorable direction.

Regional cooperation between the Visegrad countries is also important in order to promote the transition to electromobility in the region. The faster and more efficient spread of electromobility throughout the

region can be achieved with the harmonization of regulatory frameworks, the involvement of common EU funds and the development of cross-border charging infrastructure.

Limitations and future research directions

Part of the SLR, I have focused on selected studies, publications and surveys to determine the key influencing factors in the electric car purchase process in all Visegrad countries. Some of the surveys were not representative and used different questions and methodology. As the spread of the electromobility accelerates, to get more precise and most up to date results, new primary empirical future investigations must be performed in each Visegrad country to validate and quantify these identified influencing factors and follow up the potential changes. This future research's findings enable us to compare these V4 findings with different studies executed within the framework of the European Union's general influencing factors as well. In addition to the future primary empirical investigations, these new findings could be compared with the influencing factors identified in the world biggest car market, in China.

Conflict of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- Ajzen, I. (1991). The theory of planned behaviour. *Organizational Behavior and Human Decision Processes*, 50(2), 179–211.
- Bartosik, A., Manev, N., Pyk, A., & Pendaroska, M. (2025). Electric vehicle adoption in Poland: Insights from academia and technically educated youth. *Sustainability*, 17(11), 5–14.
- Bednarz, J., Konewka, T., & Czuba, T. (2023). Perceived value and preferences of purchasing EVs. *Journal of International Studies*, 16, 175–192.
- Chan, C., & Wong, Y. (2004). Electric vehicles charge forward. *IEEE Power and Energy Magazine*, 2(6), 24–33.
- Creswell, J. W. (2009). *Research design: Qualitative, quantitative, and mixed methods approaches* (3rd ed., pp. 98–110). SAGE.
- Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, 13, 319–340.
- Eurostat. (2025). *Greenhouse gas emission statistics*. Retrieved February 3, 2025, from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Quarterly_greenhouse_gas_emissions_in_the_EU#Emissions_by_economic_activity
- European Commission. (2019). *The European Green Deal: Striving to be the first climate-neutral continent*. Retrieved February 3, 2025, from https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en
- Gądek-Hawlena, T., & Bęben, A. (2023). Demand determinants for electric vehicles in Poland. *Military Logistics Systems*, 58, 161–180.
- Haghani, M., Sprei, F., Kazemzadeh, K., Shahhoseini, Z., & Aghaei, J. (2023). Trends in electric vehicles research. *Transportation Research Part D: Transport and Environment*, 123, 103881.
- International Energy Agency. (2023). *Global EV outlook 2023*. Retrieved February 3, 2025, from <https://www.ica.org/reports/global-ev-outlook-2023>
- Ipsos. (2021). *Változatlanul pozitív az elektromos autók megítélése*. Retrieved February 3, 2025, from <https://www.ipsos.com/hu-hu/valtozatlanul-pozitiv-az-elektromos-autok-megitelese>
- Jaderná, E., Volfová, H., Zapletal, F., & Velinov, E. (2025). Decision making and consumer behaviour towards electromobility in the Czech Republic. *Revista de Gestão - RGS A*, 19(4), 18–21.
- Khalilov, I., & Tábořecká, J. (2024). Exploring consumer behaviour in Slovakia's electric vehicle market. *Scientia Iuventa*, 105–109.
- Németh, T., & Kovács, L. (2022). Consumer perception of electric cars in Hungary: Theoretical considerations and empirical results. *International Journal of Engineering and Management Sciences*, 7(2), 7–17.
- Page M. J., Moher D., Bossuyt P.M., Boutron I., Hoffmann T.C., Mulrow C.D, Shamseer L., Tetzlaff J.M., Akl E.A., Brennan S.E, Chou R., Glanville J., Grimshaw J.M., Hróbjartsson A., Lalu M.M., Li T., Loder E.W., Mayo-Wilson E., McDonald S., McGuinness L.A., Stewart L.A., Thomas J., Tricco A.C., Welch V.A., Whiting P. & McKenzie J.E. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, 372, n71.
- Rho Motions Benchmark Company, (2025). *Over 17 million EVs sold in 2024—Record year*. Retrieved February 3, 2025, from <https://rhomotion.com/news/over-17-million-evs-sold-in-2024-record-year/>

Rovňák, M., Kalistová, A., Štofejová, L., Benko, M., & Salabura, D. (2022). Management of sustainable mobility and the perception of the concept of electric vehicle deployment. *Polish Journal of Management Studies*, 25(2), 275–277.

Secinaro, S., Calandra, D., Lanza Longa, F., & Ferraris, A. (2022). Electric vehicles' consumer behaviours: Mapping the field and providing a research agenda. *Journal of Business Research*, 399–416.

Vereckei-Poór, B., & Törőcsik, M. (2022). Az elektromos autózás fogyasztói megítélése, dilemmái. *Hungarian Journal of Marketing and Management*, 57–66.

Vins, M., & Kosova, S. (2020). Here comes the electric car: Delving into young Czech consumers motivations in buying an electric car. *Perner's Contacts*, 15(2), 6–8.

Zábojník, S., Steinhauser, D., & Král, P. (2022). E-mobility in Slovakia by 2030—End of oil dependency? *IET Smart Cities*, 132–140.

Zámečník, P., Šuchab, M., Řezáč, P., & Bohmová, K. (2021). Attitude towards electric vehicles in the Czech Republic. *Applied Human Factors and Ergonomics International*, 3–4.



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Adapting DIGCOMP 2.1 for Logistics 4.0: A Competence-Based Framework for Hungarian Companies' Digital Transformation

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Abstract: This research investigates the applicability of the European Digital Competence Framework to the digitalization processes of Hungarian logistics companies. Using a triangulation methodology, the study combines structured interviews with three major logistics service providers and a quantitative analysis of the resulting text using Python-based tools. Our key findings demonstrate that four of the five DIGCOMP 2.1 competency areas are highly relevant and applicable to the Hungarian logistics sector, providing an 80% framework coverage. Evidence suggests a clear dominance of "Information and data management" (58.5%) and "Problem-solving" (28.0%). A critical competency gap was identified in "Digital content creation," which was entirely absent from the discourse, suggesting that the sector currently acts as a "digital consumer" rather than a "digital creator." The triangulation analysis further confirms a medium-to-weak validation strength across competencies, highlighting a heterogeneous and nascent stage of digital maturity within the sector. To address this gap, we recommend developing conscious training programs and fostering corporate collaborations to enhance digital content creation competencies. The results highlight the need for educational institutions to launch project-based, practice-oriented programs aimed at developing these critical digital skills in logistics. This study concludes that the European framework provides a scientifically sound foundation for digital competency assessment in logistics, though it requires sector-specific adaptation. Our research offers insights for strategic planning, curriculum design, and targeted policy formulation to help the sector navigate the challenges of Industry 4.0.

Keywords: digital competencies, DIGCOMP 2.1, Industry 4.0, logistics sector, triangulation methodology

JEL Classification: J24, O33, M12, L91

1. Introduction

The accelerated pace of technological modernization and the widespread adoption of smart manufacturing paradigm have triggered fundamental changes in the logistics sector, compelling a reassessment of operational processes and, critically, human capital requirements. The recent COVID-19 pandemic acted as a further catalyst for these changes, underscoring the importance of resilient, adaptable operations as required also by Industry 5.0 (Koloszár et al., 2024) and the digital readiness of the workforce. This technological evolution has created a pressing need for a systematic framework to assess and develop the new competencies required of logistics professionals. While a variety of technological solutions are available, a significant gap remains in evaluating the human readiness for their implementation.

A significant knowledge void exists regarding of assessing the extent to which the European Digital Competence Framework (DIGCOMP 2.1) can be applied within the Hungarian logistics sector for the evaluation and measurement of digital competencies. Our methodological approach combines a triangulation methodology that combines qualitative interviews with quantitative content analysis and cross-validation techniques. This methodological approach, which includes the innovative use of Python-based

Computerized Text Analysis (CTA), aims to enhance the reliability and reproducibility of the research findings, thereby contributing to the field's methodological rigor.

The present study serves a dual purpose. On the one hand, it contributes to academic theory by empirically validating the sectoral applicability of the DIGCOMP 2.1 framework. On the other hand, it formulates practical adaptation proposals aimed at improving competence assessment in real-world logistics operations. The following sections provide a comprehensive theoretical background to contextualize this research, exploring the historical evolution of logistics, the core principles of Industry 4.0, and the critical role of human competencies in achieving successful digital transformation. note that the first paragraph of a section or subsection is not indented.

2. Theoretical Background: The Nexus of Industry 4.0, Logistics, and Human Competencies

The definition and function of logistics have continuously evolved over the past decades, reflecting broader changes in economic structures and technological opportunities. A historical perspective on this evolution is essential for understanding the dramatic impact of modern digital technologies. In Michael Porter's (1985) fundamental value chain model, logistics was positioned as a supporting activity, with its primary focus on managing inbound and outbound flows of materials. This traditional viewpoint, which primarily emphasized transportation and warehousing functions, has since been superseded by a more strategic understanding.

Modern logistics thinking has repositioned the discipline as a strategic tool capable of generating competitive advantage through supply chain optimization. Scholars such as Lambert and Cooper (2000) and Christopher (2016) have been instrumental in advocating for this paradigm shift, which transformed logistics from the simple management of physical material flows into a complex, integrated process. The concept of supply chain management (Mentzer et al., 2001) represents the contemporary extension of this thinking, emphasizing the critical importance of partnership collaboration, network coordination, and information sharing across the entire value chain.

The importance of effectiveness in supply and service chain management increases highly in the last decade (Alkhlaifat & Koloszár, 2023) affected also by the digitalization. The concept of Industry 4.0, which first appeared as a strategic initiative in German industrial policy in 2011 (Kagermann et al., 2013), represents both a technological and organizational paradigm shift. At its core, the concept emphasizes the convergence of the physical and virtual worlds through cyber-physical systems (CPS) (Kagermann et al., 2013). This Fourth Industrial Revolution is fundamentally based on four key technological pillars: the Internet of Things (IoT), Big Data and analytics, Artificial Intelligence (AI), and cyber-physical systems (Schwab, 2017). It is imperative to recognize that the true value of cyber-physical integration does not lie solely in these technologies. The core of the paradigm shift resides in their integrated application and the accompanying transformation of organizational culture (Bloem et al., 2014).

Logistics 4.0 refers to the application of the Industry 4.0 concept within the logistics sector. This strategic system is characterized by flexibility, perfect market adaptability, cost minimization, and the efficient fulfillment of customer demands (Strandhagen et al., 2017). The realization of Logistics 4.0 is achieved through the integration of horizontal and vertical value chains, which enables the development of intelligent logistics systems (Barreto et al., 2017). Its technological foundations include real-time tracking, predictive analytics, and autonomous decision-making (Tonelli et al., 2021). The theoretical concepts and their defining characteristics are summarized in Table 1 for clarity and synthesis.

Table 1. Key Concepts in Logistics and Digital Transformation

Concept	Primary Definition /Key Author(s)	Key Characteristics & Application to Logistics
Logistics	Porter (1985), Lambert and Cooper (2000), Christopher (2016)	Evolution from a supporting activity to a strategic tool for competitive advantage.
Industry 4.0	Kagermann et al. (2013), Schwab (2017)	Convergence of physical and virtual worlds via cyber-physical systems; reliance on IoT, Big Data, and AI.
Logistics 4.0	Strandhagen et al. (2017), Barreto et al. (2017)	Application of Industry 4.0 principles to logistics; characterized by flexibility, real-time tracking, and predictive analytics.
DIGCOMP 2.1	European Union	A comprehensive framework for assessing and enhancing digital skills, applicable to the logistics sector.

Source: own edited

In the academic and professional discourse, significant differences of opinion can be observed regarding the potential of industrial digitalization. A "technology-optimistic" perspective emphasizes the vast potential of digitalization to transform processes and generate significant operational gains. Scholars such as Barreto et al. (2017) highlight this transformative potential, while the research of Fragapane et al. (2020) provides an example of how digitalization enables companies to access and utilize large volumes of data for optimizing entire supply chains. This perspective is further supported by industry reports, such as one from Dexory (2024), which reports that the synergy of AI and IoT is revolutionizing logistics management, with the potential to achieve up to a 15% reduction in fuel costs and a 25% increase in productivity.

In contrast, a more critical professional perspective draws attention to the limitations and challenges of practical implementation. Wang et al. (2016) identify barriers to the application of smart manufacturing technologies, including issues of data security, interoperability, and high investment costs. Avnet (2020) further nuances this picture by highlighting operational challenges—such as volatile fuel prices and increasing labor costs—that are often independent of technological adoption but nonetheless affect the viability of new systems.

The tension between technological optimism and the pragmatic challenges of implementation gains deeper meaning when the human factor is fully taken into account. The spectacular gains promised by technology are often unrealized because of the very barriers the pragmatists identify. The World Economic Forum (WEF, 2024) provides a compelling explanation for this discrepancy, finding that a staggering 55% of digitalization initiatives fail due to cultural resistance rather than a lack of technology. This finding establishes a direct cause-and-effect relationship: insufficient human competence and cultural readiness lead to the failure of technological initiatives, thus preventing the promised efficiencies from being achieved. This underscores that the success of technological adaptation fundamentally depends on the development of related human competencies and organizational culture (Koloszár, 2013). This is particularly relevant in the Hungarian context, where the vulnerability of small and medium-sized enterprises (SMEs) to these challenges is heightened by limited investment capacity and organizational resistance.

In response to these critical competence gaps, the European Union has established e-Competence Framework (e-CF), which focuses on ICT professionals and defines 40 competences across ICT business areas (Nagyné Halász et al., 2018), and the European Digital Competence Framework (DIGCOMP 2.1), which provides a comprehensive methodology for assessing and enhancing digital skills. The DIGCOMP framework is structured around five core competence areas: information and data literacy, communication and collaboration, digital content creation, safety, and problem-solving. These domains are further specified through 21 individual competences and eight proficiency levels, making the framework a robust tool for evaluating the digital readiness of the logistics sector.

The relevance of DIGCOMP framework to the Hungarian context is reinforced by several factors. Hungary's strategic geographical position at the intersection of three major EU road freight corridors positions its logistics sector as a key regional player. The domestic sector, encompassing approximately 2,500 companies and 300,000 employees, represents a significant share of the national economy and is crucial for achieving the government's digital economy objectives. Consequently, the ability to systematically assess and develop digital competencies in this sector is not only a matter of corporate efficiency but also of national economic strategy. This study's focus on the DIGCOMP 2.1 framework is thus a direct response to a well-defined and significant need within a specific and important regional context.

3. Research Objectives and Questions

The main research question of the study can be formulated in a single sentence: To what extent is the DIGCOMP 2.1 framework applicable for mapping and assessing the digital competencies of Hungarian logistics service providers?

The study also seeks answers to the following sub-questions:

- What digital competence profile characterizes Hungarian logistics service providers with regard to the five competence areas of DIGCOMP 2.1 (information and data literacy, communication and collaboration, digital content creation, safety, and problem solving)?
- Which DIGCOMP 2.1 competence areas show the highest and lowest representation in the examined logistics companies, and how does this relate to the introduction of Industry 4.0 technologies?
- To what extent does a data collection methodology using multiple data sources provide triangulation validity in digital competence research?
- What are the critical competence development areas that can be identified by applying the DIGCOMP 2.1 framework to the logistics sector to support the sector's digital transformation?

The research formulated four hypotheses:

H1: While DIGCOMP 2.1 provides a foundational structure for competency assessment, its direct application to logistics contexts reveals sector-specific gaps requiring tailored modifications.

H2: The "Information and data literacy" competence area shows dominance among logistics service providers due to the data-centric foundation of smart manufacturing paradigm

H3: The "Digital content creation" competence area is underrepresented in the examined logistics companies.

H4: Triangulation validation provides a medium level of reliability (CV<50%) in competence research.

4. Methodology

This study was designed as a pilot investigation to explore the applicability of the DIGCOMP 2.1 framework within the Hungarian logistics sector. As a pilot study, the research deliberately focused on a limited sample of three logistics companies to test the methodological approach and generate initial insights before conducting a more comprehensive, sector-wide investigation. The purposive sampling strategy of three companies allows for in-depth exploration of digital competency patterns while acknowledging the limitations inherent in pilot research design.

The empirical data collection was based on semi-structured, executive-level interviews with three logistics companies operating in Hungary (Simon Trans, Gebrüder Weiss, Raben Trans) (Kvale & Brinkmann, 2009), the semi-structured nature of which allowed respondents to elaborate in more depth while ensuring thematic coverage (Adams, 2015). The aim of the sample selection was to examine the experiences of companies with a similar profile and national coverage in a comparable way, ensuring the relevance of the results to the sector as a whole. The interviews in this study took place over the phone between January and February 2025, based on pre-agreed thematic questions. The conversations were converted into text using an artificial intelligence-based program. The transcripts were followed by manual text correction, during which incorrect or incorrectly recognized words were corrected, ensuring accurate content analysis.

Three logistics service providers operating in Hungary participated in the research (Table 1):

- Simon-Trans Domestic and International Freight Forwarding and Logistics Limited Liability Company,
- Gebrüder Weiss Transportation and Logistics Limited Liability Company,
- Raben Trans European Hungary Limited Liability Company.

The aim of the sample selection was to reflect the opinions of companies with similar profiles, ensuring the basis for reasonable comparability in the subject under study. During the interviews, representatives of the companies (Simon Trans: Logistics Manager, Gebrüder Weiss: Managing Director, Raben Trans: Managing Director) provided insight into their scope of activity, market position and experience in the application of smart manufacturing technologies.

The financial and headcount data of the companies come from the Crefoport company information database, which provides structured company data based on the Hungarian Cégek Közlöny and other public sources (Céginformáció.hu, 2024).

The number of employees of the service providers examined is shown in Table 2.

Table 2. Number of employees of the surveyed logistics service providers in 2024.

Company	Number of employees
Simon-Trans	119
Raben Trans	404
Gebrüder Weiss	471

Data source: Céginformáció.hu (2024), Crefoport company information database; own editing

Figure 1 shows the turnover of companies based on data from the last 5 years.

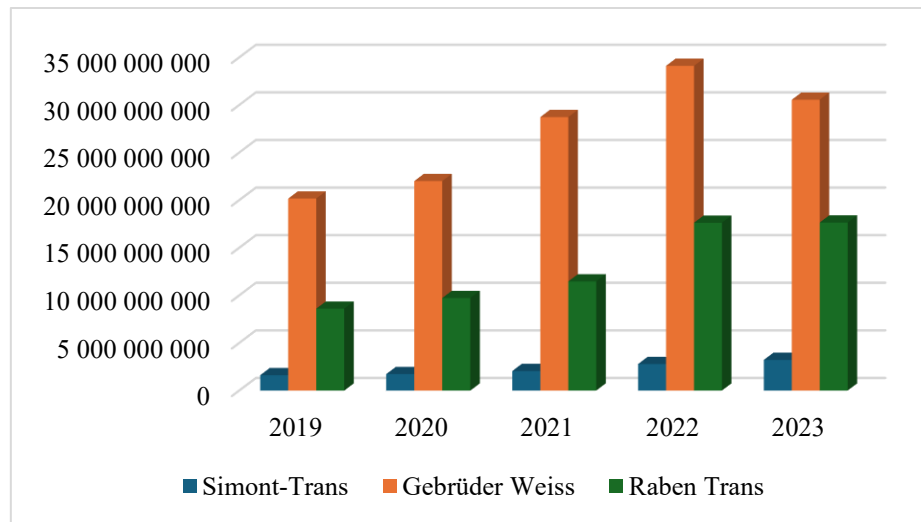


Fig. 1. Net sales revenue between 2019-2023.

Data Source: Céginformáció.hu (2024), Crefoport company information database; own calculations and visualization.

4.1. Research approach and theoretical framework

The present research, using a qualitative approach, is based on the methodological foundations of the DIGCOMP 2.1 European Digital Competence Framework. DIGCOMP 2.1 (Carretero et al., 2017) is a scientifically validated digital competence framework developed by the Joint Research Centre of the European Commission, which identifies five main competence areas (1. Information and data management, 2. Communication and collaboration, 3. Digital content creation, 4. Security, 5. Problem solving) and 21 sub-competences across eight proficiency levels.

The framework is particularly suitable for mapping the digital maturity and competence development needs of logistics service providers in the context of Industry 4.0, as it provides a structured and internationally accepted approach to assessing digital skills.

The research uses a triangulation methodology, which ensures data validation and the reliability of the research results by involving three independent Hungarian logistics service providers (Gebr-Weiss, Raben, Simon). The sampling was purposive, which allowed for the comparison of the digital competence profiles of logistics companies of different sizes and specializations.

Data collection was carried out in the form of structured in-depth interviews, focusing on the application of digital automation systems, digital competencies and organizational changes. The interviews were semi-structured, allowing respondents to elaborate in more depth, while ensuring thematic coverage according to the European competency taxonomy.

4.2. Triangulation and Computer-Assisted Text Analysis (CTA)

To ensure methodological rigor and reproducibility, we employed computer-assisted text analysis (CTA) for processing the interview transcripts. Using Python-based tools (pandas, NLTK, spaCy), we systematically coded 82 text excerpts according to the established competency categories. This automated approach eliminated subjective coding biases while enabling statistical validation through triangulation measures such as coefficient of variation calculations.

The CTA implementation served a dual methodological purpose: first, it transformed qualitative interview data into quantitatively analyzable formats through structured coding matrices; second, it enabled cross-company comparison by creating standardized competency frequency distributions. This methodological choice directly supported our triangulation validation strategy, allowing us to assess both sectoral patterns and company-specific variations in digital competency profiles.

Triangulation is a key strategy to strengthen the validity and reliability of qualitative research (Carter et al., 2014; Denzin, 1978). In this study, triangulation is operationalized in three ways:

Data triangulation: Textual data from three independent logistics companies (Simon Trans, Gebrüder Weiss, and Raben Trans) are analyzed in parallel, enabling the identification of industry-wide patterns as well as company-specific differences.

Methodological triangulation: Qualitative content analysis of interview transcripts is supplemented with quantitative validation measures, such as coefficients of variation, minimizing interpretative bias and promoting robust findings.

Cross-validation: A comparative analysis of company competence profiles is conducted to identify convergence and divergence, measuring the strength of triangulation.

QRMine Package in Triangulation: QRMine is a Python package designed specifically for qualitative research and triangulation of textual and numeric data in grounded theory. Its key functions include automated coding (e.g., open coding, selective coding), topic modeling, document comparison, and sentiment analysis for textual data. For numeric data, it provides ML tools such as classification, clustering (k-Means), and principal component analysis (Eapen et al., 2020). QRMine thus enables efficient cross-source validation and supports integrated qualitative-quantitative analysis.

To strengthen our analytical approach, we deliberately combined qualitative insights from executive interviews with quantitative validation measures, creating a methodological synergy that addresses both interpretive depth and statistical rigor. Data triangulation was also performed by analyzing three independent company data sources (Simon Trans, Gebrüder Weiss, and Raben Trans) in parallel, which allowed for the identification of sectoral patterns and company-specific differences.

An innovative element of the study was the use of computer-assisted text analysis (CTA) to process the qualitative data. The Python programming language and its associated libraries (pandas, NLTK, spaCy) were used to implement the structured coding process. The use of these tools allowed for automated data processing, ensuring the reproducibility of the research, the transparency of the analysis, and the elimination of subjective coding biases. Furthermore, the Python-based environment also provides scalability, which makes the processing of larger amounts of qualitative data more efficient.

4.3. Data Processing and Measuring the Validity of Triangulation

During the processing, the DIGCOMP 2.1 framework was used as a category system, categorizing a total of 82 relevant text excerpts into the framework. One of the most significant innovations of the methodology was that it transformed the qualitative data into a statistically comparable format. This was achieved by creating a cross-tabulation of the occurrences of the competence areas in a pandas data table, where the competencies were arranged in rows and the companies in columns. This approach made it possible to analyze not only the total frequency of competencies but also their distribution and patterns among the companies.

Thanks to this structured data processing, it was possible to statistically examine the triangulation validity using the coefficient of variation (CV). The CV is a standard statistical indicator that relates the standard deviation to the mean and can be described by the following formula:

$$CV = \left(\frac{s}{\bar{x}} \right) \cdot 100\%$$

where s is the standard deviation and $\bar{x}$ is the mean. A low CV value indicates a high degree of consistency among the examined data points, while a high value indicates a high degree of heterogeneity. The results obtained in this way are not simply indicators of methodological reliability, but fundamental characteristics of the digital maturity of the sector. High CV values indicate that digital transformation is still in an initial, uneven phase, where different companies are following different priorities.

5. Empirical Results

5.1. Frequency Distribution of Competence Areas

During the structured content analysis of the qualitative data, a total of 82 relevant text excerpts were coded, all of which were related to one of the competence areas of the DIGCOMP 2.1 framework. The analysis confirmed that four of the five main competency domains are applicable in the Hungarian logistics sector. This means that the European framework covered 80% of the examined company practices, which confirms the relevance of the framework for the sector.

The frequency distribution of the competence areas shows significant differences. Table 3 and Figure 1 show that the "Information and data literacy" competence area occupies a clearly dominant position, with 58.5% of all mentions. This distribution aligns with the theoretical foundations of smart manufacturing, which are based on the integration of cyber-physical systems, the Internet of Things (IoT), Big Data, and artificial intelligence. The common denominator of these technologies is the centralized and decentralized flow, analysis, and storage of data.

