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Foreword

The Strategic Issues of Northern Hungary focuses on analysing the socio-economic conditions of the region and its broader environment, and the recent issue deals with the topic of territorial differences and their change as an effect of the global shocks and trends after the 2000s. The issue collects 10 articles and a book review in a broad area of topics.

The article of Szendi presents the performance of the EU15 capitals from the aspect of smart cities and highlights that also inside a specific geographical region there can be persistent inequalities among the territories.

Henye and Francia-Stránszki deals with the topic of work-life balance and the role of HR management in the changing conditions to foster the employee's well-being. Another challenge of the modern world is coming from the side of artificial intelligence and chatbots (as written by Kelen and Faragó) in the patient management of healthcare institutions. In a peripheral region of Northern Hungary, the article raise attention to different access opportunities and lags from the core areas in healthcare, which underlines further inequalities.

Löwe and Kovácsné Lackó research the topic of loyalty and innovation in the automotive industry, which is one of the main contributors to Hungarian GDP. For the industry they suggest improvement in organizational culture, job security, strengthening brand loyalty, and expanding training and development opportunities.

Bereck et al. analyse another current issue of nowadays, the cryptocurrency market and the blockchain technology, by investigating the allocation of pre-sale capital by blockchain technology-based startup ventures. The authors make differences in short- and long-term effects of marketing-based strategies.

Faludi in his article checks the logistics process of dangerous goods and develops a decision supporting model for the optimal choice of logistics providers. In the model, the author considers the different risks arising from the transportation of that kind of products.

Yang et al. investigates the battery-related manufacturing from the different aspects of employment while also integrating the conditioning role of regional innovation capacity. From the results, there are also through the effects of this sector increasing territorial differences among regions as the advantages are spreading uneven.

Bokányi examines the spatial characteristics and changes in the land use of the Northern Industrial Area of Szombathely by checking the knowledge concentration and suggests a shift from labour-intensive to knowledge-intensive development. Another current issue is covered in the article of Vara, who examines the GCC (Gulf Cooperation Council) in the Arabia Gulf area, which can have huge contribution in nowadays conditions. It also compares the similarities and differences between the GCC and the European Union.

Madarász in her article deals with the topic of sustainability from the aspect of logistics an compares the V4 region to check the geographical differences. She finds by the document analysis that the logistics planning practices of the V4 countries follow a similar path.

The issue covers a broad area of topics, that is why I suggest to read this current issue carefully to check nowadays challenges of the modern world affecting this specific geographical region.

Dóra Szendi, PhD habil.
guest editor
July 2026

TANULMÁNYOK / STUDIES

Ádám Bereczk[1] – Zoltán Musinszki[2] – Erika Szilágyiné Fülöp[3]– Bettina Hódiné Hernádi[4]

The effect of ICO Capital Allocation on Project Valuation in Web3 Cryptocurrency Projects

This study investigates the allocation of pre-sale capital by blockchain technology-based startup ventures, with a specific focus on the Play-to-Earn (P2E) segment within the Web3 ecosystem, and its impact on token price performance. Our aim is to determine the proportion of initial capital that P2E startups, according to their business plan (whitepaper), allocated to key areas such as team and advisor expenses, marketing activities, and product development. Subsequently, this research centers on the question of how the focal areas of pre-sale capital utilization (team, marketing, development) correlate with the subsequent price performance of the tokens issued by these startups. The timeliness and relevance of this topic are underscored by the dynamic evolution of blockchain technology and the P2E model, as well as the critical role of startups' capital allocation decisions. Understanding how the utilization of initial funding influences long-term value is also of paramount importance for investors. Based on the results, while excessive marketing expenditures may offer a project short-term benefits, this strategy can potentially have negative long-term consequences. A project's financial viability is contingent upon competent human resources and the insights of external experts; nevertheless, these elements alone are not definitively sufficient. The significance of product development was only evident when the effect was measured in Bitcoin terms; no correlation was found when measured in Dollars.
Key words: startup, GameFi, tokenomics, blockchain technology, Web3 financing
JEL code: G32, G41, L26, M13, O33

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1. Introduction

Blockchain, a pivotal technological innovation of the 21st-century digital revolution, has fundamentally altered the modalities of data management, financial transactions, and digital trust, encompassing the storage, transmission, and authentication of information (Tapscott & Tapscott, 2016). Blockchain-based systems have the potential to become defining pillars of the future digital infrastructure, contingent upon their capacity to address technological and societal challenges (Mougayar, 2016).

The evolution of Web3 and P2E projects extends beyond mere technological considerations, holding significant implications from social, economic, and investment perspectives in the coming decades. Decentralization is fostering the emergence of novel business models that deviate from centralized corporate structures, phenomena whose analysis is both timely and forward-looking, particularly within the startup ecosystem. Following the preceding waves of ICOs, DeFi, and NFTs in recent years, P2E has emerged as the subsequent segment attracting investors, developers, and users alike. However, this rapid ascent has also harboured inherent risks: numerous projects have dissolved within short timeframes, raising substantial concerns regarding sustainability and long-term value creation. A central question concerning Play-to-Earn projects is whether they can genuinely establish sustainable economic ecosystems or serve as short-term speculative instruments. Of particular importance is the exploration of the extent to which decentralization

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contributes to the long-term success of these projects and the degree to which it creates opportunities for abuse.

The decentralisation of the financial sector has been a key determinant in the emergence of blockchain startups. In the wake of Bitcoin and Ethereum, a multitude of new cryptocurrencies, tokenized assets, and decentralized applications (dApps) have been created, offering alternative solutions across various industries in lieu of centralized services. The introduction of Ethereum enabled the utilization of so-called smart contracts, which function as self-executing programs for the automation of business logic (Wright & De Filippi, 2015).

One of the most recognized and widespread forms of funding within the realm of blockchain startups is the Initial Coin Offering (ICO), which provides businesses with the opportunity to sell digital tokens to the public in exchange for cryptocurrency. A characteristic feature of ICOs is their lack of reliance on intermediaries, stock market listings, or regulated financial institutions, thereby facilitating faster and more globally accessible funding (Fisch, 2018). Initial Coin Offerings rely heavily on the information disclosed in whitepapers, which serve as the primary communication tool for signaling project quality