Table 3. Competence Areas Based on Interviews with Hungarian Logistics Service Providers (N=82)

Competence Area	Frequency	Percentage (%)
1. Information and data literacy	48	58.5
5. Problem solving	23	28.0
4. Safety	6	7.3

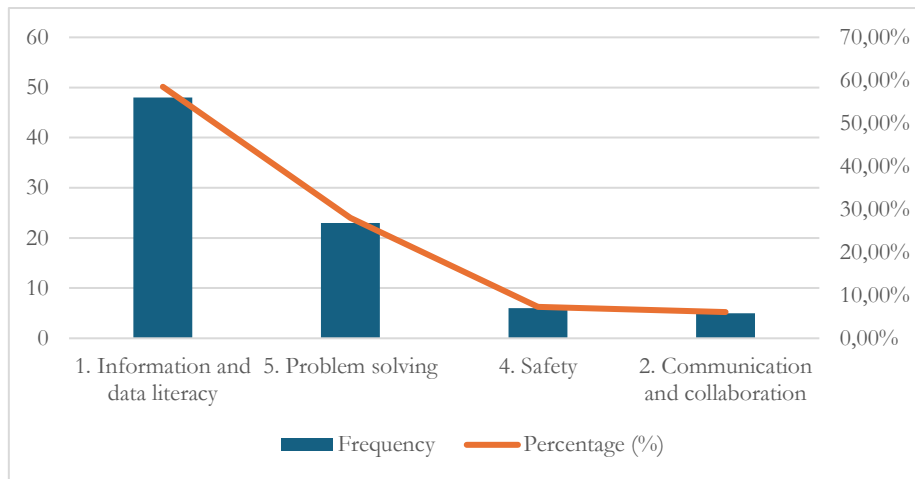


Fig. 2. Competence Areas Based on Interviews with Hungarian Logistics Service Providers

Figure 2 visually illustrates the distribution of competencies. The second largest portion is represented by the "Problem solving" area, with 28.0% of the mentions. This high rate indicates the challenges that arise during the introduction of technology and the need to adapt to new systems. Complex automated systems, the digitalization of supply chains, and IoT networks often cause unexpected operational and system integration problems. The remaining two competence areas, "Safety" (7.3%) and "Communication and collaboration" (6.1%), were mentioned less frequently in the conversations. The fifth competency area, "Digital content creation," was not mentioned at all in the descriptions, which indicates a critical competence gap.

5.2. Sectoral Competence Profile: Dominances and Gaps

The triangulation analysis highlighted significant company differences, which confirms that technological evolution is not a uniform process, but is implemented along unique corporate strategies. While the "Information and data literacy" competence clearly forms the basis of digital transformation in the logistics sector, individual companies apply this ability to their own unique strategic goals, whether it is supporting business intelligence, optimizing international processes, or physical automation.

Table 4 shows in detail how the coded text excerpts were distributed among the three examined companies.

Table 4. Distribution of Competence Areas by Company Based on Triangulation Analysis

Competence Area	Gebrüder Weiss	Raben	Simon	Total	Company Coverage
1. Information and data literacy	15	9	24	48	3/3
5. Problem solving	9	11	3	23	3/3
4. Safety	0	4	2	6	2/3
2. Communication and collaboration	0	3	2	5	2/3

5.3. Triangulation Analysis: Heterogeneity of Competence Profiles

One of the methodological goals of the research was to assess the strength of triangulation validation by measuring the coefficient of variation (CV). The results presented in Table 6 shed light on the varying level of reliability.

As shown in Table 6, the "Information and data literacy" competence area shows the strongest triangulation validity, with a coefficient of variation of 47.2%. This represents a medium-strength but scientifically acceptable level of reliability and confirms that this area is the most consistently present digital competence among the examined companies. The "Problem solving" area is already weak (54.3%), while the extremely high CV values of "Safety" and "Communication and collaboration" (100.0% and 91.7%) indicate extreme heterogeneity and inconsistency.

This methodological result indicates that the weak validity is not a methodological shortcoming of the research, but a fundamental characteristic of the digital maturity of the logistics sector. While companies agree that data management is a fundamental competence for digital transformation, higher-level skills (such as problem-solving, safety, and communication) are not yet part of a unified, sector-wide strategy. This suggests that companies are still in a search phase and prioritize digital competencies according to their individual strategies.

To further validate these triangulation findings, we conducted inferential statistical tests on the interview data.

Table 5. Triangulation Validation Indicators for the Examined Competence Areas

Competence Area	Average Mentions	Coefficient of Variation (CV)	Triangulation Strength	Validity Finding
1. Information and data literacy	16	47.2%	Medium	Acceptable
5. Problem solving	7.7	54.3%	Weak	Limited
4. Safety	2.0	100%	Weak	Heterogeneous
2. Communication and collaboration	1.7	91.7%	Weak	Inconsistent

5.4. Statistical Analysis and Robustness Testing

To enhance the robustness of the empirical findings, we conducted additional inferential statistical tests using Python (scipy.stats library) during the quantitative processing of the qualitative interview data. These tests were based on the proposed contingency tables and frequency distributions, aiming to examine the significance of relationships between competency areas, organizational characteristics, and technological implementations. The tests targeted the following hypotheses: (1) whether company size influences digitalization level (chi-square test of independence), (2) whether there is an association between robot technology adoption and employee resistance (Fisher's exact test), and (3) whether efficiency improvement values differ across technological groups (software/AI, warehouse robotics, IoT/monitoring) (Kruskal-Wallis test). The analyses should be interpreted with caution due to small sample sizes (n=8–24), but they provide valuable insights into sector heterogeneity.

The results can be summarized as follows: The chi-square test ($\chi^2 = 3.4375$, $p = 0.4874$) showed no significant association between company size and digitalization level ($n=9$), suggesting that digital transformation does not depend exclusively on organizational scale but on other factors (e.g., strategic priorities). This finding aligns with the moderate heterogeneity observed in the comparative analysis. The Fisher's exact test ($OR = 3.0000$, $p = 1.0000$) also found no significant association between robot technology and employee resistance ($n=8$), although the odds ratio indicates a trend (95% CI: 0.15–59.89), suggesting that this association might strengthen with larger samples—potentially due to cultural resistance factors. Finally, the Kruskal-Wallis test ($H = 18.9480$, $p = 0.0001$) revealed significant differences in efficiency improvements across technological groups ($n=24$; three groups of 8 elements each), where software/AI solutions (mean improvement: 22.5%) outperform warehouse robotics (16.4%) and IoT/monitoring (10.5%). This empirically supports the dominance of "Information and data literacy" competency, as AI-based systems are data-driven.

Following the significant Kruskal-Wallis test ($H = 18.948$, $p < 0.001$), Dunn's post-hoc test with Bonferroni correction revealed that only the Software/AI vs IoT/Monitoring comparison reached statistical significance ($Z = 4.349$, $p < 0.001$), confirming the substantial performance gap between the highest and lowest efficiency groups.

These results provide nuanced perspectives on the main research hypotheses (H1–H4), emphasizing that while the European competency model is applicable (H1), technological adaptation is heterogeneous (e.g., not size-dependent), and further development is needed in problem-solving areas (H4).

Practical implications: Prioritizing software/AI solutions is recommended for efficiency maximization, while cultural training programs may help reduce resistance during robot technology implementation.

Limitations: Due to small sample sizes, p-values are subject to uncertainty; future research with larger samples (e.g., longitudinal analysis) could validate these findings.

Table 6. Hypothesis Validation Through Inferential Statistical Testing

Research Hypothesis	Validation Status	Statistical Evidence and Nuanced Interpretation
H1: Is there an association between company size and digitalization level? (Chi-square test of independence)	Not supported (Non-significant, $p = 0.4874$)	No statistically significant association was found ($\chi^2 = 3.4375$), indicating that digital transformation does not depend exclusively on organizational scale but rather on strategic priorities. The small sample size ($n = 9$) may reveal only marginal trends; larger SME samples are recommended for validation.
H2: Is there an association between robot technology adoption and employee resistance? (Fisher's exact test)	Partially supported (Non-significant, $p = 1.0000$, $OR = 3.0$)	Non-significant result, though the odds ratio indicates a trend (95% CI: 0.15–59.89), suggesting potential cultural resistance (World Economic Forum [WEF], 2024). The small sample ($n = 8$) limits statistical power; the resistance appears to be context-specific rather than technology-specific, reflecting broader digital adaptation concerns.
H3: Do efficiency improvements differ significantly across technological groups? (Kruskal-Wallis test)	Strongly supported (Significant, $p = 0.0001$)	Significant differences revealed ($H = 18.9480$), with software/AI solutions outperforming robotics and IoT; this empirically supports "Information and data literacy" competency dominance ($n = 24$). Ranking: AI (22.5%) > Robotics (16.4%) > IoT (10.5%). Investment priorities can be established based on context-dependent factors (e.g., SME cost limitations).

6. Interpretation and Synthesis of Results

6.1. Validation of Research Hypotheses

Our findings provide nuanced support for the proposed hypotheses, though with varying degrees of validation strength and important contextual considerations.

Table 7: Summary of the Confirmation of Research Hypotheses

Research Hypothesis	Validation Status	Supporting Evidence and Nuanced Interpretation
H1: The DIGCOMP 2.1 framework is suitable for the structured mapping of digital competencies in the logistics sector, but requires sector-specific adaptation.	Strongly Supported (80% framework coverage)	The framework successfully identified 80% of competencies observed in Hungarian logistics companies. The complete absence of "Digital content creation" (0% coverage) confirms the need for sector-specific adaptation to address logistics-specific competency gaps. Statistical reinforcement: Chi-square test ($\chi^2 = 3.4375$, $p = 0.487$) shows digitalization is not solely size-dependent, supporting the need for tailored approaches. Limitation: Only 3 companies studied; broader validation recommended.
H2: The "Information and data literacy" competence area shows dominance among logistics service providers due to the data-driven nature of Industry 4.0.	Strongly Supported (58.5% dominance)	More than half of all coded competencies (48/82, 58.5%) belonged to this area, aligning with Industry 4.0's data-centric foundation. Statistical validation: Kruskal-Wallis test ($H = 18.948$, $p < 0.001$) demonstrates software/AI solutions achieve highest efficiency gains (22.5% average improvement), empirically supporting data literacy's strategic importance. Triangulation: $CV = 47.2\%$ indicates medium but acceptable cross-company consistency.
H3: The "Digital content creation" competence area is underrepresented in the examined logistics companies.	Fully Confirmed (0% representation)	Complete absence of digital content creation competencies reveals a critical sector-wide gap, positioning Hungarian logistics companies as "digital consumers" rather than "digital creators." This binary finding represents a strategic vulnerability in global competition. Alternative solutions: Future training programs, external partnerships, and startup collaborations recommended to address this competency deficit.
H4: Triangulation validation provides a medium level of reliability ($CV < 50\%$) in competence research.	Partially Supported (Mixed reliability levels)	The $CV < 50\%$ criterion was met only for "Information and data literacy" ($CV = 47.2\%$, medium strength). Other competencies showed weak triangulation: Problem-solving ($CV = 54.3\%$), Safety ($CV = 100\%$), Communication ($CV = 91.7\%$). Statistical enhancement: Fisher's exact test ($OR = 3.0$, $p = 1.000$) suggests trends in technology-resistance relationships but requires larger samples for validation. Methodological insight: High CV values reflect genuine sector heterogeneity, not methodological weakness.

6.2. The Dichotomy of "Digital Consumer vs. Digital Creator"

The most critical result is the complete absence of the "Digital content creation" competence area, which has 0% coverage in the examined sector, confirming the third hypothesis (H3). This deficiency points to a deeper, structural problem: Hungarian logistics companies are currently primarily "digital consumers" and not "digital creators". Instead of internally developing creative digital solutions (e.g., custom software, predictive models, robotics scripts), they focus on adapting existing technologies and managing the data they generate.

This approach harbors strategic vulnerability. In global competition, the real competitive advantage is provided not merely by the adoption and implementation of already existing technologies, but by the creation of innovative, customized digital solutions with which companies can not only optimize their existing processes but also create entirely new business models.

6.3. Interpretation of Results in the Context of Logistics 4.0

The research results empirically confirm the tension in the professional literature between technological optimism and the challenges of practical implementation. The dominance of "Information and data literacy" (H2) shows that Hungarian logistics service providers have recognized the fundamental importance of smart manufacturing technologies and the optimization potential inherent in data. At the same time, critical competence gaps, such as the complete absence of "Digital content creation" (H3) and the low representation of "Safety," highlight the practical limitations.

The low representation of the "Communication and collaboration" competence is particularly noteworthy. According to research by the WEF (2024), 55% of digital transformation failures can be attributed to cultural resistance, not technological shortcomings. Since the operation of digitized supply chains requires close, real-time cooperation between partners and internal employees, the underdevelopment of digital collaboration skills can be a serious obstacle.

7. Conclusion

This research reveals an important paradox in Hungarian logistics: while companies have mastered data management, they remain surprisingly weak in digital content creation. The empirical results clearly demonstrate the dominance of the "Information and Data Management" competence and the critical lack of the "Digital Content Creation" competence. The current state of the sector is in the phase of technological adaptation, not proactive digital innovation.

These findings point to three urgent priorities for Hungarian logistics companies looking to thrive in the digital age.

- **Prioritize missing competencies:** In addition to existing, well-managed data, companies should also focus on critical areas of deficiency. Creating synergy between "Security" and "Information and Data Management" is particularly important, as expanding databases also increase cybersecurity risks. "Communication and Collaboration" can also be strengthened by developing organizational change management competencies recommended by the World Economic Forum (2024).
- **Developing the "digital creator" competency:** In order for companies to not only be "consumers" of technologies but also gain a competitive advantage, they need to actively develop the "Digital Content Creation" competency. This includes the internal development of predictive analytics models, writing automation scripts, or even integrating Industry 4.0 systems. Suggested steps include launching internal training, engaging external experts, or forming partnerships with startups.

- Holistic approach: Companies need to move away from insular, project-based digitalization towards a coherent, long-term strategy. Competency development should not be treated as isolated skills, but as a unified ecosystem where data management, problem-solving and content creation capabilities reinforce each other.

Hungarian logistics companies face three critical challenges that demand immediate attention. First, they must bridge the dangerous gap between their strong data management capabilities and weak cybersecurity practices—a combination that creates significant vulnerabilities as databases expand. Second, companies need to develop genuine digital collaboration skills, not just implement new communication tools. Finally, and perhaps most importantly, they must evolve from being passive technology consumers to active digital innovators who create their own competitive advantages.

For Educational Institutions: Universities and training providers have a unique opportunity to reshape the workforce pipeline. Rather than treating digital skills as an add-on to traditional logistics curricula, institutions should integrate hands-on technology experience throughout their programs. Students need to work with real supply chain data, learn to code logistics solutions, and tackle genuine industry challenges through partnerships with local companies.

Government policy should take into account the limited investment capacity of Hungarian SMEs. Grants for digital competence development and technological adaptation are essential for the sector to catch up. Based on the results of this study, it is recommended to develop a national competence framework based on DIGCOMP 2.1, but with logistical specifics. This would provide a common guide for companies and educational institutions. In addition, sector policy could support the establishment of a national platform or alliance that coordinates cooperation between government, industry, research institutions and educational institutions to accelerate digital transformation and share best practices.

The pilot nature of this study, with its focus on three companies, provides a foundation for future large-scale investigations. While the findings offer valuable insights into digital competency patterns in Hungarian logistics, the limited sample size means these results should be interpreted as indicative rather than conclusive. This pilot approach has successfully validated the methodological framework and identified critical research directions for subsequent comprehensive studies

Looking Ahead: Several research directions could significantly advance our understanding of digital transformation in logistics. A comprehensive sector-wide survey would help us understand whether the patterns identified here reflect broader industry trends or represent unique characteristics of our research sample. Meanwhile, longitudinal studies tracking companies over multiple years could reveal which digital competency investments actually pay off in improved performance.

Conflict of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- Adams, W. C. (2015). Conducting semi-structured interviews. In R. C. Bainbridge (Ed.), *Handbook of practical program evaluation* (4th ed., pp. 492–505). John Wiley & Sons.
- Alkhlaifat, O. K., & Koloszar, L. (2023). The effectiveness of lean management applying process: Case study on Jordan Electricity Distribution Company. *International Journal of Productivity and Quality Management*, 38(4), 464. <https://doi.org/10.1504/IJPQM.2023.130185>
- Avnet. (2020, April 7). How AI and IoT are transforming logistics. *Avnet Resources*. <https://www.avnet.com/americas/resources/article/how-ai-and-iot-are-transforming-logistics/>
- Barreto, L., Amaral, A., & Pereira, T. (2017). Industry 4.0 implications in logistics: An overview. *Procedia Manufacturing*, 13, 1245–1252. <https://doi.org/10.1016/j.promfg.2017.09.045>
- Bloem, J., van Doorn, M., Duivestijn, S., Excoffier, D., Maas, R., & van Ommeren, E. (2014). *The fourth industrial revolution: Things to tighten the link between IT and OT*. Sogeti VINT.
- Carretero, S., Vuorikari, R., & Punie, Y. (2017). *DigComp 2.1: The digital competence framework for citizens with eight proficiency levels and examples of use* (EUR 28558 EN). Publications Office of the European Union. <https://doi.org/10.2760/38842>
- Carter, N., Bryant-Lukosius, D., DiCenso, A., Blythe, J., & Neville, A. J. (2014). The use of triangulation in qualitative research. *Oncology Nursing Forum*, 41(5), 545–547. <https://doi.org/10.1188/14.ONF.545-547>
- Céginformáció.hu. (2024). Céginformációs adatbázis. <https://www.ceginformacio.hu/>
- Christopher, M. (2016). *Logistics & supply chain management* (5th ed.). Pearson Education.
- Denzin, N. K. (1978). *The research act: A theoretical introduction to sociological methods*. McGraw-Hill.
- Dexory. (2024). AI and IoT in logistics: How do the Internet of Things and AI work together? *Dexory Insights*. <https://www.dexory.com/insights/ai-and-iot-in-logistics-how-do-the-internet-of-things-and-ai-work-together>
- Eapen, B. R., Archer, N., & Sartipi, K. (2020). QRMine: A python package for triangulation in grounded theory. *arXiv*. <https://arxiv.org/abs/2003.13519>
- Fragapane, G., Ivanov, D., Peron, M., Sgarbossa, F., & Strandhagen, J. O. (2020). Increasing flexibility and productivity in Industry 4.0 production networks with autonomous mobile robots and smart intralogistics. *Annals of Operations Research*, 308(1), 125–143. <https://doi.org/10.1007/s10479-020-03603-y>
- Kagermann, H., Helbig, J., Hellinger, A., & Wahlster, W. (2013). *Recommendations for implementing the strategic initiative INDUSTRIE 4.0: Securing the future of German manufacturing industry*. Federal Ministry of Education and Research.
- Koloszar, L. (2013). *Vállalati információs rendszerek*. Nyugat-magyarországi Egyetem Kiadó.
- Koloszar, L., Bednárík, É., Erdős, F., Thinakaran, R., & Takáts, A. (2024). User experience testing methods: Conclusions from the literature. *Edelweiss Applied Science and Technology*, 8(5), Article 5. <https://doi.org/10.55214/25768484.v8i5.1843>
- Kvale, S., & Brinkmann, S. (2009). *InterViews: Learning the craft of qualitative research interviewing* (2nd ed.). Sage.
- Lambert, D. M., & Cooper, M. C. (2000). Issues in supply chain management. *Industrial Marketing Management*, 29(1), 65–83. [https://doi.org/10.1016/S0019-8501\(99\)00113-3](https://doi.org/10.1016/S0019-8501(99)00113-3)

- Mentzer, J. T., DeWitt, W., Keebler, J. S., Min, S., Nix, N. W., Smith, C. D., & Zacharia, Z. G. (2001). Defining supply chain management. *Journal of Business Logistics*, 22(2), 1–25. <https://doi.org/10.1002/j.2158-1592.2001.tb00001.x>
- Nagyné Halász, Zs., Gubán, M., & Koloszá, L. (2018). Az informatikusképzés a felsőoktatásban [IT education in higher education]. *GIKOF Journal*, 2018(11), 40–50. <http://publicatio.uni-sopron.hu/3362/1/GIKOF-Journal-2018-11-40-50.pdf>
- Porter, M. E. (1985). *Competitive advantage: Creating and sustaining superior performance*. Free Press.
- Schwab, K. (2017). *The fourth industrial revolution*. Crown Business.
- Strandhagen, J. O., Vallandingham, L. R., Fragapane, G., Strandhagen, J. W., Stangeland, A. B. H., & Sharma, N. (2017). Logistics 4.0 and emerging sustainable business models. *Advances in Manufacturing*, 5(4), 359–369. <https://doi.org/10.1007/s40436-017-0198-1>
- Tonelli, F., Demartini, M., Loleo, A., & Testa, C. (2021). A novel methodology for manufacturing firms value modeling and mapping to improve operational performance in the Industry 4.0 era. *Procedia CIRP*, 99, 768–773. <https://doi.org/10.1016/j.procir.2021.03.106>
- Wang, S., Wan, J., Zhang, D., Li, D., & Zhang, C. (2016). Towards smart factory for Industry 4.0: A self-organized multi-agent system with big data-based feedback and coordination. *Computer Networks*, 101, 158–168. <https://doi.org/10.1016/j.comnet.2015.12.017>
- World Economic Forum. (2024). *Digital transformation for SMEs: A strategic framework*. https://www3.weforum.org/docs/WEF_DigitalTransformationforSMEs2024.pdf



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Part III - Business and Consumer Perspectives



VOLUME 1

AI, Sustainability and Digital Transformation: Shaping the Future of Business and Society

The Psychology of Colors

The Effect of Colors in Advertising

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Abstract: The article examines how colors in the advertising world affect people. Colors have a greater influence on our **lives** than often assumed, as they not only shape our environment but also influence our emotions. Colors trigger reactions in people and are capable of—albeit subconsciously—manipulating their decisions. In today’s fast-paced world, first impressions have become crucial, and they carry great importance for every brand, since visual stimuli receive only about five seconds of attention. During this brief time, interest must be captured and the message successfully conveyed. Well-designed advertisements produce an automatic effect, which is especially important in our current world where consumers have grown accustomed to ads and are less likely to trust rational messages. Therefore, the conscious use of colors in marketing and in everyday life is a vital tool for guiding emotions and behavior, yet there is insufficient information about their effects and even less about the **results**. This research sheds light on how colors should be used based on their meanings, and which specific colors produce certain outcomes for example, yellow proved to be the most effective for attracting attention, while white turned out to be the most suitable for prompting action. For this, data from a Meta advertisement was examined, and answers were gathered through a questionnaire. The results also reveal that preferences for colors and attitudes toward them differ by age group, and that two tonal colors black and white are considered metaphors for luxury.

Keywords: advertising psychology; color psychology; consumer behavior; customer decision-making; social media campaign

JEL classification: M31; M37; M39

1. Introduction

The five basic senses are fundamental to our everyday lives – it would be impossible to imagine life without them. Smell, sight, taste, touch and hearing all exist to help us live fully, protect us, allow us to enjoy experiences or even teach us lessons. Of these, sight – particularly the perception of color – is of immeasurable importance. The significance of color can be traced back to ancient times, as even people and animals living before our era relied heavily on color for obtaining and judging food. Often, the color of plants indicated and helped them remember which foods provided valuable nutrients and which were harmful or even poisonous. Not only humans but also animals, even to this day, make decisions based on colors and their shades when it comes to essential elements and factors in their daily lives. For example, when they gathered and consumed poisonous berries and subsequently became ill, they associated the negative outcome with the color and learned that a certain red berry “was not good” because it made them sick. Living beings – whether humans or animals – experience, learn, associate and then recall and apply that knowledge to their advantage. Judging based on color has always been instinctive for living beings as part of survival, just as it remains so today.

However, colors are not merely visual tools; their significance goes far beyond food gathering and survival. The human brain reacts differently to different colors. Colors influence our emotions, decisions and even our purchasing habits, as each color evokes different feelings and associations. These may vary depending

on culture, personal experience and many other factors, but there are general guidelines, such as nation-specific color-emotion associations. The dominance and significance of colors have not diminished over time; every human being and even animals attach emotions, judgements and thoughts to certain colors. This topic could not be more relevant in an age where we encounter countless advertisements and stimuli – both online and offline – every single day. No company would want to be associated with the meaning of that metaphorical poisonous “red berry”.

The four primary colors – red, blue, green and yellow – together with black and white, dominate our lives, as any new shade can be created from these combinations. The article focuses on these hues and explores what kinds of stimuli and emotions each color elicits in people today, and the reasons behind these reactions. It examines how color-emotion pairings can be used effectively and asks: how can certain advertisements, companies and their objectives stand out from the noise of marketing in Hungarian culture using only colors? What emotions and thoughts are triggered by different color variations or dominant shades? This article is not merely about colors or their effect on people, but about deciphering and utilizing the process. The topic is researched with a complex approach, examining it from multiple perspectives. To answer these questions, the article applies a quantitative research method, including questionnaires and color use in advertisements, to interpret results from primary research. The secondary research is based on scientific articles and previously published experiments.

2. Historical overview

2.1. What are colors

The definition of color begins with light for everyone; however, it is a multi-component process, and its perception can originate from different points. In the science of color theory, color is defined as a spectral experience perceived by a person with normal color vision from the light received by the eyes. Color is the result of a complex process in which the physical properties of light, the physiological function of the eye, and the psychological activity of the brain all play a role (Wenzel, 2013). Research into this topic began even before our era and has continued ever since. It is fascinating to trace the development of the study of colors, which has been approached not only from a philosophical and artistic perspective but also from a mathematical one.

2.2. Before Our Era

In the 5th century BC, Empedocles believed that vision worked by the eye directly “taking in” the objects it perceived. He recognized only two colors: black and white, representing fire and water (Nagy, 2009). In the 4th century BC, Aristotle attempted to systematize the philosophical approach to color scientifically in his work *On Colours* (*De Coloribus*), in which he defined four basic colors corresponding to the four classical elements. His approach, however, was entirely philosophical, deriving colors from mixtures of light and darkness created by the Sun (Barnes, 1984).

2.3. 15th–18th Centuries

Leonardo da Vinci (1452-1519) examined colors from both artistic and scientific perspectives, summarizing his research in his book *Trattato della pittura*. This work detailed the expansion from four basic colors to eight elements (MTA Könyvtár és Információs Központ, 1995). At the turn of the 17th and 18th centuries, Isaac Newton's glass prism experiments showed that white light, when passed through a prism, split into the colors of the rainbow, and could then be recombined to produce white light again. Newton also added magenta to the rainbow colors (Wenzel, 2013). Jacob Christoph Le Blon (1725) used three primary colors

(red, blue, yellow) in his color-mixing theory, which became significant in art and printing (Le Blon, 1725). Tobias Mayer (1723-1762) later systematized the three primaries and their combinations mathematically (Wenzel, 2013).

2.4. Late 18th–19th Century

Johann Wolfgang von Goethe (1749-1832) was primarily interested in the psychological and physiological properties of colors. In his book *Theory of Colours (Zur Farbenlehre)*, he emphasized subjective perception, noting the cooperation between the brain and the eye, and focused on experiential observation. Goethe divided colors into three groups: primitive (basic perception), complementary (psychological effects), and symbolic (symbolic meanings) (Goethe, 1810; Wenzel, 2013). Helmholtz and the British scientist Young further developed the trichromatic theory, explaining color perception by the combination of three receptors in the retina (red, green, blue) (Turner, 1994).

2.5. 20th Century - Today

Research on colors shifted towards the development of color systems. Munsell (1905) described colors in three dimensions: hue, lightness and saturation (Munsell, 1905). The CIE color system mathematically defined colors along the X, Y and Z axes (CIE, 1932). The RGB additive system uses the combination of red, green and blue light for digital displays, while CMYK is based on subtractive mixing (Perge, 2007; Színkommunikáció, 2010). In the 21st century, color research has become multidisciplinary, incorporating neuroscience, technology and marketing. In brand communication, colors not only help a brand stand out in the market but also play a crucial role in consumer decision-making. These decisions are said to be determined 90% by visual factors, of which 85% are based on the color of the product (Pszichozóna, 2015; Dér & Szente, 2021; HubSpot, 2023).

3. Color Psychology

Color psychology is an important field of study that examines the effects of color on human emotions, behavior and thought processes. Numerous studies suggest that people associate certain emotions more strongly with specific colors than with others, and colors can also influence mood. While associations can vary according to culture, personal experience, circumstances and other factors, there are widely recognized emotion-color pairs that can be applied effectively (Perge, 2007; Színkommunikáció, 2010).

3.1. Blue

Blue conveys calmness, trust and stability. It lowers heart rate and has a soothing effect, which is why brands seeking to communicate reliability often use it (Sas, 2018). It is a favored shade in the technology and financial sectors (e.g. Intel, PayPal). Globally, blue is perceived positively, although shades may vary in effect by culture. Darker tones can also be associated with melancholy (Maksat & Pakizar, 2024). Goethe described blue as special, suggesting distance yet offering tranquility (Goethe, 1810).

3.2. Red

Red evokes intense emotions: passion, energy and danger. Cultural interpretations vary – it can represent love or mourning. Biologically, it increases alertness, making it ideal for urgency. Frequently used in sale and discount messages (Sas, 2018). Its brightness can stimulate appetite (e.g. McDonald's, Coca-Cola). Deeper

tones (e.g. burgundy) convey luxury and sophistication. However, excessive use can induce stress (Walter & Novák, 1977).

3.3. Yellow

Yellow is associated with joy, energy and creativity. It is particularly effective among children and young audiences. Like red, it attracts attention but excessive use can cause unease (Walter & Novák, 1977). Its meaning varies by culture – envy in some, sadness in others. In logos, it conveys cheerfulness, dynamism and agility. Although Ferrari is known for its signature “Ferrari red”, its logo is yellow, precisely for the reasons mentioned above (Fairyworkshop, 2021; Dér & Szente, 2021).

3.4. Black

Black suggests elegance, strength and formality. While culturally associated with mourning, it is often chosen by luxury brands (e.g. Gucci, Apple). Overuse can be oppressive, but it conveys seriousness, modernity and respect (Dér & Szente, 2021). To avoid cheapening a luxury product, brands often replace bright colours with more subdued tones such as pastels, black or white (Bytyçi, 2020). Henry Ford also chose black for his iconic Model T (Formula, 2018).

3.5. White

White symbolizes purity, innocence and simplicity. It is widely used in technology and healthcare (Dér & Szente, 2021). Its significance varies culturally – positive in the West, associated with mourning in parts of Asia. It is often used as a background to highlight content but rarely stands alone. Excessive use can create a sense of sterility (Matykó, 2024). In healthcare and medical branding, it represents hygiene – seen in brands such as Dove and Colgate, where white dominates both packaging and logos, conveying cleanliness and care (Sainte-Anastasié.org, 2025).

3.6. Green

A color closely linked to nature, green has a calming effect and stimulates creativity. It is popular among eco-friendly and organic products. Light green suggests freshness, while dark green conveys security (Dér & Szente, 2021; Matykó, 2024). Research shows it improves concentration and reduces errors (Walter & Novák, 1977). The human eye can distinguish many shades of green, aiding survival in nature – a fact utilized in advertising, where various green tones can be used even within a single logo, such as BP. Green is not just a simple color but a complex psychological and aesthetic phenomenon that plays a major role in everyday life (Sas, 2018).

3.7. Combining Colours

The emotional effect of color combinations is also significant. Blue and white together are calming and encourage communication, making them a perfect match for social media (e.g. Facebook), while red and grey are attention-grabbing (Maksat & Pakizar, 2024; Bytyçi, 2020). Yellow and black create a strong contrast, often used as a warning. Yellow attracts attention while black signals seriousness – together they bring out each other's value. Many brands use this combination to convey both quality and visibility, such as Ferrari, Nikon and CAT. The contrast between yellow and blue is also striking, drawing attention while appearing fresh and harmonious, as seen in the IKEA logo (Goethe, 1810; Walter & Novák, 1977). The

red-white-yellow trio evokes strong emotions (e.g. McDonald's, Coca-Cola). Black paired with other colors (e.g. gold) enhances the sense of luxury (Goethe, 1810; Sas, 2018).

4. Offline and Online Visual Marketing

Colors have an impact on brain activity and human behavior (Agárdi, 2010). Not only colors but every visual element – such as shapes, fonts and faces – influences our decisions. The primary aim of marketing is to attract attention, and colors play a key role in this. First impressions are formed within seconds, so the use of color can be decisive. In Porsche's case, for example, the red shade became so distinctive that it became known as "Porsche red" (Gollety & Guichard, 2011).

4.1. Online Advertising

The first online banner appeared in 1994, created by AT&T. It was a colored banner bearing the message: "Have you ever clicked your mouse right here? You will." Its huge success marked the beginning of the online advertising industry (Chaffey & Bosomworth, 2013).

In the online space, colors evoke emotional reactions: for example, red tends to increase click-through rates. Platforms such as Facebook and Google make it possible to send targeted impulses to users through colour choices, eliciting emotional responses to adverts (Sas, 2018). Visual ads – images, videos, GIFs – capture attention quickly. The type of content (e.g. brand awareness versus driving website visits) determines the most suitable format (Félegyházi, 2024).

One famous example is the "Million Dollar Homepage", which sold advertising space pixel by pixel and achieved enormous success in a short time (Sterne, 2024). Online advertising can be personalized, measured quickly and adapted more easily to market changes than offline solutions (Skender, Lionel & Tuan, 2011). The Meta system enables highly detailed targeting based on factors such as gender, age, interests and location.

4.2. Offline Marketing

Although it has become less dominant, offline marketing – TV, radio, print, outdoor advertising – remains important. It is an integral part of marketing communication and an essential component of the marketing mix. It reaches a wide audience but is less targeted. Television adverts engage both visually and audibly, printed media offer demographic targeting, and billboards are primarily used for brand building. Its advantage lies in offering a tangible, personal experience – seeing and touching a product – something not possible online (Skender, Lionel & Tuan, 2011).

5. Research Methods

Two research methods were applied. The first was a questionnaire, which initially contained simpler cognitive questions, followed by emotion-based questions. It also presented colored images and advertisements to measure the respondents' subconscious perceptions and emotional reactions. The questionnaire was distributed among Hungarian citizens, and over a two-week period, responses from exactly 150 participants were collected, all of which were usable. The second method was practical: six Meta advertisements corresponding to the six colors under investigation were run in a four-day campaign. The ads were shown in Budapest (coordinates 47.4815, 19.2112 with a 15 km radius) and targeted exclusively at women. The target group was not limited to a single generation but included four age groups (X, Y, Z, Baby Boomers). The aim was to determine which colors attract the most attention in Hungarian culture, how they help break through advertising noise, and which shades most effectively encourage action, such as clicking.

The goal of the research was to identify which colors most strongly influence consumer reactions and how this can be utilized in marketing.

5.1. Meta Advertisement

In the first study, Meta advertisements by an aesthetics company were analysed over a specific period. The company is located in central Budapest and was founded in 2019. It is active on social media platforms including Facebook, Instagram and TikTok. The clinic receives an average of approximately 300 visitors per week and offers aesthetic treatments; accordingly, the advertisements used in the research focus on anti-wrinkle treatments. Comparing the effectiveness of the ads is a complex task, as numerous influencing factors exist, such as ad optimisation and the automated distribution of the budget within the campaign. The creative content of the analysed ads was produced with the dominant color being one of the six primary colors (red, blue, yellow, green, black, white), with all other aspects – content and structure – remaining identical. The company’s primary target audience is middle-aged women living in Budapest who care about their appearance and wish to rejuvenate or improve their looks. Accordingly, the demographic settings were adjusted to target women aged 25–64 (since the services are primarily aimed at women), within a 15 km radius of a central Budapest point, covering almost all of Pest. The advertisements were displayed on Facebook and Instagram between 6th and 9th January 2025. Within the campaign, the content was launched as two separate ad sets: one remarketing set targeting those who had visited the website, the company’s social media profiles, or the clinic in person, or who had subscribed to the newsletter; and one “cold” audience set aimed at attracting new patients. Apart from these segments, all other demographic and content settings remained unchanged. Since the ads ran simultaneously, the budget was distributed across the 12 creative pieces, automatically adjusting based on the performance of each ad. Taking these factors into account, the results for the same color were combined in the subsequent calculations. The campaign objective was “interested users”, specifically showing the ads to people already inclined towards the topic.

5.1.1. CPC

Table 1. Results and data of advertisements (self-edited, 2025)

Coulor	Expenditure (HUF)	Cost per Click (CPC)	Displays	Click-through rate (CTR)	Clicks	Reach of the 25–34 age group	Reach of the 35–44 age group	Reach of the 45–54 age group	Reach of the 55–64 age group
#000000	27 603	152,50 Ft	11806	1,53%	181	1058	1827	3266	1030
#fff100	10 195	175,78 Ft	4163	1,39%	58	551	857	1264	402
#ffffff	9 177	148,02 Ft	3733	1,66%	62	569	739	1054	298
#ff0300	5 236	154,00 Ft	2555	1,33%	34	261	388	861	324
#72f130	4 646	178,69 Ft	2116	1,23%	26	200	353	670	259
#0317ff	3 143	314,30 Ft	1421	0,70%	10	116	239	496	189

As can be seen from the table, the daily budget for the six colors was HUF 15,000, which Meta distributed as shown. It is noticeable that due to the high interest in the black advertisement, the system allocated the largest portion of the budget to it, while the blue ad received the smallest allocation over the four days. Averaging the amount spent against the number of clicks – indicating user activity – reveals variations in the ads’ effectiveness. Based on CPC (Cost per Click) results, the black ad, despite its high interest and expenditure, ranked as the second most successful campaign in terms of clicks per cost. The white ad achieved the most activity relative to the smallest spend, making it the top performer in this regard. The red creative ranked third in terms of CPC; its cost was almost one-quarter of the black ad, yet relative to the number of clicks, it performed well. The blue ad was the least efficient in terms of CPC, with some clicks costing over HUF 300. Interestingly, the yellow ad, despite being the second most frequently displayed and generating the third-highest number of clicks, underperformed when considering CPC.

5.1.2. CTR

Moving to the CTR (click-through rate) column, which compares impressions to clicks, the white ad again delivered the highest benefit, with 1.66% of people who saw the ad clicking on it. The success ranking was largely similar to the CPC ranking; however, the positions of the yellow and red ads were reversed. While red ranked third in CPC analysis, yellow took third place based on CTR. Consequently, red dropped back, with only 1.33% of viewers engaging with the ad. As expected, blue and green content achieved lower success in this measure. Although their costs did not even reach HUF 5,000, both ads performed poorly relative to clicks, impressions, and cost-effectiveness.

5.1.3. Conclusion

From these data, it can be concluded that the white campaign achieved the best results, both in terms of CPC and CTR, followed by black. The lowest performers were the blue and green creatives, which underperformed in all aspects. While yellow and red attracted attention, they were less effective in motivating user engagement. CPC and CTR ratios usually produce similar outcomes; however, as seen here, this is not always the case (e.g., yellow and red). Therefore, it is essential to clearly define the goal and base the creation and configuration of ad creatives on it.

5.1.4. Age Groups

The second half of the table shows the reach by age group. The campaign targeted individuals aged 25–64, as anti-wrinkle treatments are typically started at a younger age and continue to be used by older adults. The age range was divided into four groups: 25–34 and 35–44 (Z and Y generations), and 45–54 and 55–64 (X and Baby Boomer generations) due to similar results, the two pairs of age groups should be treated together as younger and older age categories.

It is important to note the difference between impressions and reach. Impressions indicate the total number of times the ad was displayed (which may include multiple views by the same person), whereas reach indicates the number of unique users who saw the ad (counted once per person). From the table, it is clear that the 35–44 and 45–54 age groups were reached most frequently by all ads.

Table 2. Reach of ads by age group (self-edited, 2025)

Color	Total reach	Percentage (25–34/total)	Reach of the 25–34 age group	Percentage (35–44/total)	Reach of the 35–44 age group	Percentage (45–54/total)	Reach of the 45–54 age group	Percentage (55–64/total)	Reach of the 55–64 age group
#000000	7181	14.73%	1058	25.44%	1827	45.48%	3266	14.34%	1030
#ffff00	3074	17.92%	551	27.88%	857	41.12%	1264	13.08%	402
#####	2660	21.39%	569	27.78%	739	39.62%	1054	11.20%	298
#ff0300	1834	14.23%	261	21.16%	388	46.95%	861	17.67%	324
#72f130	1482	13.50%	200	23.82%	353	45.21%	670	17.48%	259
#03f7ff	1040	11.15%	116	22.98%	239	47.69%	496	18.17%	189

Analyzing the age-group data in the table using percentage averages, it becomes possible to determine which color creative reached each age group most effectively. Meta’s database filters and adjusts ads according to user experiences. In the table, the highlighted red cells indicate the color with the highest reach within each age group. For the 25–34 age group, the white creative – which also achieved the best overall reach – was the most effective. For the 35–44 age group, yellow performed best, while surprisingly, for the 45–54 and 55–64 groups, blue – which performed lowest overall – was the most preferred ad. Interestingly, despite receiving significant attention, black did not achieve the highest reach in any age group; nevertheless, overall, it still acted as a strong motivator. Based on literature findings, the research delivered the expected results. Since the study relates to an aesthetic clinic, people associate it with qualities such as simplicity, elegance, quality, professionalism, and beauty. The two “winning” colors according to CPC and CTR precisely evoke these emotions, thereby confirming the solid foundation of the secondary research.

5.2. Questionnaire Research

The next research method involved questionnaires, examining the topic from multiple perspectives. A total of 150 participants from different generations completed the survey. The study explored colour associations, attention-grabbing potential, elicited emotions, and pairings, comparing results across generations. Responses were received from 34 individuals in Generation X, 20 in Generation Y, 92 in Generation Z, and four from the Baby Boomer generation. The first question investigated how much the product's appearance influences consumers' decisions. Respondents rated their opinions on a scale from 0 to 4. The majority indicated that product presentation matters, giving an average score of 3.6. Similar scores were observed across all generations. Based on this, the next question asked whether there had been occasions where the product's appearance alone convinced them to purchase. Eighty per cent responded affirmatively. Of the 150 respondents, 129 indicated that they most often gather product information via online advertisements. These results provide a solid basis for the research, demonstrating that the majority of people are aware that product appearance strongly influences them. Furthermore, 27 respondents specifically confirmed that they encounter products and advertisements most frequently online.

5.2.1. Color Associations

The second part of the questionnaire focused in more detail on colors and their associated emotions and associations. The first question asked respondents to match the six colors under investigation with eight descriptive terms (three negative and five positive). From this data, it is possible to examine the attitudes people hold towards each color.

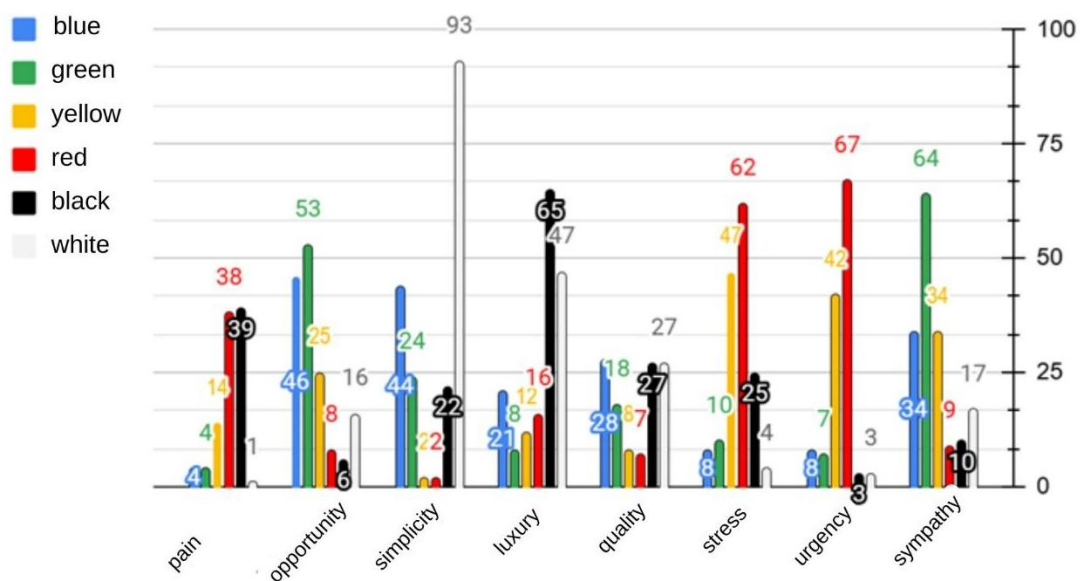


Fig. 1. Results of color-expression pairing (self-designed, 2025)

As the figure shows, blue was most commonly associated with the concept of opportunity; however, most respondents linked this term to green rather than blue. For all negative expressions (pain, stress, urgency), blue received very low scores, indicating that people perceive it as predominantly positive, despite being categorized as a cool color. Green was the most widely liked color, standing out clearly compared with the others. This is unsurprising, as previously mentioned, it is associated with nature, giving most people a sense of familiarity and closeness. The results for yellow and red were very similar in most respects, which makes sense given that both are strong, highly pigmented, warm colors. They scored particularly high for stress

and urgency, which explains their frequent use in sales promotions, discounts, and warning or caution signs. Red scored high on all negative expressions and low on positive ones, suggesting it is generally a less-liked color but one that effectively provokes action. While red and yellow achieved almost identical scores across most measures, they differed in terms of likability. As the figure illustrates, despite yellow's ability to attract attention and prompt urgency, respondents rated it as equally likable as blue. Finally, black and white produced the most outstanding results overall. White led strongly in associations with cleanliness, while black dominated in associations with luxury. Both colors were also equally associated with the concept of "quality," allowing for the parallels: luxury = quality and quality = cleanliness. Despite these strong positive associations, neither black nor white matched green in terms of likability. Even yellow, which performed strongly for negative associations, received more "likability points" than both black and white. It is important to note that for this question, respondents made associations based on cognitive reasoning rather than emotional response. Therefore, the emotions evoked by each color are not revealed here; this will be addressed in the following section.

5.2.2. Color-Emotion Pairs

Each color was also examined from an emotional perspective. Respondents were asked to assign the six colors to six basic emotions: joy, sadness, fear, anger, disgust, and surprise. In this section of the questionnaire, participants could also provide individual responses, often using synonyms for the listed emotions. These were consolidated to create the table presented below.

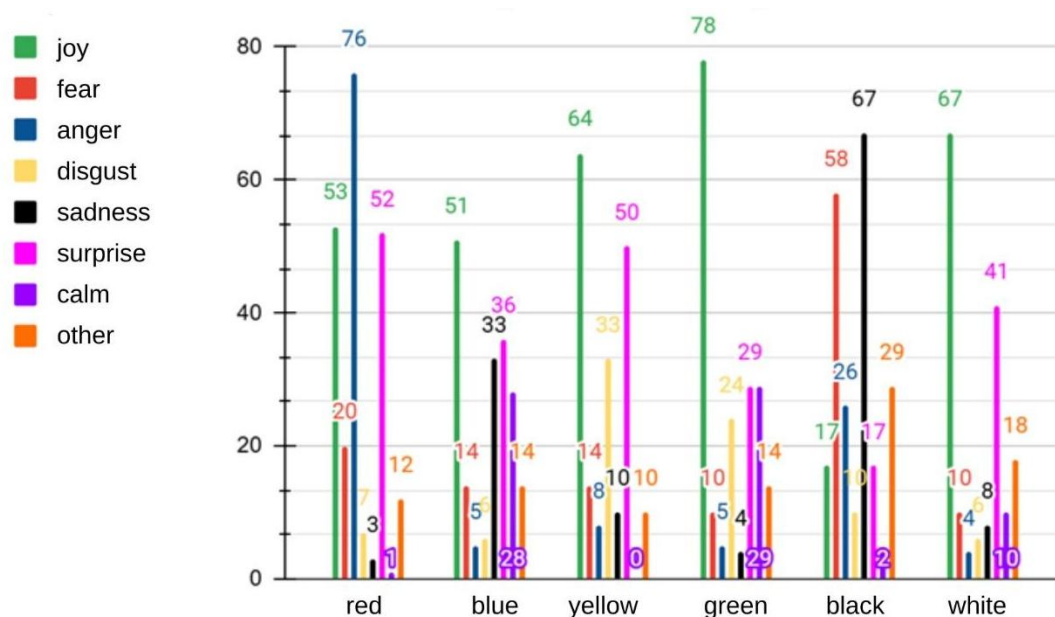


Fig. 2. Results of the color-emotion association (self-edited, 2025)

Since the focus of this question was on emotional rather than cognitive associations, it can be considered a measure of the emotional impact of colors. For nearly every color, "calmness" appeared as a free-text response, and in the diagram it is represented as a separate column, alongside other miscellaneous emotional alternatives. As shown in the figure, red predominantly elicited feelings of anger among respondents, which corresponds with the previous question where it was associated with stress, as the two descriptors are closely linked. In contrast, anger was least associated with blue and green, which are strongly linked to a sense of calm. This is likely influenced by the frequent appearance of these colors in nature, such as the sky, water, grass, and trees. Another notable finding for red was that it also elicited joy and surprise, while calmness

was least associated with it. This confirms that red is linked to all intense emotions, which is unsurprising given its strong pigmentation and typical use in warning signs, both of which provoke strong reactions in humans. Some earlier observations regarding yellow, however, were not fully confirmed. While literature suggested that yellow would be most strongly associated with joy, the survey data indicated otherwise. In the color–emotion pairings, yellow ranked only third for joy, behind green—which far outperformed all other colors and emotions—and white, both of which elicited a stronger sense of happiness among respondents. Black produced predictable results, evoking sadness and fear, which can be associated with death and darkness. Interestingly, black also generated the most “other” responses, suggesting it provokes the most diverse range of emotions and is harder to categorize than other colors, likely due to personal experiences and individual perceptions.

Unexpected results emerged for white. It clearly evoked strong emotions, with joy and surprise being the most prominent. White, as a color of cleanliness and freshness, may be linked to positive associations and likability, which explains these findings. Regarding surprise, all colors except black scored highly, indicating that color perception varies individually—people may visualize different shades of “red,” for example, when hearing the word. The next question explores how people’s evaluations of colors change, if at all, when they are visually presented.

5.2.3. Standing Out from the Crowd

In the following section, respondents were shown a neutral-themed advertisement—chosen to avoid influencing their associations—rendered in the six studied colors. Each image had identical content and layout; the only difference was the color, using exactly the same shades as in the Meta ad research. Participants were asked which colored advertisement captured their attention the most. The figure below presents the results achieved.

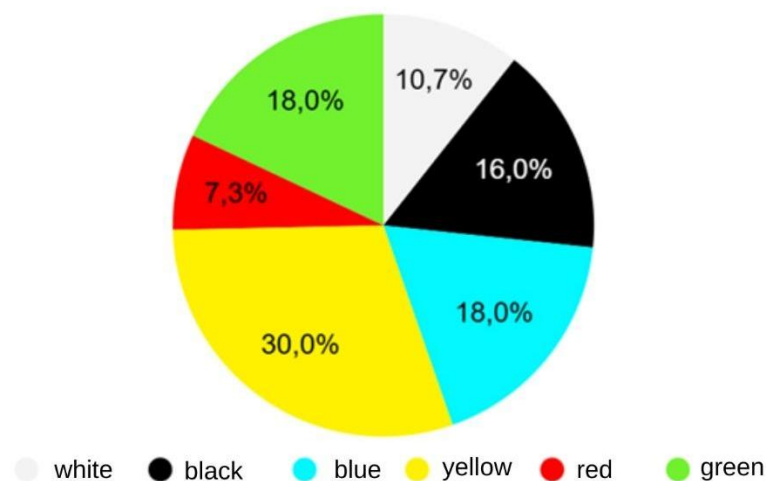


Fig. 3. Percentage of attention grabbing from advertisements (self-edited, 2025)

It is worth mentioning that in the creative content, the text was either black or outlined, while on a black background it was white, to ensure contrast. It can be seen that the yellow advertisement attracted by far the most attention, followed by green and blue. The strong contrast, combined with the highly pigmented and bright colors, contributed to their prominence. However, it is interesting that without their pigmentation – that is, “without their color” – the contrast alone is not as attention-grabbing, as demonstrated in the case of white. In such instances, it is advisable to “swap” the colors and use them in an inverse manner, as shown in the figure, since people considered the black-background advertisement with white text 5.3% more attention-grabbing. The red advertisement performed less well, despite its vivid tone, which may be

attributed to the depth of its shade and the color composition of the text. Given the numerous differences between generations, tastes naturally vary, as each experiences the present stage of life differently. This raises the question of whether there are generational differences in how the color of an advertisement captures attention.

Table 3. Generating Generational Awareness of Ads (self-edited, 2025)

Coulor	Proportion of Generation X	Proportion of Generation Y	Proportion of Generation Z	Proportion of Baby boomer
White	8,82%	10,0%	11,96%	0,0%
Black	2,94%	15,0%	21,74%	0,0%
Blue	23,53%	5,0%	18,48%	25,0%
Yellow	26,47%	50,0%	27,17%	25,0%
Red	8,82%	10,0%	6,52%	0,0%
Green	29,41%	10,0%	14,13%	50,0%

As can be seen in the highlighted data in the table, the preferred colors vary. From the previous figure, it was evident that yellow creatives were considered the most attention-grabbing. However, when the proportions are broken down by age group in the table (also indicated with highlighted cells), it becomes clear that yellow was not the most frequently chosen color in every generation. The two oldest generations surveyed both selected the green advertisement, whereas the Z and Y generations chose the “winning” yellow as the most attention-grabbing. This difference may be attributed to variations in generational lifestyles: the X and Baby Boomer generations tend to live more slowly and deliberately due to their age, while the younger generations are more energetic and active. The two lifestyle patterns and the associated meanings of the colors align perfectly, supporting the findings described in this thesis.

By swapping the vertical and horizontal axes of the table, the interpretation highlights the significance of black and white. These colors were most often selected by the Z generation, followed by Y, X, and finally the Baby Boomer generation. The combination of black and white is most strongly associated with modernity, which is particularly reflected in a linear trend of increasing age yet decreasing emphasis on values using the black-and-white pairing. Naturally, it is rare today to encounter advertisements that use only two colors.

5.2.4. Color combinations

In the previous section, the prominence of the advertisements was analysed, but as noted earlier, black text was always used on colored backgrounds (except for black backgrounds). A key question remains: which colors are most effective to pair in logos or advertisements to achieve maximum attention? The figure below illustrates the results for black and white backgrounds, showing how the same colors (as used previously) performed in terms of which color the survey respondents noticed first.

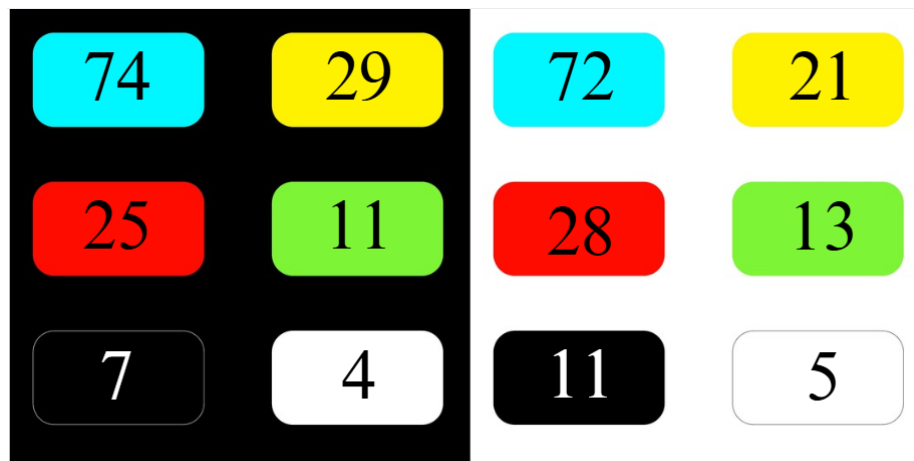


Fig. 4. Color pairing on a black and white background in terms of their attention-grabbing effect (self-designed, 2025)

As can be seen, on a black background the highest score was achieved by blue, with 71 respondents noticing this color first; a similarly high number was recorded on a white background as well. The previously underperforming red color achieved the second-highest result on a white background, while on black it came close but was still surpassed by yellow. In the earlier question, where the winning advertisement was yellow with black text, it now ranked second when paired with black and third when paired with white. The previously popular green color did not stand out as much on either black or white backgrounds, which is naturally influenced by human color perception rather than the popularity or meaning of the color itself. Black and white performed poorly in both cases, but contrary to the earlier findings, the white on a black background was less striking than black on a white background, according to the survey respondents.

6. Conclusion

The main aim of the research was to examine how different colors affect various generations and how they influence emotions, attention, and the motivation to act. The results indicate that the older generations (X and Baby Boomers) are most drawn to the calming blue and green, whereas the younger generations (Y and Z) respond most strongly to energetic yellow. Black and white symbolize cleanliness and quality, particularly for younger respondents. Red can be effective for attracting attention when used sparingly, but excessive use can provoke negative reactions. Green emerged as the most positive color (associated with calmness, sympathy, and happiness), while white surprisingly scored highly for evoking joy and encouraging action. Yellow carried a dual meaning, simultaneously eliciting sympathy and negative emotions. The conclusions suggest that successful marketing communication hinges on precise target audience definition and a clear understanding of the advertisement's purpose—whether to stimulate action or build brand recognition. Color selection can be effective when guided by this knowledge. A conscious, measured use of colors is recommended, as well as careful attention to color pairings, since proportions and contrasts significantly influence impact. For future research, the use of black and white in advertisements remains an open question. Although both convey clarity and quality, the two studies produced contradictory results, indicating that further investigation is warranted. The research is limited by people's current emotions, as well as their quality of life and place of residence. Therefore, it is important for future research to take all of these factors into account, to place greater emphasis on each color according to the field of work, and to consider the proportions of the colors used.

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Conflict of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- Agárdi, I. (2010). *Kereskedelmi marketing és menedzsment*. Akadémiai Kiadó.
- Barnes, J. (Ed.). (1984). *The complete works of Aristotle* (Vols. 1–2). Princeton University Press.
- Bytyçi, S. (2020). *Influence of colors as a key element in consumer marketing*.
- Commission Internationale de l'Éclairage. (1932). *Commission Internationale de l'Éclairage proceedings*. Cambridge University Press (CIE).
- Dave, C., & Danyl, B. (2013). *Digital marketing strategy: Planning template*.
- Dér, Cs. D., & Szente, B. (2021). *Márkázás és kulturális községsszervezés*. Nemzeti Művelődési Intézet.
- Félegyházi, Zs. (2024). Facebook hirdetések vizuális hatékonyságának növelése és helyzete az online hirdetések piacán. *Acta Carolus Robertus*.
- Fairyworkshop. (2021). *Színek jelentése*. <https://fairyworkshop.hu/wp-content/uploads/2021/06/szinek-jelentese.pdf>
- Színkommunikáció. (2010). Additív színkeverés – RGB. *Szín + Kommunikáció*. https://szinkommunikacio.hu/13_05.htm
- Formula. (2018, October 8). *110 éves a világ első népaútója, a Ford T – Model*. <https://formula.hu/auto/2018/10/08/110-eves-a-vilag-elso-nepautoja-a-ford-t-model>
- Goethe, J. W. (1978). *Szín-tan* (I. Mészáros, Trans.). Akadémiai Kiadó. (Original work published 1810)
- Gollety, M., & Guichard, N. (2011). *The dilemma of flavor and color in the choice of packaging by children*.
- Gyalog, V. Á. (1999). *Hatásvadászat*. M&M Pr és Reklám.
- HubSpot. (2023). *A színek pszichológiája*. <https://blog.hubspot.com/the-hustle/psychology-of-color>
- Le Blon, J. C. (1725). *Coloritto: Or, the harmony of colouring in painting*.
- Maksat, S., & Pakizar, S. (2024). *Color and sentiment: A study of emotion-based color palettes in marketing*.
- Matykó, N. (2024). *A színek pszichológiája a marketingben | Marketing MSc Podcast* [Video]. YouTube. <https://youtu.be/p3kiZltGyUM>
- MTA Könyvtár és Információs Központ. (1995). *Filozófiai Szemle*. MTA Könyvtár és Információs Központ.
- Munsell, A. H. (1905). *A color notation*. Geo. H. Ellis Co.
- Mustafi, S., Jost, L., & Nguyen, Q. T. (2011). *The relationship between online and offline marketing*. University of Applied Sciences Northwestern Switzerland.
- Nagy, B. V. (2009). *Az emberi színidentifikáció és színindiszkrimináció mérés technikája* (Doctoral dissertation). Budapesti Műszaki és Gazdaságtudományi Egyetem.
- Perge, E. (2007). A szín-tan alapjaitól a nyomtatásig. *Debreceni Műszaki Közlemények*.
- Pszichozóna. (2015). *Színpszichológia*. <https://pszichozona.hu/szinpszichologia>
- Sainte-Anastasia. (2025). *A színek jelentése és az egyes színek érdekességei pszichológiája*. <https://hu.sainte-anastasia.org/articles/psicologia/psicologia-del-color-significado-y-curiosidades-de-cada-color.htm>
- Sas, I. (2018). *A kiegyezés kora: Reklám és pszichológia a webkorszakban*. Sas és Társa Bt.
- Sterne, S. (2024). *The million dollar homepage*. Webdesigner Depot. <https://webdesignerdepot.com/blast-from-the-past-the-million-dollar-homepage/>

- Turner, R. S. (1994). *In the eye's mind: Vision and the Helmholtz-Hering controversy*. Princeton University Press.
- Walter, E., & Novák, L. (1977). *A színek világa*. Műszaki Könyvkiadó.
- Wenzel, K. (2013). *Színtan*. Budapesti Műszaki és Gazdaságtudományi Egyetem.



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VOLUME 1

AI, Sustainability and Digital Transformation: Shaping the Future of Business and Society

Economic Opportunities and Social Constraints for Women's Participation in Business in Hungary

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Abstract: The economic and social significance of women's presence in corporate management and the entrepreneurial sector is receiving increasing attention worldwide, not only in terms of promoting equal opportunities, but also in terms of competitiveness and sustainable growth. Gender balance in decision-making positions can positively impact innovation, corporate performance, and social capital. At the same time, different cultures interpret and treat the economic role of women differently, and there are significant regional differences in the intensity and opportunities for women's business activity. Based on a review of the literature, the study examines the economic value of women's presence in business and the social, institutional, and cultural factors that hinder its development. It focuses on Hungary, where, although women's economic activity has increased in recent years, their share in management positions remains low. The aim of the research is to reveal the structural and cultural barriers to women's **economic** participation and to contribute to the development of an economic policy discourse that promotes gender equality in the Hungarian business sector.

Keywords: Female entrepreneurs, Leadership, Financial impact, Incentives, Mobbing

JEL Classification: J16, M14, J71, G32, L26

1. Introduction

Over the past five decades, the proportion of women entrepreneurs in the United States has increased more than eightfold and now exceeds 40% (American Express, 2018). In contrast, in Europe and Hungary, this proportion is closer to 30% (European Commission, 2014). The proportion of female senior managers in Fortune 500 companies remains low, at between 10% and 12% (S&P Global Market Intelligence, 2024). The picture is more favorable for mid-market companies worldwide, where the proportion of female executives is 33.5% (Thornton, 2024). In Hungary, the proportion of women in management positions is 37% (Központi Statisztikai Hivatal, 2024). According to OPTEN data, this number increased by a thousand in 2022, meaning that there are currently 83,000 companies with female CEOs, but this still only represents 17% of the total number of companies (OPTEN, 2023). Women's business activity is underrepresented worldwide and hampered by structural, social, and financial barriers.

The situation is similar in Hungary: women's businesses are typically smaller, have less access to capital, and female managers have less social capital. Stereotypes, traditional gender roles, and hidden organizational male-centeredness further hinder their success. Despite this, international research confirms that the presence of women in leadership positions demonstrably improves business results and that companies with women in leadership positions are more stable, conservative, and sustainable. Women-founded businesses

use the resources at their disposal more efficiently, yet they remain underfunded. Supporting women's businesses and women leaders is therefore not only a social but also an economic imperative.

2. Methods

During our review of the relevant literature, we identified a total of **442 items**, of **which 420** came from the designated scientific databases (Emerald Insight, Elsevier, Google Scholar, SpringerLink, JSTOR, Wiley Online Library), while a further **22 items** came to our attention as a result of manual searches. From the compiled list, we filtered out **65 duplicates** automatically and manually, leaving **377 unique publications** as the basis for the initial screening. During the pre-screening, we excluded **270 items**, primarily due to their irrelevance to the research (e.g., results not related to the target population), the language of publication (not Hungarian or English), and publication outside the predefined time frame covering studies published between 2020 and 2025. After reviewing the full text of the remaining **107 studies**, we found that **47 studies** were not based on empirical research, were not adequately supported by methodology, or did not fit into the theoretical framework of the research. A total of **60 studies** were ultimately included in the literature review.

The steps of the systematic selection process are illustrated in the figure below, in accordance with the PRISMA 2020 guidelines (Page et al., 2021):

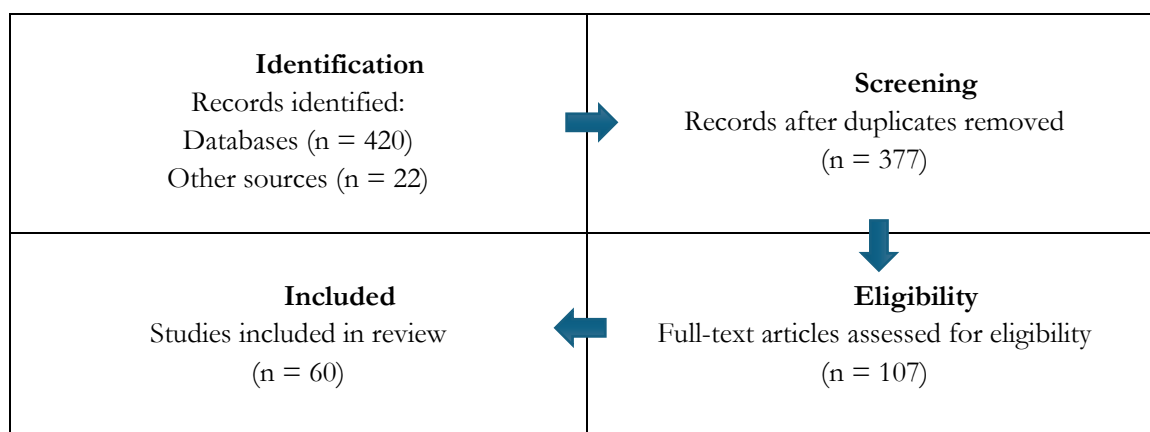


Figure 1. Selection steps for literature review according to PRISMA 2020 guidelines

Source: own edited

Of the 60 studies included in the literature review, 41 (68%) were published between 2020 and 2025, which reflects the topicality of the research topic and the current focus of research. Of the 19 previous sources, 15 studies (25%) were published between 2000 and 2019, while 4 studies (7%) were published between 1993 and 1999, primarily serving to provide a theoretical foundation for the phenomenon under investigation. Of the 60 sources, 29 (48%) are Hungarian, and 31 (52%) are international, while 39 (65%) are scientific publications and 21 (35%) are other types of documents (e.g., reports, policy documents, statistical databases), ensuring a diverse and well-founded background for the research.

3. Results

3.1. The economic significance of women's business activity

Several international studies and research projects have examined the economic outcomes of women's business activity and the impact of their participation in management and entrepreneurship on financial performance. Based on these studies, the most significant findings are as follows.

According to a PIIIE study of 62,000 companies in 58 countries, gender diversity is not only a social value but also a business advantage. A 1 percentage point increase in the proportion of female managers can lead to an average profit increase of 15%. Companies with at least one female manager consistently achieve better financial results (Han & Noland, 2020).

In the case of companies listed on the S&P 500, female managers have a positive impact on results, and companies with female managers have a lower risk profile and more stable financial results (Chadwick & Dawson, 2018). According to a 2016 study by the Credit Suisse Research Institute, companies where at least 15% of the management is female achieve higher returns on equity (ROE) and return on assets (ROA) on average and maintain a more balanced and conservative balance sheet. Companies led by female CEOs generate an average of 19% higher return on equity (ROE) (Dawson et al., 2016).

According to a study based on the Amadeus Top 250,000 database, European listed companies led by female CEOs are more stable, sustainable and have lower leverage (Faccio et al., 2016). Based on accounting indicators, the transition from male to female CEOs demonstrably reduces corporate risk-taking, while the opposite transition increases it.

Research based on an analysis of data from companies in 118 countries from the World Bank shows that female leadership contributes to improving corporate financial performance (Alexeeva-Alexeev et al., 2025), although gender-based constraints on access to finance represent a productivity disadvantage of 5.5-6.7%. (Mazas et al., 2025), although gender-based constraints on access to resources represent a productivity disadvantage of 5.5-6.7% for them (Bournakis et al., 2025). This approach confirms an earlier study, also conducted by the World Bank, which found that women's presence in the business sector is key to sustainable development and national economic resilience (Meunier et al., 2017). Countries that promote women's entrepreneurship achieve higher GDP growth in the long term (Chandel & Gupta, 2025). According to the Boston Consulting Group, women's business activity could result in a 3-6% increase in global GDP (Unnikrishnan & Blair, 2019), and women-owned businesses use invested resources much more efficiently, generating an average of \$0.78 in revenue for every dollar of capital, compared to only \$0.31 for men-owned businesses (Fackelmann, & De Concini, 2020). The latter study also points out that the underfunding of women-led businesses is not based on economic rationality, but on structural distortions.

The growth potential of women's businesses is lower, partly due to limited access to capital and less ambitious goals (Fisher et al., 1993). Financing difficulties are reinforced by stereotypes: women entrepreneurs receive less venture capital (Brush et al., 2018), and access to credit may also be hampered by prejudice (Carter et al., 2007). As a result, many do not even apply for credit for fear of rejection (OECD, 2023). Women entrepreneurs are more risk-averse, which also discourages them from borrowing (Branan, 2013).

In Hungary, women's businesses are typically smaller, with lower revenues and fewer employees, and they follow more conservative risk-taking strategies, which can reduce their creditworthiness and investor confidence (Gódány, 2018). Due to their income constraints, they have more modest growth potential and rely mainly on their own or family resources for financing, as their opportunities to attract external capital are limited (Szekeres, 2014). According to recent research, the majority of domestic female startups start with their own capital, and the involvement of venture capital is not typical (Kézai, 2020). Although female companies do not underperform in terms of business performance, this is often not sufficiently recognized by traditional economic indicators (Szathmári, 2022). The development of female entrepreneurs in Hungary is often hampered by limited access to development programs and information disadvantages (Vargáné, 2020), and the motivations and self-image of female entrepreneurs often differ from those of men, as they place greater emphasis on value-based operations and social embeddedness (Hollósy et al., 2022).

Female leaders are structurally disadvantaged in terms of networks, as they have fewer formal and informal economic connections, which limits their influence on decision-making. This phenomenon is not due to a

lack of competence, but rather to social reasons. Social capital and network position have a significant impact on corporate performance, but female managers benefit less from this. At the same time, women tend to build more cooperative, less hierarchical relationships, which can lead to more stable decision-making in the long term. The presence of women brings a new leadership model that can trigger a fresh perspective and positive cultural change in companies (Kürtösi, 2004). According to the KINCS survey, Hungarian society is fundamentally performance-oriented: 91% of respondents believe that leadership positions should be filled based on performance rather than gender. At the same time, more than half of respondents (52%) would support an increase in the number of female managers, and 61% believe that it is more difficult for women to build a career than their male counterparts (KINCS, 2023).

Targeted support for women's enterprises is justified not only to promote equal opportunities but also from an economic growth perspective. For Hungary, this support could bring national economic benefits in the form of GDP growth, crisis resilience, and sustainable development.

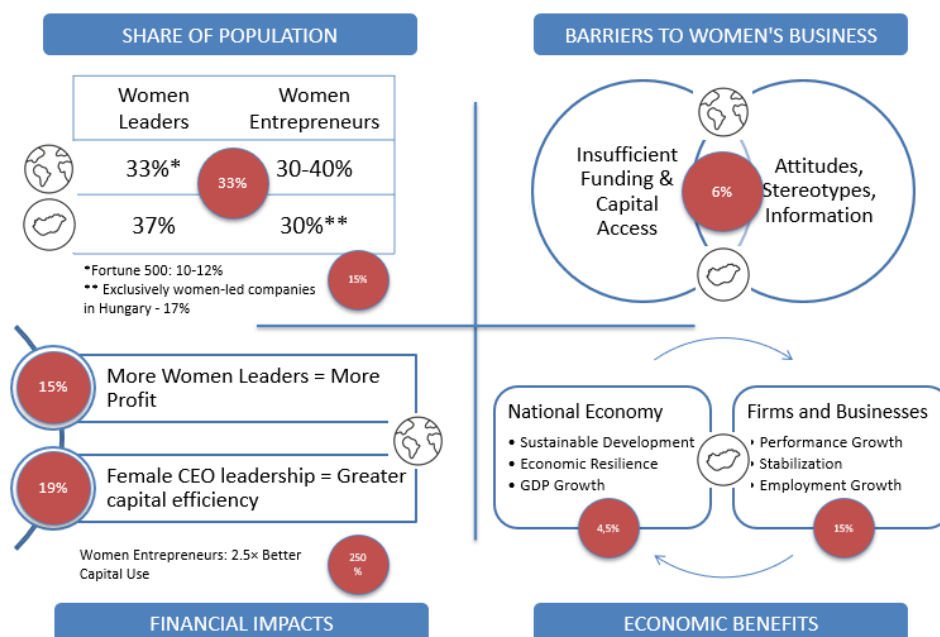


Figure 2: The Economic Significance of Women's Business Activity. *Source: Own*

Figure 2 shows that women represent approximately one-third of the business sector in both Hungary and globally in terms of managers and entrepreneurs. They face similar problems and barriers in business both within and outside their country, which can reduce their performance by at least 5-7%. International data shows that the presence of women can increase financial results by approximately one-fifth to one-sixth, bringing nearly 5% GDP growth to economies. This model could also provide an opportunity for further increasing Hungary's national economic performance.

4. Motivational patterns behind women becoming leaders and entrepreneurs

When examining entrepreneurial motivations, we distinguish between "push" and "pull" factors. Push factors may stem from dissatisfaction with the traditional labor market, fear of unemployment, or lack of career opportunities, while pull factors may be fueled by a desire for independence, the opportunity for self-fulfillment, the hope of financial success, or the ambition to realize an innovative idea.

The motivation of Hungarian female leaders can be interpreted on several levels: internal driving forces, environmental support, and social expectations. The primary internal motivating factors are the desire for personal development, enjoyment of the work, the opportunity to take on responsibility, and the desire for recognition (Czeglédi, 2007). These Herzbergian motivators—such as opportunities for advancement, recognition, and challenging tasks—increase female managers' job satisfaction and long-term commitment (Czeglédi, 2007). Another important motive for taking on a leadership role is a sense of social responsibility, especially among women working in the public sector. According to research, many women feel that as leaders they serve a community or institution and thereby create value (Cseh, 2020). Another important motivating factor is the possibility of reconciling family and work, which, however, often encounters obstacles. For women in leadership positions, a supportive spouse and external help (e.g., babysitters, cleaning ladies) are key to maintaining their leadership role (Balla & Fenyvesi, 2024).

However, research also shows that women managers are often found in lower-prestige sectors (education, social services), where a managerial title does not necessarily bring financial or social recognition (Cseh, 2020). This can reduce motivation, especially if the position only offers apparent autonomy, while institutional expectations leave little room for actual maneuver. In addition, for many women, becoming a leader is a "defensive ambition," i.e., not an internal aspiration but a forced path resulting from circumstances (e.g., there was no other candidate, a leader left, etc.), which reduces the strength of internal commitment (Cseh, 2020). A positive workplace culture that supports knowledge sharing, recognition of competencies, and career development opportunities plays a key role in maintaining and strengthening motivation (Balla & Fenyvesi, 2024).

The literature offers several typologies for characterizing female entrepreneurs. Goffee and Scase (1985) developed a classic typology that distinguishes between conventional, innovative, home-bound, and radical female entrepreneurs based on their adherence to entrepreneurial ideals and traditional gender roles. Other authors focus on the motivations behind entrepreneurship (e.g., performance-oriented, pragmatic, manager types; young achievers, entrepreneurs with inhibiting factors, family-driven entrepreneurs, income-driven entrepreneurs), the reasons for career breaks (e.g., returnees), or differences between modern and traditional entrepreneurial patterns (e.g., business skills, growth ambitions). (Górány, 2018) Entrepreneurial ecosystem-based research increasingly emphasizes environmental and social embeddedness (Kiss, 2024), while other analyses categorize female entrepreneurs based on their life history and career path (Filep et al., 2024b).

5. Entrepreneurial motivations and gender dimensions in Hungary: the situation of female entrepreneurs in light of the GEM 2023 research

The Global Entrepreneurship Monitor (GEM) research conducted by the Budapest Business School (BGE), its national report and its special publication on women entrepreneurs (Filep et al., 2024a; Csákné Filep et al., 2023) provide a detailed picture of the entrepreneurial activity of the Hungarian population and the motivations of entrepreneurs. Based on the 2023 survey, the motivations of Hungarian female entrepreneurs are determined by several factors. According to the research, the five most important motivational factors for female entrepreneurs are as follows: securing a livelihood, independence, self-fulfillment, wealth and high income, and accomplishing something meaningful.

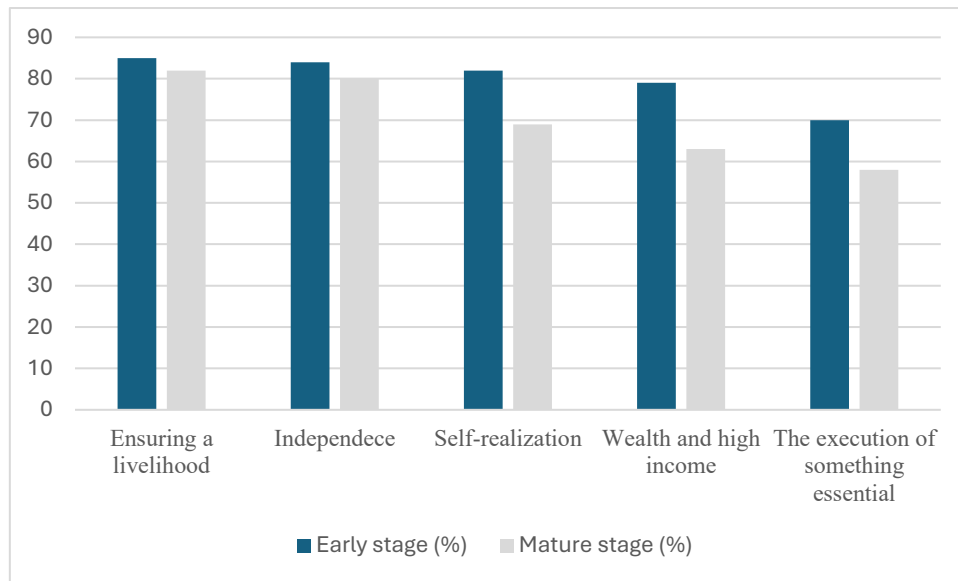


Figure 3: Top 5 motivations for female entrepreneurs *Source: Own*

Figure 3 shows that, according to GEM (Global Entrepreneurship Monitor) data for 2023, internal, personal motivations dominate among female entrepreneurs, especially in the early stages of entrepreneurship. The most common motivation is to secure a livelihood (91.2%), which indicates that in many cases, starting a business is a forced response to economic uncertainty and limited employment opportunities (Csákné Filep et al., 2023). Independence (90.1%) and self-fulfillment (82.9%) follow closely as motivations, supporting the theoretical approach that entrepreneurship often serves as a space for self-determination for women (Fischer et al., 1993). “Achieving something meaningful” also proved to be an extremely strong driving force (71.6%), far exceeding the global and European averages. This suggests that a significant proportion of female entrepreneurs do not engage in entrepreneurship purely for financial reasons, but are driven by social or individual values (Filep et al., 2024a). Although wealth and high income appear among the motivations (78.7%), they are not the main focus, which differs from the motivations of male entrepreneurs (Csákné Filep et al., 2023).

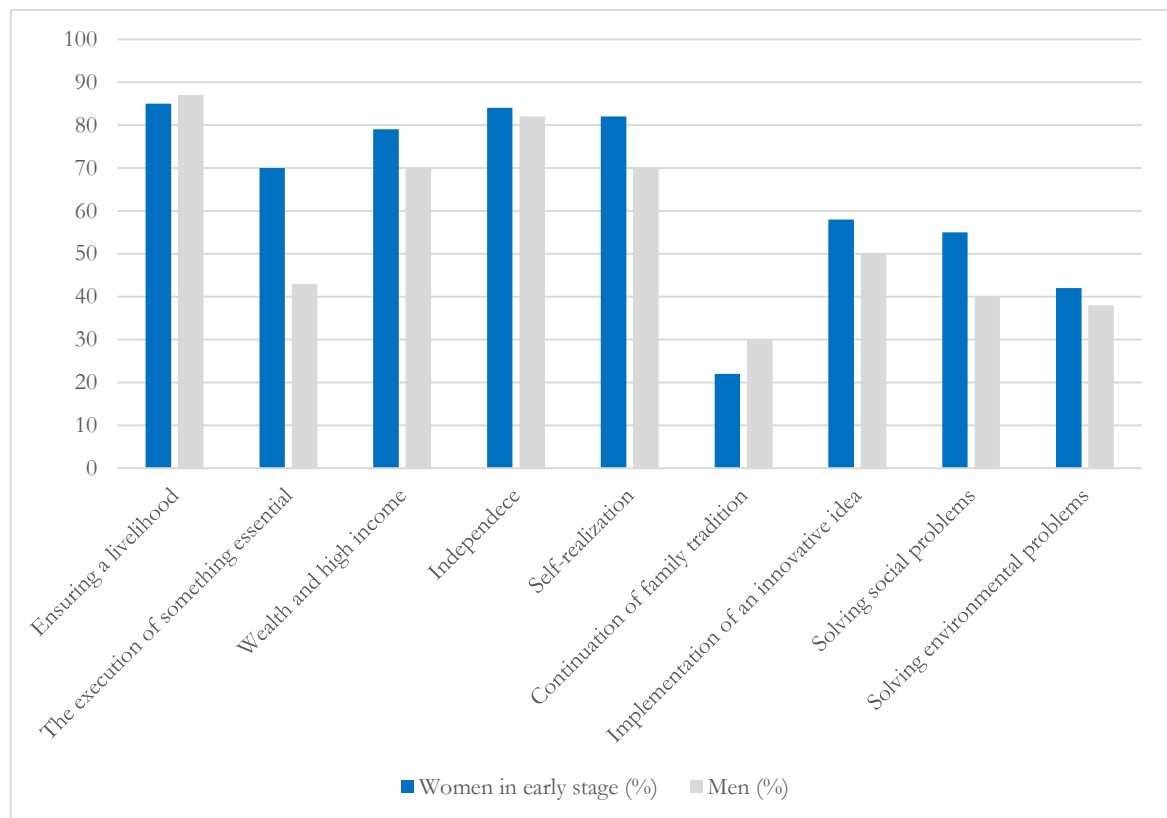


Figure 4: Motivations of female and male entrepreneurs (GEM, 2023)

Source: Own edited

Figure 4 shows the motivational patterns of female and male entrepreneurs. Based on the GEM 2023 survey, the data show significant differences in this area, especially in the early stages of entrepreneurship. For women, securing a livelihood and achieving independence are the dominant motivating factors, while for men, wealth accumulation and continuing family traditions are more prominent (Filep et al., 2024a). Self-actualization and social goals are more prevalent in women's motivations. This gender difference is consistent with previous research, which found that female entrepreneurs are more likely to approach entrepreneurship with value-based, community, and social goals (Fischer et al., 1993; Gódány, 2018). In the case of men, however, a growth-oriented entrepreneurial attitude based on market success is more common. It is important to note that the differences in motivation between the two genders are not always statistically significant, i.e., the differences are more of a trend than a rigid boundary (Csákné Filep et al., 2023). Therefore, when designing policy instruments to support business start-ups, it is worth taking into account both gender and life cycle differences.

6. The effects of mobbing on female employees

Female employees are more likely to be victims of mobbing, especially in hierarchically organized, paternalistic corporate structures where the balance between emotional stress and dual expectations—work and caregiving—is disrupted (Czifra & Csukonyi, 2024; Daphne Project, 2006). In the long term, mobbing increases the demand for healthcare services, exacerbates mental disorders such as anxiety and depression, and in some cases can even lead to complete withdrawal from the labor market (Soós & Czibor, 2022).

All of these have direct economic consequences: female labor productivity declines, sick leave increases, and turnover costs rise (Ilieva et al., 2024). 's vulnerability further reinforces the wage gap and hinders career advancement opportunities for female employees, especially at management levels.

6.1. The economic impact of mobbing on employers

Mobbing at the organizational level, whether originating from management or colleagues, entails direct and indirect costs for the employer. Direct costs include sick leave and replacement and training costs, while indirect costs include a deterioration in workplace morale, reduced employee commitment, and damage to the company's reputation. (Bányai et al., 2016; Garami, 2023).

Hungarian employers typically have low conflict management capacity, which further exacerbates the problem (Tóth & Solymosi-Szekeres 2023). Managers themselves can also be sources of mobbing, for example through toxic leadership styles, narcissism, or abusive behavior (Czifra & Csukonyi, 2024). This not only demotivates employees in the short term, but also reduces their willingness to innovate in the long term.

6.2. Macroeconomic consequences of mobbing and statistical overview

According to European Union data, 8% of employees suffer from mobbing-type harassment, which causes billions of euros in losses each year in the form of lost working hours, healthcare costs, and reduced productivity (EU-OSHA, 2009). In Hungary, it is estimated that 5-6% of employees were directly affected in the early 2020s, which represents hundreds of thousands of people (Garami, 2023; Vajda, 2006). Women account for more than 50% of this figure.

The estimated annual indirect costs of stress and health damage caused by psychological harassment at work can reach 0.5–1% of GDP, which includes early retirement, sick days, and productivity losses due to mental illness (Ilieva et al., 2024). It is particularly worrying that the Hungarian legal and institutional environment is currently unable to provide effective protection to victims (Tóth & Solymosi-Szekeres, 2023).

6.3. The indirect economic costs of mobbing and the restraint of women's entrepreneurship in Hungary

The effects of mobbing are not limited to the employee sphere, but are also reflected in female entrepreneurial activity. According to the Global Entrepreneurship Monitor (GEM) 2023/24, the proportion of female entrepreneurs in Hungary is lower than the European average, and the main obstacles include fear of failure, lack of social trust, and a discriminatory organizational culture (GEM, 2024). Mobbing, especially when targeted at female managers or start-up entrepreneurs, further reinforces the tendency to stay out of business.

Women's enterprises could play a key role in innovation, employment, and regional economic development, but psychosocial pressures and structural disadvantages significantly hamper their development. Women often lack access to business networks, mentoring programs, and resources that would facilitate their exit from traditional employment structures (GEM, 2024; Garami, 2023).

In addition, according to the WHO Global Burden of Disease study, mental illness, including depression and anxiety, is one of the leading causes of work loss and reduced productivity among women (Murray & Lopez, 1996). Based on Disability-Adjusted Life Year (DALY) indicators, women are disproportionately affected by loss of working capacity for psychological reasons, especially in environments where harassment or psychological terror is present.

According to the WHO, mental health problems, which can also develop as a result of mobbing, will represent the greatest economic burden by 2020. This is supported by the growing number of people struggling with symptoms of depression and anxiety in Hungary, as well as the fact that mental disorders account for a significant proportion of early retirement pensions (Tóth & Solymosi, 2023; WHO, 1996).

In light of these trends, increasing female economic activity – including starting and maintaining businesses – is not only an economic goal, but also a health policy and social task. The management of psychosocial risks, including mobbing, prevention programs, the development of organizational culture, and the promotion of female entrepreneurship, must go hand in hand with economic policy objectives.

7. Conclusion

The aim of this study was to provide a comprehensive analysis of the economic significance and social constraints of women's business participation in Hungary, with particular emphasis on female entrepreneurship, leadership representation, motivational patterns, and the economic consequences of workplace mobbing. Based on a systematic literature review conducted in accordance with the PRISMA 2020 guidelines, the findings clearly demonstrate that women's participation in business is not merely a matter of social equity, but a measurable driver of firm-level performance and macroeconomic sustainability.

From a practical perspective, the results support the need for targeted and integrated policy interventions aimed at strengthening women's entrepreneurial and leadership potential. Key recommendations include improving access to finance for women-led enterprises, expanding mentorship and professional networking programmes, and promoting organizational practices that foster inclusive leadership cultures. In particular, the prevention and management of workplace mobbing should be treated as a strategic economic issue, as psychosocial risks generate significant productivity losses, increase employee turnover, and undermine long-term organizational performance.

The study is subject to certain limitations. It relies exclusively on secondary sources and published literature, without primary empirical data collection at the firm or individual level. Consequently, causal relationships could not be tested directly. Future research should therefore focus on empirical and longitudinal analyses examining the financial performance of women-led enterprises, the role of social and relational capital, and the long-term economic effects of workplace mobbing on women's career trajectories.

Overall, the findings underline that women's economic potential can only be fully realized through a coordinated approach that simultaneously addresses financial constraints, organizational culture, and psychosocial working conditions. Such evidence-based economic and organizational policies may contribute to more inclusive, resilient, and competitive economic development in Hungary and beyond.

Conflict of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- Alexeeva-Alexeev, I., Guaita-Fernandez, P., & Mazas-Perez-Oleaga, C. (2025). Cross-country analysis of sustainable innovation and female entrepreneurship and their influence on the presence of women in managerial positions. *Sustainable Technology and Entrepreneurship*, 4(2), 100102. <https://doi.org/10.1016/j.stae.2025.100102>
- American Express. (2018). *The state of women-owned businesses report*.
- Balla, G. B., & Fenyvesi, É. (2024). Nők vezetői szerepben Magyarországon – Fékek és lehetőségek. *Polgári Szemle*, 20(1–3), 160–175. <https://doi.org/10.24307/psz.2024.0814>
- Bányai, G., Boruzs, K., & Bíró, K. (2016). A munkahelyi mobbing kezelésének jogi vetületei. *International Journal of Engineering and Management Sciences*, 1(1), 1–10.
- Bournakis, I., Motta, V., & Vidali, M. E. (2025). No road with roses in developing countries: Gender diversification in firm leadership and total factor productivity. *Macroeconomic Dynamics*, 29, e75. <https://doi.org/10.1017/S1365100524000798>
- Brana, S. (2013). Microcredit: An answer to the gender problem in funding? *Small Business Economics*, 40(1), 87–100. <https://doi.org/10.1007/s11187-011-9346-3>
- Brush, C. G., Greene, P. G., Balachandra, L., & Davis, A. E. (2018). The gender gap in venture capital: Progress, problems, and perspectives. *Venture Capital*, 20(2), 115–136. <https://doi.org/10.1080/13691066.2017.1349266>
- Carter, S., Shaw, E., Lam, W., & Wilson, F. (2007). Gender, entrepreneurship and bank lending. *Entrepreneurship Theory and Practice*, 31(3), 427–444. <https://doi.org/10.1111/j.1540-6520.2007.00181.x>
- Chadwick, I. C., & Dawson, A. (2018). Women leaders and firm performance in family businesses. *Journal of Family Business Strategy*, 9(4), 238–249. <https://doi.org/10.1016/j.jfbs.2018.10.002>
- Chandel, D. S., & Gupta, N. (2025). Women-led development through microfinance-led interventions: Myths or reality? *Social Sciences & Humanities Open*, 11, 101409. <https://doi.org/10.1016/j.ssaho.2025.101409>
- Csákné Filep, J., Radácsi, L., Szennay, Á., & Timár, G. (2023). *Tenni akarás és megélhetés – vállalkozói motivációk és lehetőségszűrés Magyarországon*. https://doi.org/10.29180/2939-8320_978-615-6342-55-3
- Cseh, T. (2020). A női vezetők motivációi és kihívásai a köznevelési intézményekben. In T. Cseh (Ed.), *Vezetőnők a közszolgáltatásban* (pp. 43–58). KRE-ÁJK. <https://doi.org/10.17625/NKE.2020.003>
- Czeglédi, Cs. (2007). A női vezetők munkával való elégedettsége. *Marketing & Menedzsment*, 41(4–5), 140–147.
- Czifra, J., & Csukonyi, Cs. (2024). A toxikus vezetés ismérveinek exploratív vizsgálata. *Vezetéstudomány / Budapest Management Review*, 55(10), 2–10.
- Daphne Project. (2006). *Mobbing – Raising awareness of women victims of mobbing*. MONA Foundation.
- Dawson, J., Natella, S., & Kersley, R. (2016). *The CS gender 3000: The reward for change*. Credit Suisse Research Institute.
- Durugy, A., Gál, D., & Kővágó, P. (2024). Felső- és középvezetők a versenyszférában és a közszférában. *Humán Innovációs Szemle*, 15(2), 4–21. <https://doi.org/10.61177/hisz.2024.15.2.1>
- EU-OSHA. (2009). *Psychosocial risks in Europe: Prevalence and strategies for prevention*.
- European Commission. (2014). *Statistical data on women entrepreneurs in Europe*.

- Faccio, M., Marchica, M.-T., & Mura, R. (2016). CEO gender, corporate risk-taking, and the efficiency of capital allocation. *Journal of Corporate Finance*, 39, 193–209. <https://doi.org/10.1016/j.jcorpfin.2016.02.008>
- Fackelmann, S., & De Concini, A. (2020). *Funding women entrepreneurs: How to empower growth*. European Investment Bank. <https://doi.org/10.2867/323848>
- Filep, J. C., Szennay, Á., & Timár, G. (2024a). *Opportunities, motivation, environment: Entrepreneurial activity in Hungary*. Global Entrepreneurship Monitor National Report.
- Filep, J. C., Szennay, Á., & Timár, G. (2024b). *Women entrepreneurs in Hungary*. <https://doi.org/10.29180/978-615-6342-78-2>
- Fischer, E. M., Reuber, A. R., & Dyke, L. S. (1993). A theoretical overview and extension of research on sex, gender, and entrepreneurship. *Journal of Business Venturing*, 8(2), 151–168. [https://doi.org/10.1016/0883-9026\(93\)90017-Y](https://doi.org/10.1016/0883-9026(93)90017-Y)
- Garami, M. (2023). A mobbing gazdaságra káros hatásai. *Miskolci Jogi Szemle*, 18(2), 222–230. <https://doi.org/10.32980/MJSz.2023.2.222>
- Goffee, R., & Scase, R. (1985). *Women in charge: The experiences of female entrepreneurs*. Allen & Unwin.
- Gódány, Z. (2018). Női vállalkozók – kutatási területek. *Vezetéstudomány / Budapest Management Review*, 49(4), 58–67. <https://doi.org/10.14267/veztud.2018.04.06>
- Han, S., & Noland, M. (2020). *Women scaling the corporate ladder: Progress steady but slow globally* (Policy Brief No. 20-7). Peterson Institute for International Economics.
- Hollósy-Vadász, G., & Révész, B. (2022). Női vállalkozók jellemzői és társadalmi beágyazottsága. *Studia Mundi*, 9, 21–34. <https://doi.org/10.18531/Studia.Mundi.2022.09.01.21-34>
- Ilieva, J., Stoilkovska, A., & Todosovski, A. (2024). Enhancing workplace environment by addressing mobbing. *UTMS Journal of Economics*, 15(1), 54–63.
- Kézai, P.K., Konczosné, Sz.M. (2020). WOMEN IN THE WORLD OF STARTUP ENTREPRENEURS IN HUNGARY VEZETÉSTUDOMÁNY LI. ÉVF. 2020. 10. SZÁM/ ISSN 0133-0179 DOI: 10.14267/VEZTUD.2020.10.05 51-62
- KINCS. (2023). *A női kvóta megítélése Magyarországon*.
- Kiss, J. (2024). Társadalmi vállalkozások Magyarországon. *Civil Szemle*, 20(4), 51–69. <https://doi.org/10.62560/csz.2024.04.3>
- Központi Statisztikai Hivatal. (2024). *Fenntartható fejlődés indikátorai*.
- Kürtösi, Zs. (2004). Nők a felsővezetésben. *Szociológiai Szemle*, 14(2), 77–95.
- Meunier, F., Krylova, Y., & Ramalho, R. (2017). Women's entrepreneurship: How to measure the gap (Policy Research Working Paper No. 8242). World Bank. <https://doi.org/10.1596/1813-9450-8242>
- Murray, C. J. L., & Lopez, A. D. (Eds.). (1996). *The global burden of disease*. Harvard School of Public Health.
- OECD & European Commission. (2023). *The missing entrepreneurs 2023*. <https://doi.org/10.1787/230efc78-en>
- OPTEN (2023) www.opten.hu
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., ... Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, 372, n71. <https://doi.org/10.1136/bmj.n71>
- S&P Global Market Intelligence. (2024). *Elusive parity: Key gender parity metric falls for first time in two decades*.

Soós, A. R., & Czibor, A. (2022). A munkahelyi pszichoterror alakulása az egészségügyben a COVID-19 járvány alatt. *Impulzus: Szegedi Pszichológiai Tanulmányok*, 9(1), 2–27. <http://pszich.u-szeged.hu/impulzus/wp-content/uploads/2022/12/3-soos-czibor.pdf>

Szathmári E, Czibor A, Bents R, Szabó ZP and Kiss OE (2023) Jungian personality type preferences of female and male Hungarian leaders. *Front. Psychol.* 14:1222568. doi: 10.3389/fpsyg.2023.1222568

Thornton, G. (2024). *Women in business 2024: Defining pathways to parity*.

Tóth, A., & Solymosi-Szekeres, B. (2023). Mobbing – or the face of psychological terror in the workplace. *Miskolc Legal Expert*, special issue (3), 66–75.

Unnikrishnan, S., & Blair, C. (2019). *Want to boost the global economy by \$5 trillion? Support women as entrepreneurs*. Boston Consulting Group.

Vajda, R. (2006). *A munkahelyi pszichoterror Magyarországon*. MONA Foundation.

Vargáné Mező, K. (2020). A nők részvétele a KKV-szektorban. *Társadalom és Gazdaság*, 42(1–2), 182–202.



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Part IV - Emerging Sectors and Applications



VOLUME 1

AI, Sustainability and Digital Transformation: Shaping the Future of Business and Society

Technological Trends in the Event Management Market

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Abstract: The event management sector has experienced a significant technological transformation, creating both new opportunities and complex challenges for organizers and participants. This study explores emerging trends reshaping the planning and experience of events, with a focus on artificial intelligence (AI), which enables personalized program recommendations, chatbot interactions, and predictive analytics. Hybrid and virtual formats have become standard, offering interactive digital environments and gamified experiences. Technologies such as augmented and virtual reality (AR/VR) enhance engagement through virtual venue walkthroughs and immersive exhibitions. Smart devices, wearables, and Internet of Things (IoT) applications support access control, real-time analytics, and contactless transactions, while blockchain and non-fungible tokens (NFTs) add security and exclusivity to ticketing systems. Digital marketing strategies—like influencer outreach, short-form video content (TikTok, Instagram Reels), and AI-generated media—are also examined for their role in increasing event visibility and audience interaction. The study highlights sustainability efforts such as digital ticketing, energy-efficient infrastructure, waste reduction, and carbon offsetting. These innovations position technology not just as a logistical tool but as a driver of sustainable and impactful event design. Drawing on Hungary's recent experience in hosting international sporting events, we analyze fan engagement tools like dance cams, AI-powered look-alike cams, and personalized athlete intro cards. Expert interviews from the FINA World Championships (2022), World Athletics Championships (2023), and Swimming Championships (25m) (2024) offer insights into how such tools enhanced audience involvement and operational efficiency. The findings emphasize the strategic role of technology in enriching attendee experiences and delivering innovative, future-ready event solutions.

Keywords: Event Management, Innovations, Trends.

JEL Classification: JEL83

1. Introduction

Event management represents a dynamic and intellectually stimulating field of professional practice. Drawing on our experience, we can assert that no two events are alike; each presents unique challenges and opportunities for learning and adaptation. This inherent variability fosters continuous professional development and makes the field particularly attractive to those who pursue it as a vocation. The present study is grounded in these practical insights, with a primary focus on the role of emerging technological trends and innovations in contemporary event organization.

In the past decade, the event management sector has undergone a profound transformation driven by the rapid development and integration of new technologies. These innovations have reshaped nearly every dimension of event organization, from logistical planning and operational execution to audience interaction and post-event evaluation. Technologies such as artificial intelligence (AI), augmented and virtual reality (AR/VR), the Internet of Things (IoT), and blockchain are no longer futuristic concepts, but tangible tools that are being actively employed to enhance participant experiences and streamline management processes. As the expectations of audiences grow and digital engagement becomes increasingly essential, understanding the strategic application of these technologies has become vital for event professionals and researchers alike.

This paper aims to explore the transformative role of emerging technologies in modern event management, with a particular focus on fan engagement and experiential innovation. Specifically, the study investigates

how technologies such as AI-driven personalization tools, immersive digital platforms, and secure, transparent systems like blockchain are redefining how audiences interact with events. These developments are especially relevant in the context of large-scale international sports events, where technological integration can serve both as a differentiating factor and a driver of long-term value for organizers, participants, and stakeholders.

The relevance of this topic is underscored by the increasing competition within the global events industry, the shift towards hybrid and virtual formats accelerated by the COVID-19 pandemic, and the growing importance of sustainability in event planning. As event organizers strive to deliver memorable, inclusive, and efficient experiences, technology is becoming a central pillar in achieving these goals. Moreover, the digital preferences of younger generations and the widespread use of social media platforms such as TikTok and Instagram are prompting organizers to rethink traditional communication and engagement strategies, giving rise to a new era of interactive and data-driven event experiences.

To examine these dynamics, the study is guided by the following research questions:

1. How do AI-powered fan engagement tools influence audience interaction, emotional involvement, and overall satisfaction at international sporting events?
2. What are the operational and strategic benefits of implementing technologies such as IoT, AR/VR, and blockchain in event management?
3. In what ways do these technologies contribute to the long-term innovation, competitiveness, and sustainability of event planning practices?

The methodological approach chosen for this research is qualitative, centered on in-depth expert interviews. This method was selected due to its ability to capture nuanced, experience-based insights that go beyond surface-level observation. Interviews were conducted with professionals directly involved in the planning, development, and execution of fan engagement initiatives at three major international sports events hosted in Hungary: the 2022 FINA World Championships, the 2023 World Athletics Championships, and the 2024 Swimming Championships (25m). These events serve as rich case studies due to their scale, global visibility, and the variety of technological tools implemented—from AI-powered look-alike cams and personalized athlete intro cards to interactive audience activations.

The structure of the paper is as follows: the next section presents a comprehensive literature review that outlines key trends and theoretical frameworks related to technology in event management. This is followed by a detailed methodology section explaining the research design and interview process. The findings section then summarizes key insights from the interviews, illustrating how specific technologies impacted both audience experience and operational performance. The discussion section interprets these results in light of the research questions, highlighting implications for future practice. Finally, the conclusion offers a synthesis of the findings and recommendations for further research and technological innovation in the event sector. Through this investigation, the paper seeks to contribute to a deeper understanding of how technology is not only enhancing events operationally but also serving as a catalyst for engagement, innovation, and sustainable growth in the field of event management.

2. New trends in the Event Management Market

The sports event management industry has experienced rapid transformation due to the integration of advanced digital technologies, including artificial intelligence (AI), augmented and virtual reality (AR/VR), the Internet of Things (IoT), blockchain, and sustainability-focused innovations. These technologies improve operational efficiency, enhance fan engagement, and support stakeholder satisfaction, particularly in large-scale international sports events where audience expectations are increasingly digital and interactive.

2.1. Artificial Intelligence and Chatbots

AI technologies facilitate dynamic personalization and predictive analytics within event contexts. Machine learning models analyze attendee behavior, enabling customized program recommendations and intelligent matchmaking, which ultimately enhance satisfaction and networking outcomes (Buhalis & Amaranggana, 2015; Wang et al., 2022). The Web Summit in Lisbon exemplifies this trend by utilizing AI-driven matchmaking to connect participants with shared interests (Web Summit, 2024). Additionally, chatbots serve as virtual assistants, providing instant responses regarding schedules, venue information, and ticketing, which significantly improves customer service (Gretzel et al., 2015). These AI systems also leverage big data from previous events to predict attendance and optimize resource allocation. *“AI systems can also continuously ‘learn from experience’ and therefore the route taken to the outcome might be different each time the AI system is run.”* (WTTC, 2024, pp9).

Functions in sports events:

- Personalized match and session recommendations
- Interactive Q&A and fan engagement support
- Real-time notifications for schedule updates

2.2. Hybrid and Virtual Events

The COVID-19 pandemic accelerated the adoption of hybrid event formats, combining in-person and virtual participation. This shift has been widely studied, showing increased accessibility and engagement, but also challenges in maintaining immersive experiences and community building (Getz & Page, 2020; Neuhofer et al., 2015). Apple Keynote and Microsoft Ignite demonstrate best practices in delivering high-quality streams with interactive features such as live polls and Q&A, which enhance attendee involvement (Apple, n.d.; Microsoft Ignite, n.d.). Virtual festivals like Tomorrowland’s Around the World leveraged 3D virtual spaces and multiple camera angles to mimic physical event dynamics (Filo et al., 2015). Virtual components of events such as FIFA Fan Fest and the NBA 2K League demonstrate how hybrid formats increase accessibility while challenging organizers to maintain immersive experiences and community building (Apple, n.d.; Microsoft Ignite, n.d.).

Functions in sports events:

- Remote participation for international audiences
- Interactive elements such as live polls, quizzes, and Q&A
- Virtual community building and engagement

2.3. Augmented and Virtual Reality (AR/VR)

Immersive technologies such as AR and VR enrich event experiences by facilitating novel ways to explore venues and products (Neuhofer, et al, 2015). AR applications at Coachella allowed attendees to experience performance visuals through mobile devices, fostering greater engagement (Sánchez-Cañizares & López-Guzmán, 2012). Similarly, the Mobile World Congress showcased VR demonstrations of emerging 5G tech, while New York Fashion Week offered fully virtual runway shows accessible remotely (Tussyadiah et al., 2018). Research suggests that immersive technologies increase emotional engagement and recall in event

settings (Hilken et al., 2017). VR solutions have been used for virtual stadium tours and live match simulations, enhancing emotional engagement and recall (Hilken et al., 2017). Examples include AR visualizations at UEFA Champions League matches and fully virtual fan experiences at swimming championships.

Functions in sports events:

- Virtual stadium exploration and match visualization
- Real-time data overlays and immersive fan experiences
- Interactive sponsor content and marketing activation

2.4. Smart Contracts and Vendor Management

Smart contracts serve as automated tools that streamline the logistics of events by enforcing specific terms, including deadlines and payment schedules, based on conditions that have been previously agreed upon. This automation plays a crucial role in minimizing administrative inefficiencies and reducing the likelihood of disputes among stakeholders (Chen et al., 2021). By leveraging this technology, event supply chains are poised for a significant transformation, enabling more agile and transparent relationships between vendors and organizers, ultimately enhancing the overall efficiency of the event planning process (Chen et al., 2021).

2.5. IoT and Smart Devices

IoT solutions like RFID-enabled badges and NFC smart wristbands are critical for streamlining event operations, enabling real-time crowd analytics, and improving security (Gretzel et al., 2015). Disney's MagicBand+ wristbands provide a seamless contactless experience integrating entry, payments, and ride interactions, exemplifying IoT's role in enhancing visitor journeys (Buhalis & Leung, 2018). Studies indicate that IoT-enabled environments allow data-driven event planning, including heatmaps and flow optimization, improving safety and satisfaction (Leung et al., 2013). CES utilizes RFID for real-time visitor tracking, enabling organizers to adapt spatial layouts dynamically (Wang et al., 2022). Real-time crowd tracking enables organizers to optimize stadium layouts, improve safety, and enhance the overall experience (Leung et al., 2013).

Functions in sports events:

- Contactless entry and cashless payments
- Real-time crowd flow and safety monitoring
- Personalized fan engagement and experiences

2.6. Blockchain and NFT Ticketing

Blockchain technology provides a tamper-proof solution for ticketing, significantly reducing fraud and resale abuses. Additionally, NFTs create new opportunities for innovative digital assets and exclusive VIP access (Regner et al., 2019; Ulrich et al., 2021). YellowHeart's groundbreaking blockchain ticket sales for Kings of Leon concerts were a pioneering effort in integrating NFTs with the delivery of exclusive content, thereby enhancing fan engagement (Müller et al., 2023). Coachella's 2022 NFT ticket pilot further demonstrates the potential of blockchain to create unique digital memorabilia while ensuring secure event entry (Coachella, 2022). Scholarly research underscores the capacity of blockchain to decentralize event management, thereby

enhancing transparency and fostering trust among stakeholders (Atzori, 2017). Early implementations in music events have inspired sports organizations to integrate NFTs for memorabilia, premium access, and interactive fan content, increasing loyalty and engagement (Müller et al., 2023).

Functions in sports events:

- Secure, transparent ticketing systems
- Exclusive digital content and collectibles
- Enhanced fan trust and decentralized management

2.7. Social Media and Digital Marketing

The use of short-form videos (TikTok, Instagram Reels), influencer partnerships, and user-generated content (UGC) increasingly drives event promotion and engagement (Zeng et al., 2021). VidCon's TikTok Live sessions and the NFL's AR-enhanced Super Bowl campaigns demonstrate effective digital engagement strategies (Li et al., 2020). Research underlines the efficacy of AI-powered content generation in enhancing marketing reach and personalization (Wang et al., 2022).

Functions in sports events:

- Interactive fan engagement through social media
- Personalized marketing and promotion
- Live streaming and behind-the-scenes access

2.8. Sustainable Tech solutions

Sustainability has emerged as a vital component of event management, with an increasing emphasis on digital tickets, renewable energy utilization, and waste reduction strategies (Mair & Jago, 2010). The Glastonbury Festival stands out with its initiative to eliminate single-use plastics and implement solar-powered stages, serving as a model for environmentally conscious event practices (Glastonbury, n.d.). Coldplay's "Music of the Spheres" tour showcases innovation through kinetic energy-harvesting dance floors, demonstrating how technology can engage audiences while minimizing environmental impact (Energy Floors, n.d.). Additionally, the carbon-neutral certification of the Google I/O Developer Conference illustrates the practicality of incorporating sustainability into large-scale tech events (South Pole, 2023). Stadiums and events increasingly adopt energy-efficient technologies, carbon-neutral certifications, and initiatives to minimize single-use plastics, catering to environmentally conscious fans (South Pole, 2023).

Functions in sports events:

- Reduced environmental footprint via sustainable technology
- Energy-efficient stadium operations
- Eco-friendly fan engagement experiences

Emerging technologies converge to create fan-centric, efficient, and sustainable sports event ecosystems. Challenges remain, including data privacy concerns, energy demands, and unequal access to digital

platforms. Future research should focus on responsible technology adoption, interoperability standards, and long-term impacts on fan experience and sports event economics (Getz & Page, 2020; Müller et al., 2023).

3. Methodology and results

3.1. Methodology

The topic of our research necessitated the application of two complementary methods to provide a comprehensive overview: both primary and secondary research were conducted. As secondary research, we primarily analyzed relevant literature related to digital technologies, artificial intelligence (AI), smart devices, social media, sustainability, and online and hybrid events. These topics are essential for the scope of our study, and thus both earlier and recent publications were reviewed. Given that this is a constantly evolving field, up-to-date knowledge is indispensable; therefore, we supplemented the literature review with insights obtained from interviews.

For the primary research, we conducted interviews with professionals working in event management whose expertise is relevant to the subject. Each interviewee has significant experience in organizing major events and works in different areas of the industry, which is reflected in the variety of perspectives—particularly regarding the importance and role of AI in event planning, organization, and execution. In total, we interviewed four experts who have recently and frequently engaged with AI, applying it in various phases of events, although the perceived usefulness and importance of AI differ depending on their professional domains. For instance, its perceived value varies between those who use AI in designing entertainment programs and those responsible for delivering these experiences to audiences. This divergence in viewpoints was the most notable; in other respects, there was broad consensus.

The interviews were conducted between June and July 2025, lasting between thirty minutes and one hour each. We chose interviews as our research method because they allow for an in-depth understanding of expert perspectives within the specific professional domain—in this case, the use of digitalization and AI in events. The process yielded positive experiences, with all interviewees being cooperative and forthcoming. We consider the number of interviews conducted to be sufficient for the current stage of research. All interviews followed a preliminary interview guide, ensuring comparability, while also allowing flexibility to reflect the specific expertise and experiences of each participant. In total, we asked our interviewees 11 open-ended questions covering topics such as the trends characterizing event management, our level of competitiveness, the use of digital technologies and artificial intelligence in event management, possibilities for audience entertainment, similarities and differences among the examined three events, and future trends in the use of technologies.

3.2. Results

The interviews were conducted in the summer of 2025 with individuals experienced in organizing sports events. We have had the opportunity to collaborate with them on multiple occasions, including at the events under study (FINA 2022 World Championships, 2023 World Athletics Championships, and 2024 Swimming Championships (25m)), enabling us to assess their professional expertise first-hand. The interviewed professionals were:

Gábor Varga, Presentation Manager, Sport Events

Gábor Korpás, Program Editor, Sport Events

Zoltán Mag, Television Director, Chief Director at sports events

Lajos Varga-Nagy, TV Technical Manager, Director at sports events

The interviewees' diverse professional backgrounds are reflected in the variation of opinions in certain areas of the findings. Overall, however, responses to most questions were aligned. While four interviews are insufficient for establishing definitive categories, there was a clear pattern: the two professionals responsible for sport presentation and program content shared largely similar views, as did the two TV directors, albeit from a different perspective.

All interviewees indicated 2017 as the year from which they began working on sporting events organized primarily by Sport Events. Prior to that, each had accumulated experience in various areas of event management, and all had worked for television channels in roles aligned with their professional expertise, thus possessing substantial broadcasting experience. This is a significant detail, as it means all participants have a clear understanding of what spectators and fans seek, and how their attention can be captured and maintained for both shorter and extended periods.

Following the first interview, it became evident that questions relating to digital technology were no longer particularly relevant, as it is virtually impossible to plan or execute an event without it (although, in our framework, these were still addressed alongside questions concerning artificial intelligence). In contrast, questions about AI were both timely and, in certain respects, divisive, as noted earlier.

Competitiveness

Respondents agreed that Hungary is competitive in organizing large-scale international sporting events, with budget being the most decisive factor, as many aspects depend on it. Naturally, there is a significant difference between an event held weekly and one staged every four years. In terms of audience entertainment, however, one interviewee noted that Hungary lags behind, as there is often a lack of conceptual input from clients, making it difficult to finance impactful program elements within a given budget. All participants concurred that engaging the audience is essential, as these moments create lasting memories and experiences—both before and after the competition itself—and thus play a crucial role in the overall event experience.

The role of digitalization in event management

As previously noted, digital technology is employed at every stage of event organization and is therefore considered a fundamental element. In contrast, artificial intelligence is approached with a degree of caution, as it is less familiar and still being learned; nevertheless, it is already being used in planning, lighting design, educational initiatives, and idea generation, as well as experimentally in graphic design. While the ease of implementation remains a question, AI has the potential to open new avenues in event management. Larger events, supported by more substantial technical resources, can more readily incorporate both digital and AI solutions, whereas smaller events typically do not employ them.

For spectators, it is essential to receive memorable experiences from entry to departure, and AI can contribute to this through various entertainment activities—though such applications are budget-dependent. The first such implementation occurred at the 2024 Swimming Championships (25m). However, there have also been instances (outside the scope of the events studied) where ChatGPT was used to prepare

quiz questions, but the system was unaware of recent rule changes, making it necessary to treat its proposed questions and answers with caution.

An important consideration is the extent to which professional organizations are open to adopting these technologies and regard them as significant for a given event. The interviews revealed that while some organizations are not receptive to sport presentation, others—such as the Handball Federation, Volleyball, Fencing, and Water Polo Federations—are open to it and even have dedicated staff responsible for such initiatives.

As previously noted, events cannot function without digital technology. Artificial intelligence introduces new possibilities, facilitating and accelerating organizational processes. For instance, it can be effectively used to draft running orders, contracts, and quizzes, or to quickly retrieve “consumable” information—although the generated content must be verified (as illustrated by an earlier example). AI represents an opportunity worth exploiting, as it can be intelligently integrated into the planning process or incorporated into entertainment elements. One respondent highlighted its usefulness for image manipulation, although this requires substantial programming expertise.

The ease of use and time requirements for implementing these technologies in event organization elicited somewhat differing responses, depending on the specific domain in which they are applied. Considering digitalization alone, respondents unanimously agreed that it is easy to use and reduces the time required for planning and organization, as previously mentioned. However, when focusing specifically on artificial intelligence, issues such as legal concerns, copyright, and the novelty of the technology itself often extend the required time, as its full scope of applications is not yet entirely clear. In addition, prompts must often be refined repeatedly for AI systems such as ChatGPT to generate satisfactory answers. Over time, as AI proficiency increases, searching for results and implementing solutions will become easier and faster.

The conceptualization and execution of an entertainment element often take longer, which does not always fit within an event’s time constraints. Consequently, AI-based entertainment is sometimes abandoned in favor of simpler games, particularly given the high costs associated with AI-driven activities. During preparations, an effective solution may be to employ an MC (master of ceremonies) capable of filling time in the event of a technical issue with AI implementation.

Audience entertainment

AI-powered entertainment—such as a face swap game, in which the face of a selected spectator is transformed into that of a famous individual—must be tested multiple times before being used in a live setting, as several potential sources of error may occur.

Spectators tend to enjoy games, a preference often influenced by the openness of the audience and their degree of engagement with the activities. Without such engagement, even elaborately designed games, which often require substantial financial investment, fail to resonate due to a lack of audience receptivity. Frequently, a minimalist approach proves more effective; for instance, activating the audience through collective shouting or coordinated wave motions can generate a stronger impact and enhance the overall experience more than more complex interactive tasks—such as requiring participants to play a game on their phones, imitate Hungarian words as foreigners, dance cam, catch virtual birds, become celebrity look-alikes using AI-assisted face-swapping technology, or mimic emojis. Consequently, continuous gameplay integration is not always feasible due to budgetary constraints or limited broadcast time.

The use of these digital technologies and innovations is also of interest from the athletes' perspective. Based on our analysis of international sporting events, it is observable that, especially during the initial days, some athletes experience discomfort (although not all) when required to enter the field through unconventional means—such as an introductory gate showcasing competitors or passing through a revolving gate. For this

reason, organizers often provide athletes with rehearsal opportunities to ensure they can enter the competition venue in a manner that preserves their comfort and concentration. Coaches frequently shield their athletes from these elements to maintain optimal focus.

From a broadcasting standpoint, however, it is essential to consider the visual presentation of athletes during live coverage, prompting the incorporation of deliberate show elements in how competitors approach the starting line. Thus, the reception of these performative aspects is highly individualized; some athletes may mentally disengage due to concentration demands, effectively being absent from the show element as they focus on their event. Modern awareness underscores the necessity of enhancing the appeal and engagement of competitions and their broadcasts for spectators and fans alike.

An alternative perspective regarding digital technology pertains to its widespread use in statistical data collection and performance measurement by athletes and their support teams. This demonstrates that digitalization manifests across multiple domains within sports.

All respondents agreed that the United States can be regarded as a leading example in the utilization of digital technology and artificial intelligence, followed by the United Kingdom, Saudi Arabia, and Qatar, with the latter two primarily due to financial resources. In these countries—particularly in the USA—the entertainment of spectators and fans, and notably entire families, is managed in a highly complex manner, reflecting the fact that these sporting events function as family-oriented programs.

Hungary is considered competitive in the use of digital technology and artificial intelligence within the domain of sports events, although this largely depends on the event's budget. Beyond openness, there is a need to boldly adopt these technologies and to further develop entertainment aspects, with the USA serving as a prominent example in this regard.

Comparison of the examined events

A key similarity across all three international sports events analyzed is that the respective international federations (swimming and athletics) evaluated them as highly well-organized, which is a significant accolade for Hungary and confirms its competitiveness in hosting major international sporting events. Nonetheless, the World Aquatics (WA) expresses a desire for new directions, citing a decline in the popularity of these sports. They believe that broadcasts must become more marketable, necessitating increased drama, excitement, and audience engagement from the spectators' perspective.

Since swimming competitions are held in enclosed venues, the spectator atmosphere tends to be darker and less vibrant compared to events such as water polo matches, which are often hosted in open facilities. Consequently, the sport presentation teams must consider these factors when designing entertainment elements.

A further similarity observed across the three examined events was the inclusion of various interactive games involving audience participation (e.g., kiss cams, dance cams). Additionally, all events employed the so-called intro gate or intro card, a modernized method for athlete presentation involving short introductory video clips projected onto LED screens, allowing athletes to showcase themselves as they wish. Each sporting event featured mascots designed to entertain and engage the audience, thereby enhancing the spectator experience. In the United States, the tradition and application of mascots are more extensive and multifaceted compared to Hungary, where their presence is primarily limited to photo opportunities.

An innovation first introduced at FINA 2022—the intro gate and intro card—was subsequently adopted at other sporting events, including the 2023 World Athletics Championships held in Hungary, setting a precedent that other countries later followed. The “walking DJ,” a performer carrying a DJ console on their shoulder while dressed as a disc jockey, also debuted at the Athletics World Championships and received great acclaim. While the concept holds potential for repeated use, it is challenging to find individuals capable

of effectively engaging the audience and sustaining a vibrant atmosphere in this role. Alongside the walking DJ, the live music medal plaza also represented a novelty. This concept, later emulated at events in other countries, involved postponing the medal ceremonies to the day following the competitions, prior to the afternoon or evening sessions. This arrangement allowed athletes to celebrate their podium finishes directly in front of the spectators, fostering closer interaction between athletes and fans.

Another innovation at the Athletics World Championships was the presence of live intro bands performing as finalists entered the competition arena.

In 2024, artificial intelligence was employed for the first time at the Swimming Championships (25m) to entertain spectators through interactive singing games—an approach not used previously. In addition, the intro gate, which debuted in 2022, was updated with a revolving gate mechanism.

The interviews clearly revealed that the nature of the on-site audience on a given day significantly influences outcomes. It was frequently observed that what worked successfully on one day did not necessarily achieve similar success at another time. Often, less is more; for example, activating mobile phone cameras in the evening, coordinated wave motions, or encouraging the audience to sing or wave their hands can have a much greater impact during an event. This indicates that while digital solutions are effective, they do not always achieve the desired effect. As previously noted, digital technologies tend not to function well at smaller events but have a much higher likelihood of success at large international competitions.

An illustrative counterexample can be found in the World Athletics Championships and the Swimming Championships (25m), where one of the most popular audience engagement programs was the “T-shirt cannon.” This device, which launches pre-packaged t-shirts using compressed gas, generated significant excitement, with spectators eagerly running to catch the apparel in the targeted zones. Many attendees appreciate receiving tangible items, and the t-shirt cannon served both as a physical giveaway and a memorable experience for the audience.

Another contemporary and much-discussed example highlights the drawbacks of digital technology use. Certain entertainment elements may pose significant risks; for instance, during a Coldplay concert in the summer of 2025, a segment featuring a couple who were later revealed not to be in a romantic relationship but instead had separate families, sparked widespread attention. The incident generated extensive online discourse and became a source of internet memes. From a research perspective, however, the focus lies not on the viral nature of the event but rather on the implications for entertainment programming. Specifically, it raises questions about the extent to which such entertainment is truly enjoyable for participants who may not wish to appear publicly, and concerns related to data protection regulations such as GDPR, as well as broader ethical and legal considerations.

Thus, while the application of these technologies can be innovative and engaging, their use also prompts numerous important questions. It was repeatedly noted that spectators often exhibited reluctance to participate in entertainment activities involving digital technology or artificial intelligence, frequently due to shyness or discomfort with public exposure, rendering such situations uncomfortable for them.

Future digital trends

The final section of the research focused on the anticipated changes in digital technology and artificial intelligence (AI) over the coming years, as perceived by the interviewed experts, and how these developments are expected to impact the organization of sporting events. All interviewees agreed that AI will continue to evolve and be increasingly utilized across a growing number of events, particularly as its most effective applications become better understood. Advancements are expected in lighting, sound technology, and imaging, alongside an expanded role for drones. AI will be progressively employed in visual

design, control systems, data analysis, automation, and the deployment of intro cards, as well as in entertainment games, which are likely to have shorter life cycles and will require openness to innovation.

Event organizers, however, hold a somewhat different perspective regarding the role and future of AI. While they concur that AI's use will expand and become necessary in many areas, they question whether investing substantial resources and attention into AI is always justified or cost-effective. Notably, AI is not currently used in program editing but is applied in design planning. As previously discussed, audience activation through simple means—such as coordinated clapping, t-shirt cannons, or communal singing—generates significantly stronger experiences and atmospheres than digital interactions like playing games on mobile phones or mimicking emojis. The emphasis lies on evoking emotions and promoting physical engagement.

Summary of the examined topics

Table 1. Result of the interview

Topic	Key Findings from Interviews	Comparative Insights
Competitiveness	Hungary is competitive in hosting large international sporting events; budget is the decisive factor.	Large-scale events allow more innovation than smaller or recurring events.
Audience Entertainment	Audience engagement is essential for creating memorable experiences.	Simple activation tools (clapping, singing, waves) often outperform digital games.
Digitalization	Digital technologies are fundamental and used in all phases of event management.	High effectiveness regardless of event type or size.
Artificial Intelligence (AI)	AI is in an early adoption phase; mainly used for planning, design, and idea generation.	Larger events are more capable of integrating AI solutions.
AI-based Entertainment	Innovative but costly and technically risky; requires extensive testing.	Frequently replaced by simpler, more reliable entertainment elements.
Athletes' Perspective	Reactions to show elements vary; some athletes experience discomfort.	Rehearsals help maintain concentration and acceptance.
International Comparison	The USA leads in digital and AI-driven entertainment, followed by the UK, Saudi Arabia, and Qatar.	Financial resources strongly influence implementation depth.
Future Trends	Increasing AI use, automation, drones, and advanced visual technologies.	Shorter life cycles of entertainment concepts and growing need for innovation.

Source: Own edited

In summary, the interviews provided valuable and insightful information that complements the theoretical framework outlined earlier. Given that event management is a highly practical discipline, the study prioritized presenting practical examples and firsthand experiences that can be readily applied by professionals in the field.

Based on the above, the following conclusions can be drawn in response to the research questions.

Regarding the first question (“How do artificial intelligence-driven fan engagement tools influence audience interaction, emotional involvement, and overall satisfaction at international sporting events?”), the interviews with experts clearly indicate that we are still in the early stages of understanding how and in what forms AI can be effectively applied to engage audiences, and therefore experience remains limited. As

mentioned, AI was first utilized for audience entertainment at the 2024 Swimming Championships (25m). This represented a novelty for both organizers and spectators. The reception of the face swap game was positive, with fans expressing enjoyment. Future inquiries will focus on identifying additional entertaining elements that can be developed and implemented to enhance audience engagement. Consequently, limitations arise primarily from available funding, creativity, and the demographic composition of the audience.

However, it is also important to emphasize—based on the interview data—that simpler audience activation methods such as collective singing, coordinated clapping, and wave motions produced greater emotional involvement and satisfaction among spectators. These traditional forms of engagement remain the most effective and reliable means of fostering audience participation at sporting events.

Regarding the second research question (“What are the operational and strategic advantages of applying technologies such as IoT, AR/VR, and blockchain in event management?”), the focus primarily lies on the perspectives of event organizers and sports presentation teams. In contemporary event management, these technologies are indispensable; for example, real-time data on the number of spectators present at the venue directly influences the type, frequency, and duration of interactive games conducted. There have been instances where, despite the original schedule including the use of a T-shirt cannon, its deployment was cancelled due to insufficient audience numbers. LED walls and other projection technologies significantly enhance the fan experience, as the mode of communication—through graphics, sound, and lighting effects—plays a critical role in how effectively information and content are conveyed to the audience. The responsibility of the sports presentation team is to design increasingly engaging and impactful virtual and other elements to entertain spectators, for example by creating fan zones, quiz tasks, and providing additional statistics and information.

The third research question addressed how these technologies contribute to the long-term innovation, competitiveness, and sustainability of event management practices. Based on both interviews and our own experience, it can be concluded that the use of digital technologies is fundamental, as they are employed across all areas of event organization. The availability of documents such as event scripts in cloud storage supports sustainability by reducing the need for printed materials compared to previous practices. Artificial intelligence, however, represents a somewhat different case, as it is relatively new, and limited experience exists regarding its precise and effective applications. AI facilitates preparatory work, for instance, by assisting in writing running orders or compiling quiz questions. Conversely, AI-based entertainment games present more complex and costly challenges. Nonetheless, AI enables innovative solutions, and with accumulating experience from event to event, increasingly competitive applications can be developed.

4. Conclusion

This study provides a comprehensive examination of the latest trends in digital and AI technologies within event management, with a particular focus on their application in Hungarian and international sports events. While digital technology is firmly established across all phases of event organization, AI remains in the early stages of adoption, constrained by budget, time, and familiarity. Tools that simultaneously enhance audience experience and operational efficiency offer the highest added value.

The results of the expert interviews conducted as part of the primary research reveal that while digital technology has become an indispensable prerequisite in all phases of event organization, the application of artificial intelligence remains in an experimental stage, often constrained by limitations in budget, time, or expertise. The findings indicate that the tools delivering the greatest added value are those capable of simultaneously enhancing audience experience and supporting organizational efficiency. At the same time, the interviews emphasize that audience engagement is often achieved most reliably through simple, low-cost methods (e.g., orchestrated applause, audience waves, T-shirt cannons).

Case studies from FINA 2022, the 2023 World Athletics Championships, and the 2024 Swimming Championships (25m) demonstrate Hungary's competitiveness in hosting large-scale international events, while also revealing opportunities for further development in entertainment and interactive elements. For successful future integration, expanding technical expertise, fostering creativity, and considering audience receptiveness will be essential.

Based on the interviews, a clear distinction emerges between the perceptions of digital technology and artificial intelligence (AI). While digitalization has become a fundamental and indispensable tool in event management, the application of AI remains largely experimental, primarily serving supportive functions such as planning and preparation.

A comparison of the examined events indicates that large international sporting events provide a more favorable environment for testing innovative digital and AI-based solutions, whereas the effectiveness and return on investment of these technologies are more limited at smaller-scale events.

In terms of audience entertainment, the interviews consistently highlighted that simple, emotionally engaging, and community-oriented activities (e.g., collective singing, clapping, waves, T-shirt cannons) often have a greater impact than costly and technologically complex digital games. This finding was recurrent across multiple events and respondents.

From an international perspective, Hungary can be considered competitive, particularly in terms of organizational quality and innovation. However, budgetary constraints and audience receptiveness represent significant influencing factors. The example of the United States demonstrates that the effective implementation of advanced technological solutions and complex entertainment concepts is closely linked to adequate financial and cultural resources.

The research findings contribute to the strategic and informed use of technological innovations in event management, aiming to enhance long-term competitiveness, sustainability, and the overall audience experience.

Conflict of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- Apple. (n.d.). Apple events – Special event stream. <https://www.apple.com/apple-events/event-stream/?useASL=true>
- Atzori, M. (2017). Blockchain technology and decentralized governance: Is the state still necessary? *Journal of Governance and Regulation*, 6(1), 45–62. https://doi.org/10.22495/jgr_v6_i1_p5
- Buhalis, D., & Amaranggana, A. (2015). Smart tourism destinations enhancing tourism experience through personalisation of services. *Tourism Management*, 47, 186–198. <https://doi.org/10.1016/j.tourman.2014.09.012>
- Buhalis, D., & Leung, D. (2018). Smart hospitality—Interconnectivity and interoperability towards an ecosystem. *International Journal of Hospitality Management*, 71, 41–50. <https://doi.org/10.1016/j.ijhm.2017.11.011>
- Chen, Y., Xu, H., & Whinston, A. B. (2021). Blockchain smart contracts: Applications, challenges, and future directions. *Information & Management*, 58(7), 103496. <https://doi.org/10.1016/j.im.2021.103496>
- Coachella to sell lifetime festival guest passes as NFTs. (2022, February 2). Hypebae. <https://hypebae.com/2022/2/coachella-nft-lifetime-festival-guest-passes-sell-ftx-partnership-cryptocurrency-vip>
- Energy Floors. (n.d.). Coldplay’s energy-generating dance floors. <https://energy-floors.com/coldplay/>
- Filo, K., Funk, D., & O’Brien, D. (2015). Examining event experiences: An interaction approach. *Event Management*, 19(1), 49–64. <https://doi.org/10.3727/152599515X14281435315871>
- Getz, D., & Page, S. J. (2020). *Event studies: Theory, research and policy for planned events*. Routledge.
- Glastonbury Festivals. (n.d.). Sustainability initiatives. <https://www.glastonburyfestivals.co.uk/>
- Gretzel, U., Sigala, M., Xiang, Z., & Koo, C. (2015). Smart tourism: Foundations and developments. *Electronic Markets*, 25(3), 179–188. <https://doi.org/10.1007/s12525-015-0196-8>
- Hilken, T., de Ruyter, K., Chylinski, M., Mahr, D., & Keeling, D. I. (2017). Augmenting the eye of the beholder: Exploring the strategic potential of augmented reality to enhance online service experiences. *Journal of the Academy of Marketing Science*, 45, 884–905. <https://doi.org/10.1007/s11747-017-0529-6>
- Leung, R., Law, R., van Hoof, H., & Buhalis, D. (2013). Social media in tourism and hospitality: A literature review. *Journal of Travel & Tourism Marketing*, 30(1–2), 3–22. <https://doi.org/10.1080/10548408.2013.750919>
- Mair, J., & Jago, L. (2010). The development of a conceptual model of greening in the business events tourism sector. *Journal of Sustainable Tourism*, 18(1), 77–94. <https://doi.org/10.1080/09669580903022728>
- Müller, J. M., Kiel, D., & Voigt, K. I. (2023). What drives the implementation of industry 4.0? The role of opportunities and challenges in the context of sustainability. *Sustainability*, 15(4), 3227. <https://doi.org/10.3390/su15043227>
- Neuhofer, B., Buhalis, D., & Ladkin, A. (2015). Smart technologies for personalized experiences: A case study in the hospitality domain. *Electronic Markets*, 25(3), 243–254. <https://doi.org/10.1007/s12525-015-0195-9>
- Regner, F., Urbach, N., & Schweizer, A. (2019). NFTs in practice – Non-fungible tokens as core component of a blockchain-based event ticketing platform. In *ECIS 2019 Proceedings*. https://aisel.aisnet.org/ecis2019_rp/127/

Sánchez-Cañizares, S. M., & López-Guzmán, T. (2012). The use of mobile phones and smartphones as a tourist resource. *Tourism & Management Studies*, 8(1), 91–99.

South Pole. (2023). Climate neutral events. <https://www.southpole.com/>

Tussyadiah, I. P., Wang, D., Jung, T. H., & tom Dieck, M. C. (2018). Virtual reality, presence, and attitude change: Empirical evidence from tourism. *Tourism Management*, 66, 140–154. <https://doi.org/10.1016/j.tourman.2017.11.003>

Ulrich, S., Trenz, M., & von Flotow, P. (2021). Digital transformation and the role of blockchain technology in event management. *Information Systems Frontiers*, 23(2), 399–416. <https://doi.org/10.1007/s10796-020-10008-5>

Wang, D., Li, X., & Li, Y. (2022). Artificial intelligence in event management: Opportunities, challenges, and future directions. *Journal of Hospitality and Tourism Technology*, 13(1), 41–57. <https://doi.org/10.1108/JHHT-05-2021-0123>

World Travel & Tourism Council. (2024, January 29). AI set to revolutionise travel & tourism, says latest WTTC report. <https://wttc.org/news/ai-set-to-revolutionise-travel-and-tourism-says-latest-wttc-report>

Zeng, B., Gerritsen, R., & Hu, C. (2021). The impact of short-video platforms on event marketing: An empirical study on TikTok. *Journal of Interactive Marketing*, 55, 1–16. <https://doi.org/10.1016/j.intmar.2021.03.002>



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VOLUME 1

AI, Sustainability and Digital Transformation: Shaping the Future of Business and Society

Theme and fun parks: a review paper (2020-2024)

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Abstract: Theme and fun parks have become integral components of the global tourism industry, serving as major attractions that drive both domestic and international travel. A comprehensive approach systemizing research, relevant to the words theme / fun parks and tourism from the Scopus database, shows how these parks have changed from basic entertainment spots to complex, immersive experiences that combine storytelling, technology, and themed environments. The paper also explores the various ways these parks benefit local economies, such as by creating jobs, boosting tourism revenue, and supporting regional growth. The issues related to the role of theme parks and fun parks in tourism, primarily their economic, social, and cultural impacts, are also examined. Furthermore, the paper signals the need to explore more the challenges and sustainability concerns that the growth of these parks entails, such as environmental impacts, over-tourism, and resource management. The paper's originality stems from the lack of similar systematic research and the identification of under-researched relevant topics. The review concludes with a reflection on future trends in the theme park industry, including the increasing use of technology, the slowly growing emphasis on sustainability, all in order to facilitate the expansion of tourism markets.

Keywords: theme parks, fun parks, tourism entertainment, economic impact of theme and fun parks, sustainability of theme and fun parks.

JEL Classification: L83, Z32, R11, Q01

1. Introduction

Theme and fun parks have become key attractions in the global tourism industry, offering immersive experiences that blend entertainment, technology and storytelling. Nowadays, they play a crucial role in local economies, regional branding, and cultural exchange, drawing millions of visitors annually (Hsieh, Yi-Chih You, Peng-Sheng, 2024). They have overgrown their function of entertainment centers and become narrative and technology based and tourist destinations (Liang, Zengxian & Li, Xiang, 2023).

Despite their popularity, the growth of theme parks presents challenges, including sustainability issues, environmental impacts, and the management of large visitor flows. Furthermore, the integration of digital technologies and virtual experiences is reshaping the future of the industry.

This review paper aims to provide a comprehensive overview of researched topics which address theme and fun parks in tourism, analyzing their economic, social, and cultural impacts, while addressing the challenges and opportunities they present.

The aim of this review paper is to explore the impact of theme and fun parks on the tourism industry detecting their key challenges and under-researched correlated topics in order to tackle better future issues, focusing on:

- The evolution and integration of theme parks into global tourism along with their economic contributions, including revenue generation and job creation.

- The social and cultural impacts on communities and visitors.
- The challenges related to sustainability and technological innovation.

The goal is to analyze the impact of theme and fun parks on tourism, particularly related to visitor demographics, economic contributions, and emerging industry trends, and to provide actionable recommendations for future developments in the sector.

This paper consists of four chapters. After the introduction, the second chapter is the methodology, followed by the results of the desk analyses of the available relevant papers according to the Scopus database. The last chapter is the conclusion, which provides a summary of key findings, contributions to theory and practice, along with limitations of the research and future research suggestion directions.

2. Methodology

This review paper was based on a comprehensive search of academic literature to gather relevant sources that address the relationship between theme and fun parks and tourism. The Scopus database was used to choose and examine these sources. The desk research was carried on from October 2024 till Novembre 2024.

The first step in the methodology involved defining the criteria for selecting sources relevant to the topic. The primary focus was on articles that explore the intersection of theme and fun parks with the tourism industry. To ensure the relevance and quality of the sources, the following criteria were applied to the Scopus search within the article title for the key topic (fun/theme + parks) and by using a broader search criterion (Article title, Abstract, Keyword) for the field of application (tourism):

Table 1 Search strategy

SEARCH WITHIN	SEARCH DOCUMENTS
Article title	theme
OR	
Article title	fun
AND	
Article title	parks
AND	
Article title, Abstract, Keywords	tourism

Source: authors' contribution

Secondly, to ensure the sources were current and relevant to the field, only documents published between **2020 and 2024** were included in the search results. This time frame was chosen to capture the latest trends and research on theme and fun parks and their role in tourism.

After applying the above search criteria and date limitations, a total of **58 sources** (11/2024) were found. Namely, the article title search for all terms provided a list with 1/3 less papers, while almost double where the titles found by searching for all the relevant terms using the filtering option “within article title, abstract and keywords”

These 58 sources were then screened to determine their relevance to the review topic.

- *Exclusion of Irrelevant Sources:* Four sources were excluded because they did not directly relate to the theme and fun park-tourism nexus.
- *Unavailability of Documents:* Thirty-two sources were excluded due to the unavailability of full documents, making it impossible to analyze them further.
- *Access Limitations:* Three sources were inaccessible due to restrictions in accessing the full text.

Finally, following the screening process, **19 sources** remained that met the inclusion criteria and were available for analysis. These sources formed the basis of the review paper and were summarized and analyzed in the final discussion.

3. Results

YEAR	AUTHORS	TITLE	RELEVANT FINDINGS	SUMMARY	METHODOLOGY / METHODS / DATA
2024	Song, Xiaoqing, Wu, H., Jiang, W. <u>Zhi, Junjun</u> <u>Xia, Xinyu</u> <u>Long, Yi</u> <u>Su, Qin</u>	Using geotagged facial expressions to visualize and characterize different demographic groups' emotion in theme parks	This research underscores the necessity of considering demographic factors in tourism studies to better understand and cater to the emotional needs of different tourist groups.	Tourism is an emotional sphere, and researchers focus on emotions to optimize tourism experiences. Tourism studies on emotions mostly ignore differences in emotions across demographic tourist groups by gender and age, thus limiting the understanding of emotions to the explicit characteristics of tourists' emotions. On the basis of geotagged facial expressions on social media platforms, this study aims to visualize the emotions of groups in scenic spots and then reveal the variations between groups' emotions within theme parks. By employing a facial recognition algorithm, an emotion distribution graph was proposed to represent groups' emotions in detail. Some analytical methods were combined to characterize of the emotion distribution of each group. Through a comprehensive comparison, the results suggest that there are unique characteristics of emotion distribution for each group and considerable variations between them.	Photos of visitors collected from social media, facial emotion recognition software analyses / secondary data
2024	<u>Hsieh, Yi-Chih</u> You, Peng-Sheng	A comparison of three evolutionary algorithms for group scheduling in theme parks with multitype facilities	This research provides valuable insights into addressing operational challenges faced by theme parks and improving the overall visitor experience,	During the peak tourist season, large theme parks often experience a simultaneous influx of visitors, resulting in prolonged waiting times for popular attractions. This extended waiting significantly reduces tourists' satisfaction and may negatively impact their willingness to revisit the theme park. In Taiwan, schools at all levels often plan graduation	Developed a novel approach called the Theme Park Problem with Multitype Facilities (TPP-MTF). Implemented and compared three evolutionary algorithms: a)

YEAR	AUTHORS	TITLE	RELEVANT FINDINGS	SUMMARY	METHODOLOGY / METHODS / DATA
			particularly for student groups.	trips to theme parks for their students. Students are divided into groups and must enter and exit the theme park at the same time. This article presents a new theme park problem with multitype facilities (TPP-MTF) for student groups. Based on the group's preference for theme park facilities, multitype reserved tickets with popular facilities are designed for groups, so groups do not need to wait for the reserved facilities. Since the waiting time for groups can be reduced, the theme park can also obtain ticket fees in advance and estimate the number of visitors to the theme park, so the theme park and the group can achieve a win-win situation. This article proposes a new decoding approach for a random permutation of integer sequence and embeds it into an immune-based algorithm, genetic algorithm, and particle swarm optimization algorithm to solve the TPP-MTF problem.	Immune-based algorithm b) Genetic algorithm c) Particle swarm optimization algorithm. Retrieval of data from one park (case study) and experimentations of group scheduling system / Secondary data

YEAR	AUTHORS	TITLE	RELEVANT FINDINGS	SUMMARY	METHODOLOGY / METHODS / DATA
2024	Ryndach, Marina Kazak, Anatoliy Selivanov, Victor Gurevskikh, Olga Dolgushina, Yulia Leonid, Maksimov Chudnovskaya, Tatyana Kryukova, Anastasia	Recreational and health aspect of theme park activities	The paper highlights that theme parks can be a viable alternative to new hotel construction in resort areas, supporting the Russian government's goal to double tourist flows by 2030. It emphasizes improving occupancy rates of existing hotels and notes that year-round theme parks can mitigate tourism seasonality. Overall, the study argues that theme parks can enhance local economies by attracting millions of tourists.	The paper examines the recreational and health aspect of theme park activities. This study substantiates the idea that theme parks in the modern tourism business should become an alternative to the prohibitive construction of hotels in resort areas and traditional recreation areas. This paper is also devoted to understanding the problem of fulfilling the ambitious goals formulated by the government of the Russian Federation to form a new domestic tourism industry by 2030. According to this project, the tourist flow should double, reaching 140 million tourists per year. By 2030, 300 thousand rooms will be built; this is approximately a third of the existing ones. However, there is an alternative solution to this problem. For the development of the tourism industry, today it is more important not to build new hotels, but to create an additional tourist flow in order to increase the occupancy and profitability of existing hotels. The most effective tool for this is the creation of year-round theme parks.	Conceptual analysis and analyses of available strategic documents and studies of the effects of parks vs. hotel construction / Secondary data
2024	Florido-Benítez, Lázaro	Analysis of Latin American Theme Parks in a Tourism Context	The manuscript analyzes Latin American theme parks as key tourist attractions to boost post-pandemic tourism. It evaluates the most visited	The main goal of this manuscript is to analyze Latin American theme parks as tourist attractions for stimulating future tourism demand after the pandemic crisis. The methodology used in this study is a set of qualitative and quantitative indicators for measuring the most visited Latin American parks	Multiple case study, qualitative and quantitative indicators from various sources, correlation analyses / Secondary data

YEAR	AUTHORS	TITLE	RELEVANT FINDINGS	SUMMARY	METHODOLOGY / METHODS / DATA
			parks from 2011 to 2022 and their locations, finding that parks like Six Flags Mexico and Beto Carrero World significantly enhance local tourism. A key finding is that buses are the most efficient transportation mode, and there is a strong correlation between a park's success and its accessibility.	from 2011 to 2022 and where they are localised to address the importance of the location of these theme parks and the cities in which they are operating. The results reveal that Latin American parks such as Six Flags Mexico, Beto Carrero World, Hopi Hari, La Feria de Chapultepec and Parque Xcaret are tourist attractions that promote and improve the tourism industry in Latin American cities, and their entertainment activities attract millions of visitors each year. One of the most important findings from this study is that the bus is the primary and most efficient (regarding travel time) mode of transportation in the cities analysed, as well as that there is a high correlation between the success of tourist attractions, their accessibility by plane and on land and their distance to Latin American cities.	
2024	Yuan, Li Marzuki, Azizan	What keeps historical theme park visitors coming? Research based on expectation confirmation theory	The article explores the impact of culture on tourist experiences at historical theme parks in China, particularly the Song Dynasty park in Kaifeng. It highlights the park's role in promoting local history and culture. The study identifies five key constructs: tourism motivation, service quality, tourism experience, satisfaction, and post-trip behavioral intentions. It finds that	In China, “theme park” is a new field of tourism research, an excellent theme park can not only drive the development of a city’s tourism industry, but also help it better publicize its history and culture. The article takes Kaifeng, China as the background, and selects the Song Dynasty historical and cultural theme park, which was established based on the traditional ink painting Qingming Riverside Drawing, as an example, to study the factors affecting tourists’ travel experience in historical and cultural theme parks, and based on which it explores the reasons for the formation of tourists’ satisfaction and post-trip behavioral intentions, to provide references and suggestions for the development of cultural theme parks from the point of view of travel experience. Based on the expectation confirmation	Expectation confirmation theory, case study / primary data

YEAR	AUTHORS	TITLE	RELEVANT FINDINGS	SUMMARY	METHODOLOGY / METHODS / DATA
			tourism motivation and service quality significantly influence the overall experience, which affects satisfaction and future behavior. The research emphasizes the need for cultural theme parks to improve service quality and understand tourist motivations to enhance experiences.	theory, this paper introduces five constructs, namely, expectation (tourism motivation), performance (service quality), confirmation (tourism experience), satisfaction, and post-trip behavior intention, to construct a model of the factors influencing tourists' satisfaction by tourism experience in historical theme parks and analyze the intrinsic correlation among the factors within the model. It is found that tourists' tourism experience is mainly affected by tourism motivation and service quality, satisfaction and post-trip behavior intention are jointly determined by the above three.	
2023	Bai, Shizhen He, Hao Han, Chunjia Yang, Mu Yu, Dingyao Bi, Xinrui Gupta, Brij B. Fan, Weijia Panigrahi, Prabin Kumar	Exploring thematic influences on theme park visitors' satisfaction: An empirical study on Disneyland China	The study examines how thematic influences affect visitor satisfaction at Shanghai Disney Resort using 112,000 reviews from June 2016 to March 2022. It finds that satisfaction is closely linked to service quality and enjoyment. Early visitors focus on specific rides, while later visitors emphasize the overall experience. Additionally, the relationship between review content and ratings weakens over time, indicating that reviews capture subjective experiences better than ratings.	This study aims to explore thematic influences on theme park visitors' satisfaction through user-generated data. To this end, the authors first used an unsupervised machine learning method, structural topic modeling, and analyzed 112,000 reviews post by visitors to Shanghai Disney Resort from June 16, 2016 to March 4, 2022. The findings suggest that visitors' satisfaction is highly related to service in the theme park and their playing feeling, and early tourists pay more attention to the experience of specific playing items while later tourists focus on the overall playing experience. In addition, an empirical study is conducted by treating the ratings associated with each review as dependent variable and each topic represented by comments as independent variables, which shows that the relationship between the customer reviews and ratings by tourists becomes less pronounced over time. In other words, as time goes, customers review can reflect their subjective feelings or experience, but the rating is not.	Empirical study, case based, demand side / primary data

YEAR	AUTHORS	TITLE	RELEVANT FINDINGS	SUMMARY	METHODOLOGY / METHODS / DATA
2023	Liang, Zengxian Li, Xiang	What is a Theme Park? A Synthesis and Research Framework	The article defines theme parks using five main characteristics: thematic identity, controlled access, hybrid consumption, performative labor, and merchandising. It highlights the need for a uniform framework in theme park research, proposing a multidisciplinary approach to assess these characteristics. A research framework covering four domains is introduced.	Theme parks have been studied from various stances, yet a uniform definition and integrated framework remain lacking for theme park research and practice. Based on a comprehensive review and research synthesis, this paper defines a theme park as a dedicated space featuring five main characteristics: thematic identity, closed space with controlled access, hybrid consumption, performative labor, and merchandising. This paper further considers multidisciplinary lenses in theme park studies, particularly in terms of how these five characteristics can be assessed. A research framework covering four domains (industry, tourists/visitors, environment, and impacts) is accordingly proposed to inspire theoretical advances, identify research gaps, promote relevant research, and facilitate managerial practices. Scholars are encouraged to move beyond current empirical confines and shape the interdisciplinary future of theme park tourism research.	Synthesis of secondary data and research papers
2023	Wang, Xiaohuan Fan, Zhi-Ping Li, Haibin Li, Yujie	Discriminatory Pricing Strategy for Sustainable Tourism in Theme Parks Considering Visitors' Price Fairness and Service Value Perceptions	The paper examines how discriminatory pricing strategies can enhance sustainable tourism in theme parks amid rising carbon emissions. It emphasizes the need for parks to invest in clean energy, funded by admission fees and in-park spending. The proposed pricing model aims to secure revenue for low-carbon initiatives	With the increase in carbon emissions in the tourism industry, more tourism enterprises need to make sustained investments in clean energy and green technologies. From the perspective of theme park revenue and operational management, such investments mainly come from admission fees and in-park consumption. The objective of this study is to discuss the role of discriminatory pricing strategies in supporting sustainable tourism in theme parks. Based on transaction utility theory and equity theory, visitors' price fairness perception and service value perception are incorporated into the visitor utility function. On this basis, a goal-programming-based discriminatory pricing model with three goals	Statistical model and its testing according to data collected from visitors / primary data

YEAR	AUTHORS	TITLE	RELEVANT FINDINGS	SUMMARY	METHODOLOGY / METHODS / DATA
			while ensuring equity among visitors and fairness between them and the parks. By considering perceptions of price fairness and service value, the strategy helps generate funds for sustainability and improves visitor satisfaction, brand loyalty, and revisit likelihood.	is proposed: achieving the established revenue target, achieving distributed justice between visitors with unequal status (advantaged visitors and disadvantaged visitors), and achieving distributed justice between visitors and theme parks. The research results show that, for one thing, the proposed discriminatory pricing model can enable theme parks to secure sufficient funds to invest in low-carbon activities (Goal 1) while for another, visitors' satisfaction, brand loyalty, and willingness to revisit and sustainably consume in theme parks are improved by the realization of distributed justice through the discriminatory pricing strategy (Goals 2 and 3).	
2023	Li, Shugang Dou, Qian Chen, Hui Yu, Zhaoxu	The Impact of Consumer's Adaptation to the Creative Culture of Theme Parks on Review Usefulness	The study reveals that consumers' cultural adaptation to creative symbols in theme parks enhances their evaluation of online review usefulness, especially when reviews exhibit high symbolic creativity. Cultural factors also help simplify the information consumers process during decision-making, making reviews more effective. Furthermore, advanced ticket levels influence the usefulness of reviews, moderating extremely positive ones	There has been limited exploration into the influence of consumers' cultural adaptation to creative symbols in theme parks on the usefulness of online reviews, which is significant for enhancing tourism experiences, targeted marketing, personalized services, and informed tourism choices. This study aims to bridge this gap by examining how cultural adaptation factors interact and impact the review usefulness, and by considering the role of cultural adaptation in simplifying information during consumer decision-making processes. The study investigates how consumers' decision reference points, represented by advanced ticket levels, moderate their attention to attribute consistency when evaluating the review usefulness. A sample of 5929 consumer reviews of Disney theme parks from 2019 to 2022 on Meituan.com is analyzed using latent semantic analysis and Tobit regression to test the proposed hypotheses. It was found that high	Sematic analyses of reviews on available platforms / secondary data

YEAR	AUTHORS	TITLE	RELEVANT FINDINGS	SUMMARY	METHODOLOGY / METHODS / DATA
			but not extremely negative ones, with the impact varying based on the symbolic creativity of the reviews.	symbolic creativity reviews stimulate cultural adaptation and increase attention to service attributes when evaluating review usefulness. Moreover, advanced ticket levels do not moderate the usefulness of extremely negative reviews. However, they do have a moderating effect on the usefulness of extremely positive reviews.	
2023	Bai, Shizhen He, Hao Han, Chunjia Yang, Mu Bi, Xinrui Fan, Weijia	What makes a theme park experience less enjoyable? Evidence from online customer reviews of Disneyland China	The study explores reasons for tourists' less enjoyment of theme parks by analyzing reviews of Shanghai Disney Resort. Key issues identified include "parking," "service attitude," "recommendation feeling," "experience comparison," and "entrance" processes. Group travelers often face dissatisfaction with parking and fast track issues, while solo or small group visitors are more concerned about staff service and entrance procedures. The findings can help address dissatisfaction and enhance visitor experience.	The aim of this study was to explore the causes of tourists' lesser enjoyment of theme parks through an unsupervised machine learning approach—structural topic modelling. Specifically, the research extracted a comprehensive list of discussion topics about the travel experience of tourists through the analysis of 112,000 customer reviews released by visitors to the Shanghai Disney Resort from 16 June 2016 to 4 March 2022. Then, sentiment analysis was used to distinguish positive and negative topics and to explore the relationship between tourists who buy different ticket types and sentiments in negative topics. The results show that problems such as “parking,” “service attitude,” “recommendation feeling,” “experience comparison,” and “entrance” may be the main reasons for an unpleasant experience. In addition, it was also found that when tourists travel in groups (e.g., via family tickets), customers feel unhappy because of parking and fast track problems. Moreover, when tourists travel alone or with small groups, staff service attitudes, experience comparisons, and entrance processes are the sources of greater concern.	Content analyses of online reviews / Secondary data

YEAR	AUTHORS	TITLE	RELEVANT FINDINGS	SUMMARY	METHODOLOGY / METHODS / DATA
2022	Wang, Xi Yu, Yun Zhu, Zhe Zheng, Jie	Visiting Intentions toward Theme Parks: Do Short Video Content and Tourists' Perceived Playfulness on TikTok Matter?	The study examines factors influencing customers' visiting intentions toward Universal Studios Beijing on TikTok. Key findings reveal that social interaction, informativeness, and trust significantly affect perceived usefulness, which in turn impacts visiting intentions through ease of use and playfulness.	The purpose of this study was to look into the potential determinants of customers' visiting intentions toward Universal Studios Beijing on short video platforms such as TikTok. In addition, descriptive analysis was also conducted to show the demographic and other basic characteristics of the sample. The findings revealed that social interaction, informativeness, and trust had significant effects on perceived usefulness, as well as significant influences on the related visiting intentions from the perceived usefulness, ease of use, and playfulness. This study filled in the research gaps of the TikTok studies based on the extended technology acceptance model (TAM) and explored the effects of perceived playfulness on the theme park. The study provides insights for theme park marketers, internet vloggers, and local governments.	Demand side analyses, extended technology acceptance model (TAM) / Primary data
2022	Zhou, Liting Ouyang, Fei Li, Yang Zhan, Jieling Akhtar, Nadeem Ittefaq, Muhammad	Examining the Factors Influencing Tourists' Destination: A Case of Nanhai Movie Theme Park in China	The study explores theme park tourism in China using a stimulus-organism-response (S-O-R) framework. It identifies a second-order tourism experience made up of four factors: activity, environment, facility, and interaction experiences, with activity experience being the most impactful. The research highlights a critical pathway from brand identity to brand	The present study used a stimulus-organism-response (S-O-R) theoretical framework to examine the relationship between theme park tourists' experience, brand identity, brand satisfaction, and brand loyalty in China. By using the structural equation model (CB-SEM), this paper illustrates the process of forming destination brand loyalty for sustainable tourism on theme parks. The results suggested a second-order structure of tourism experience. The first-order four factors have different impacts on the second-order tourism experience. Activity experience is the most important factor influencing tourism experience, followed by environment experience, then facility experience, and finally interaction experience. In terms of tourism experience, individual brand	SEM (Structural equation modelling), structure and path analyses of model / primary data

YEAR	AUTHORS	TITLE	RELEVANT FINDINGS	SUMMARY	METHODOLOGY / METHODS / DATA
			satisfaction and then to brand loyalty, which influences tourists' behavior. Additionally, brand satisfaction plays a significant mediating role in the relationship between brand identity and destination loyalty.	identity-brand satisfaction-brand loyalty is the most important path of a theme park on tourists' behavioral intention, among which brand satisfaction plays the most significant partial mediation effect in the relationship between individual identity and destination loyalty. It is expected that the results of this study provide a reference for improving tourists' brand loyalty to achieve sustainable development of theme parks.	
2022	Wu, Meiju He, Jianmin	Horizontal Tourism Coopetition Strategy for Marketing Performance – Evidence From Theme Parks	The study examines how COVID-19 has prompted tourism enterprises in China to adopt new management strategies, focusing on the role of coopetition in marketing and performance. It finds that coopetition—comprising resource similarity, market commonality, and willingness to cooperate—acts as an intermediary in the relationship between tourism marketing and performance. The results indicate that coopetition positively impacts non-financial performance more significantly than financial performance.	Unprecedentedly impacted by COVID-19, tourism enterprises are pushed to adopt new strategic management to cope with the changes in tourists' consumer perception for sustainable development, such as corporate and compete simultaneously with their competitors. The study aims to investigate the intermediate role of coopetition, including the three dimensions of resource similarity, market commonality, and willingness to cooperate in the marketing and performance relationships. Primary data on 360 observers were collected via questionnaire distribution to theme park managers in China with 85.3% accuracy in response rate. Structural equation modeling (SEM) was used to verify the intermediate effect of coopetition on marketing performance in tourism enterprises. The results of SEM indicate (1) the intermediate role of tourism coopetition, including the three dimensions existing in the relationship between tourism marketing and performance, (2) more significant positive impact on non-financial performance than that on financial performance, and (3) the mechanism of implementing coopetition. This study gives supportive evidence for tourism enterprises to	Regression analyses of financial data from 31 theme parks in China / secondary data

YEAR	AUTHORS	TITLE	RELEVANT FINDINGS	SUMMARY	METHODOLOGY / METHODS / DATA
			The research also highlights effective mechanisms for implementing coopetition strategies.	implement coopetition and highlights the implications for appropriately developing coopetition strategies and tactics to achieve the synergy effect for the individual enterprises and the spillover effect for the destination regarding policy-making, mindset, and partner selection.	
2022	Zhu, Chris Fong, Lawrence Hoc Nang Shang, Ziye Gan, Manrong	Rethinking the Impact of Theme Park Image on Perceived Value and Behavioral Intention: The Case of Chimelong Ocean Kingdom, China	The study examines the role of theme park image in enhancing tourist experiences during COVID-19. It finds that both cognitive and affective aspects of destination image positively influence tourist-perceived value, including functional, social, and emotional value. While social and emotional values boost behavioral intentions, functional value does not.	The emergence of theme parks is enriching the tourist experience in the COVID-19 period. This study rethinks the impact of theme park image on tourist-perceived value (functional, social, and emotional value) and behavioral intention during COVID-19. Data were collected from 304 respondents who visited Chimelong Ocean Kingdom during COVID-19. This study results indicated that theme park destination image (cognitive and affective) positively predicts tourist-perceived value (functional, social, and emotional) during COVID-19. Moreover, this study also indicated that although social and emotional value positively predict tourist behavioral intention, functional value does not positively predict tourist behavioral intention during COVID-19.	Survey of visitors, model definition and its testing using SEM / Primary data
2022	Pan, Yu Xu, Jing Luo, Jian Ming Law, Rob	How Fear of COVID-19 Affects Service Experience and Recommendation Intention in Theme Parks: An Approach of Integrating Protection Motivation Theory	The study examines the impact of COVID-19 on theme park visitors' recommendation intentions. The findings reveal that fear of COVID-19 increases perceived risk, reduces the desire for active participation, and	The unprecedented public panic caused by COVID-19 will affect the recovery, especially in theme parks, which are generally crowded due to high visitor volume. The purpose of this study is to discuss these effects. This study aims to predict recommendation intentions of theme park visitors by exploring the complicated mechanism derived from the fear of COVID-19. It uses a quantitative research method, and SPSS 20.0 and AMOS 22.0 were used for data analysis. An online survey was conducted with 420	Online survey of visitors, SEM for hypothesis testing / primary data

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		and Experience Economy Theory	negatively affects service experience. While perceived risk does not directly harm recommendation intentions, these factors collectively impair them.	Chinese respondents who visited Shanghai Disneyland after its reopening. The study explored the relationship between Fear of COVID-19, perceived risk, participation, service experience, and revisit intention. Results indicated the perceived risk of theme park visitors will not directly ruin their recommendation intention. Visitors' fear of COVID-19 enhanced their perceived risk, reduced their desire for active participation and impaired their service experience, which affected their recommendation intention.	
2021	Chang, Min-Yen Hsu, Yi-Sheng Chen, Han-Shen	Choice experiment method for sustainable tourism in theme parks	The study explores tourists' preferences for theme park attributes using the Choice Experiment method and analyzes willingness to pay (WTP) through Conditional Logit and Random Parameter Logit models, surveying 549 respondents in Taiwan. Key findings reveal that the most valued attributes are recreational facilities, followed by theme characteristics and fast pass services. Respondents are willing to pay most for thrilling recreational facilities and unlimited fast pass services. They believe	Previous relevant studies on theme parks lack an exploration of various tourism attributes, e.g., recreational facilities, themes, wait times, fast pass drawings, and pricing, etc., all of which inspired the research motivation of this study. First, the Choice Experiment (CE) method explores tourists' preferences for theme park attributes. Second, the Conditional Logit (CL) and Random Parameter Logit (RPL) models explore the differences in tourists' willingness to pay (WTP) for various attributes from the perspective of their socioeconomic background. The study used purposive sampling to survey questionnaire answers face-to-face in Taiwan, and 549 copies are valid, with an effective recovery rate of 80.7%. The research findings suggest the following: (1) The most valued theme park attributes for consumers are the recreational facilities, followed by theme characteristics, and fast pass drawing. (2) Regarding the respondents' WTP for various attributes, they are willing to pay the highest price for thrilling recreational facilities, then for unlimited fast pass	Face-to-face questionnaire and within statistical analyses: conditional logit model and random parameter logit to test the willingness to pay / primary data

YEAR	AUTHORS	TITLE	RELEVANT FINDINGS	SUMMARY	METHODOLOGY / METHODS / DATA
			that having both enhances overall satisfaction but show limited purchase intention for fast pass services.	services, and cartoon character themes. (3) Respondents believe that if thrilling recreational facilities and fast pass drawing are available at the same time, then the overall effectiveness will be improved. (4) Respondents relatively have no purchase intention for fast pass drawing. It is hoped that the research findings can provide theme park operators reference basis for making plans and decisions.	
2021	Zhang, Zi'ang Liang, Zengxian Bao, Jigang	From theme park to cultural tourism town: Disneyization turning of tourism space in China	The study explores the impact of theme parks and cultural tourism towns on urban tourism in China, focusing on the trend of "Disneyization." It highlights that theme parks serve as models for cultural tourism towns, exemplified by the "Wuzhen Town Mode," which features theming, hybrid consumption, merchandising, and performative labor. A unique aspect of these towns is their residential function, distinguishing them from traditional tourist destinations. The Disneyization process is driven by local government initiatives, tourist demand, social	Theme park development has become an important choice for tourism space development in Chinese cities, and the theming of space as well as the implied consumption symbols and cultural implications are usually viewed as examples for the development of other urban spaces, such as cultural tourism towns. The result is the Disneyization of urban tourism space. With the construction of characteristic towns being vigorously promoted throughout China, cultural tourism towns are springing up. They are typical of the "Wuzhen Town Mode" and represent the process of the Disneyization of tourism space in China. This research reflects on the evolution of the characteristics of tourism space in China. Taking the Wuzhen Town Mode as an example, this study reveals the characteristics and conversion mechanism of the Disneyization of tourism space in Chinese cities. According to this research, the Wuzhen Town Mode of the Disneyization is characterized by theming, hybrid consumption, merchandising, and performative labor. Residential function is a unique characteristic of the Disneyization of cultural tourism towns in China.	Case study approach, in-depth interviews, observation, strategic document analyses (content analyses) / primary and secondary data

YEAR	AUTHORS	TITLE	RELEVANT FINDINGS	SUMMARY	METHODOLOGY / METHODS / DATA
			environment, and capital investment. The study also offers policy recommendations for managing this trend.	Moreover, the Wuzhen Town Mode of the Disneyization is jointly motivated by the driving force of local governments, the propulsive force of tourist demand, the attractive force of the social environment, and the driving force of capital. Finally, suggestions and policy proposals are provided for the Disneyization of tourism space.	
2021	Sarinastiti, Eska Nia Wicaksono, Muhamad Sidiq	Commercialization and tourism: Challenges in sustainable wildlife animal conservation-based Theme Park management in Central Java area	The study explores the impact, challenges, and concept of ecotourism in managing theme parks for sustainable wildlife conservation in Central Java. It finds positive outcomes from conservation and sustainable tourism practices but also identifies management challenges. Externally, tourists often do not comply with conservation guidelines, while internally, insufficient funding hampers effective management and infrastructure development..	The purpose of this study was to determine the impact, challenges, and concept of ecotourism in managing theme parks based on sustainable wildlife animal conservation in Central Java. This research uses qualitative exploratory research. Data collection techniques include in-depth interviews and direct observation as primary data, while documentation, questionnaires, and literature studies are secondary data. Data analysis is divided into several stages: data coding, finding patterns, labeling themes, and developing category systems. The results showed that, first, positive impacts were obtained from conservation and sustainable tourism. Second, management challenges include external (outside the company scope) and internal (within the company scope). The external challenge most often faced by managers is the behavior of tourists who do not comply with the appeal in the theme park area. Meanwhile, the most crucial internal challenge is insufficient funding sources for the management and development of infrastructure. Third, ecotourism offers an alternative concept for sustainable management of theme parks economically and in conservation but requires large funds for realization.	Qualitative descriptive study, in-depth interviews, observation and document analyses & thematic analyses of transcripts / primary and secondary

YEAR	AUTHORS	TITLE	RELEVANT FINDINGS	SUMMARY	METHODOLOGY / METHODS / DATA
2020	Yang, Zhang Jiacheng, Li Lei, Li	Time-dependent theme park routing problem by partheno-genetic algorithm	The study addresses the challenges tourists face in planning visits to theme parks due to excessive information on park websites. It introduces a Time-Dependent Theme Park Routing Problem (TDTPRP), based on the Traveling Salesman Problem (TSP), which factors in walking time, congestion, and fatigue. The model aims to maximize the number of attractions visited while minimizing queues and walking time. To validate its effectiveness, the research uses the Partheno-Genetic Algorithm (PGA) and an improved Annealing Partheno-Genetic Algorithm (APGA). Results show that the APGA offers better optimization than the standard PGA, especially with larger data scales.	With the improvement of people's living standards and entertainment interests, theme parks have become one of the most popular holiday places. Many theme park websites provide a variety of information, according to which tourists can arrange their own schedules. However, most theme park websites usually have too much information, which makes it difficult for tourists to develop a tourism planning. Therefore, the theme park routing problem has attracted the attention of scholars. Based on the Traveling Salesman Problem (TSP) network, the study proposes a Time-Dependent Theme Park Routing Problem (TDTPRP), in which walking time is time-dependent, considering the degree of congestion and fatigue. The main goal is to maximize the number of attractions visited and satisfaction and to reduce queues and walking time. To verify the feasibility and the effectiveness of the model, the Partheno-Genetic Algorithm (PGA) and an improved Annealing Partheno-Genetic Algorithm (APGA) was used to solve the model in this paper. Then, in the experimental stage, two experiments were conducted, and the experimental data were divided into real-world problem instances and randomly generated problem instances. The results demonstrate that the parthenogenetic simulated annealing algorithm has better optimization ability than the general parthenogenetic algorithm when the data scale is expanded.	Model development; algorithm implementation: developed a Partheno-Genetic Algorithm (PGA) and created an improved Annealing Partheno-Genetic Algorithm (APGA); experimental design and 2 experiments / primary data

Source: authors' contribution

Across the reviewed literature (2020–2024), theme and fun park research converges strongly on the visitor-centered paradigm. A dominant similarity among most studies is the treatment of theme parks not merely as entertainment venues but as complex experiential systems where emotional, cognitive, and behavioral responses mediate tourism outcomes. Studies on visitor satisfaction, emotions, and experience formation—whether through expectation confirmation theory, stimulus–organism–response models, or user-generated content analyses—consistently confirm that service quality, experiential intensity, and perceived value are the primary drivers of satisfaction, loyalty, and revisit intention.

However, clear differences emerge in how experience is acknowledged. Earlier and conceptually oriented papers emphasize holistic experience elements (e.g. motivation, image, brand identity), whereas more recent studies increasingly rely on granular, data-driven approaches, such as facial emotion recognition, sentiment analysis, and structural topic modeling of online reviews. This signals a methodological shift from perception-based surveys toward behavioral and digital data, although both approaches arrive at similar conclusions regarding the role of experience quality.

A second major similarity lies in the growing interest towards application of technology, distributed across different topics. Operational and optimization-focused studies (e.g. group schedules, pricing algorithms) adopt advanced computational models to address issues such as congestion, waiting times, and revenue efficiency. In contrast, technology in marketing and experience research is mainly based on social media and big data analytics, focusing on short-video content, online reviews and social media engagement metrics. Despite these advancements, the literature remains fragmented, with limited integration between operational technologies and visitor-experience technologies, indicating a gap, signaling the need for a more integrated approach to technological use.

In terms of economic and managerial perspectives, most studies acknowledge theme parks as catalysts of tourism development, destination competitiveness, and regional growth. However, economic impacts are more often indirectly included within studies on satisfaction, pricing, or branding rather than examined directly. Only a small subset explicitly addresses macro-level tourism development, seasonality reduction, or infrastructure substitution (e.g. theme parks as alternatives to hotel expansion). This clearly shows a stronger micro-level focus on individual visitor behavior, rather than to a destination-level.

Sustainability represents one of the clearest points of divergence. While sustainability is frequently invoked rhetorically, only a limited number of studies operationalize it through concrete actions such as low-carbon investment, discriminatory pricing for equity, cooptation strategies, or conservation-based park management. Environmental and social sustainability concerns—over-tourism, resource use, wildlife protection—remain marginal compared to economic and experiential priorities. This imbalance suggests that sustainability is still treated as an additional objective, rather than a core dimension of theme park tourism research.

Culturally oriented studies examine historical theme parks, cultural tourism towns, and Disneyization processes. These works extend the conceptual boundaries of theme parks beyond enclosed attractions to broader tourism spaces and hybrid urban forms. Compared to experience-focused studies, they focus on symbolism and spatial transformation, thereby enrich the theoretical landscape but remaining relatively isolated from the most empirical tourism research.

Regarding the geographical concentration of case studies, these are fragmented and oriented particularly in China and selected emerging markets. While this provides depth in specific contexts, it constrains generalizability and limits comparative international perspectives.

The researches are unified in recognizing theme and fun parks as multidimensional tourism systems driven by experience, technology, and branding, yet fragmented in its treatment of sustainability, macroeconomic impact, and integrated technological application.

Most researches reveal the dominance of demand-side studies, thus many macroeconomic aspects are not enough explored (e.g. governance, policy, labor and impacts at the destination level)

The most significant emerging trend is the methodological shift toward data-intensive and algorithmic approaches, while the most persistent gap remains the limited alignment between rapid technological adoption in practice and its systematic examination in academic research.

4 Conclusion

This review examined the role of theme and fun parks in tourism, analyzing their impacts on local economies, communities, and tourism trends. After screening 58 sources from the Scopus database, 19 relevant articles were selected for analysis. The findings provide valuable insights into the theoretical and practical contributions of these parks while highlighting some key challenges.

The analyzed papers contribute to the understanding of theme parks as major influencers in tourism. They show that parks are not only entertainment venues but also key drivers of tourism economies. The integration of new technologies and immersive experiences is also a growing theme, reflecting changing consumer expectations. Various sustainability aspects are less frequently investigated, signaling a gap in the literature, with the exception of the economic aspects, which are more prominently addressed. Almost 25% of studies apply the case study format or multiple case studies while almost 70 % are focused on investigating the demand side. Out of the studies analyzed, 8 use primary data, 9 use secondary and 2 use both sources of data. Quantitative methodology is used in more than half of the studies. The use of content analyses in various variations along with models and relationship testing among variables using SEM is pretty often used.

Based on the provided research summaries, here's an analysis of the most frequently researched topics within theme and fun parks in the timespan of five years:

- visitor experience and satisfaction: 25% (includes studies on emotions, cultural adaptation, and factors affecting enjoyment)
- marketing and pricing strategies: 20% (covers research on discriminatory pricing, coopetition, and social media marketing)
- operational management: 15% (focuses on group scheduling, routing problems, and facility management)
- economic impact and tourism development: 10% (examines the role of theme parks in local economies and tourism growth)
- technology and data analysis: 10% (utilizes methods like facial recognition, structural topic modeling, and online review analysis)
- sustainability and environmental impact: 5% (addresses issues of sustainable tourism and low-carbon initiatives)
- brand management: 5% (explores brand identity, loyalty, and image in theme parks)
- cultural and historical aspects: 5% (studies historical theme parks and cultural tourism towns)
- health and recreation: 3% (examines the recreational and health benefits of theme park activities)
- transportation and accessibility: 2% (analyzes the relationship between park success and transportation infrastructure).

This breakdown reflects the diverse range of topics studied in theme park research, with a clear emphasis on understanding and improving visitor experiences, as well as optimizing marketing and operational strategies. This is one of the rare review papers which systematically collected and analyzed the topic of both theme and fun parks vs. the study regarding only theme parks of Liang, Zengxian & Li, Xiang (2023). This fact, along with the signalization of under researched topics, represents the theoretical contribution.

Theme parks have significant economic benefits, such as job creation and tourism revenue which, along with the detection of concrete case studies, represents a contribution to practice. Furthermore, case studies also highlight challenges, such as environmental issues and over-tourism, particularly in regions with major parks.

This review paper has several limitations that should be acknowledged:

- *Errors in Analysis:* Some sources may have contained errors due to incomplete or inaccessible data, affecting the overall findings. The exclusion of unavailable documents limited the scope of analysis.
- *Source Selection Limitations:* The search focused on English-language articles from 2020-2024, possibly missing relevant studies outside these limits.
- *Incomplete Topic Search:* The search criteria may not have fully captured all relevant aspects of the topic and some important terms may have been missed.

Future studies should explore theme parks in emerging markets and further investigate sustainability, digital innovations, and the long-term social effects of over-tourism. Expanding research to smaller parks and their local communities would provide a more holistic understanding of their impact. Surprisingly, the research focusing on technological aspects is not following the rhythm in of its application in real-world theme and fun parks.

Theme parks play a vital role in tourism and addressing the challenges of sustainability and over-tourism remains crucial. This review provides insights and directions for future research and practice in the industry.

Conflict of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- Bai, S., He, H., Han, C., Yang, M., Bi, X., & Fan, W. (2023). What makes a theme park experience less enjoyable? Evidence from online customer reviews of Disneyland China. *International Journal of Environmental Research and Public Health*, 20(13), 6410. <https://doi.org/10.3390/ijerph20136410>
- Chang, M. Y., Hsu, Y. S., & Chen, H. S. (2021). Choice experiment method for sustainable tourism in theme parks. *Sustainability*, 13(11), 6293. <https://doi.org/10.3390/su13116293>
- Florido-Benítez, L. (2024). Analysis of Latin American theme parks in a tourism context. *Tourism Management Perspectives*, 49, 101013. <https://doi.org/10.1016/j.tmp.2023.101013>
- Hsieh, Y. C., & You, P. S. (2024). A comparison of three evolutionary algorithms for group scheduling in theme parks with multitype facilities. *International Journal of Environmental Research and Public Health*, 21(19), 7352. <https://doi.org/10.3390/ijerph21197352>
- Li, S., Dou, Q., Chen, H., & Yu, Z. (2023). The impact of consumer's adaptation to the creative culture of theme parks on review usefulness. *Sustainability*, 15(3), 2559. <https://doi.org/10.3390/su15032559>
- Liang, Z., & Li, X. (2023). What is a theme park? A synthesis and research framework. *Tourism Management*, 94, 104630. <https://doi.org/10.1016/j.tourman.2022.104630>
- Pan, Y., Xu, J., Luo, J. M., & Law, R. (2022). How fear of COVID-19 affects service experience and recommendation intention in theme parks: An approach of integrating protection motivation theory and experience economy theory. *International Journal of Environmental Research and Public Health*, 19(5), 2666. <https://doi.org/10.3390/ijerph19052666>
- Ryndach, M., Kazak, A., Selivanov, V., Gurevskikh, O., Dolgushina, Y., Maksimov, L., Chudnovskaya, T., & Kryukova, A. (2024). Recreational and health aspect of theme park activities. *Journal of Environmental Management and Tourism*, 15(1), 124–133.
- Sarinastiti, E. N., & Wicaksono, M. S. (2021). Commercialization and tourism: Challenges in sustainable wildlife animal conservation-based theme park management in Central Java area. *IOP Conference Series: Earth and Environmental Science*, 716(1), 012038. <https://doi.org/10.1088/1755-1315/716/1/012038>
- Song, X., Wu, H., Jiang, W., Zhi, J., Xia, X., Long, Y., & Su, Q. (2024). Using geotagged facial expressions to visualize and characterize different demographic groups' emotion in theme parks. *Tourism Management*, 100, 105011. <https://doi.org/10.1016/j.tourman.2023.105011>
- Wang, X., Fan, Z. P., Li, H., & Li, Y. (2023). Discriminatory pricing strategy for sustainable tourism in theme parks considering visitors' price fairness and service value perceptions. *Sustainability*, 15(19), 14429. <https://doi.org/10.3390/su151914429>
- Wu, M., & He, J. (2022). Horizontal tourism coemption strategy for marketing performance – Evidence from theme parks. *Frontiers in Psychology*, 13, 938355. <https://doi.org/10.3389/fpsyg.2022.938355>
- Yang, Z., Li, J., & Li, L. (2020). Time-dependent theme park routing problem by parthenogenetic algorithm. *IEEE Access*, 8, 224391–224405. <https://doi.org/10.1109/ACCESS.2020.3044018>
- Yuan, L., & Marzuki, A. (2024). What keeps historical theme park visitors coming? Research based on expectation confirmation theory. *International Journal of Environmental Research and Public Health*, 21(5), 2087. <https://doi.org/10.3390/ijerph21052087>

Zhang, Z., Liang, Z., & Bao, J. (2021). From theme park to cultural tourism town: Disneyization turning of tourism space in China. *Tourism Management*, 86, 104326. <https://doi.org/10.1016/j.tourman.2021.104326>

Zhou, L., Ouyang, F., Li, Y., Zhan, J., Akhtar, N., & Ittefaq, M. (2022). Visiting intentions toward theme parks: Do short video content and tourists' perceived playfulness on TikTok matter? *Journal of Hospitality and Tourism Management*, 53, 45–56. <https://doi.org/10.1016/j.jhtm.2022.08.003>

Zhou, L., Ouyang, F., Li, Y., Zhan, J., Akhtar, N., & Ittefaq, M. (2022). Examining the factors influencing tourists' destination: A case of Nanhai Movie Theme Park in China. *Frontiers in Psychology*, 13, 957325. <https://doi.org/10.3389/fpsyg.2022.957325>

Zhu, C., Fong, L. H. N., Shang, Z., & Gan, M. (2022). Rethinking the impact of theme park image on perceived value and behavioral intention: The case of Chimelong Ocean Kingdom, China. *Sustainability*, 14(4), 2451. <https://doi.org/10.3390/su14042451>



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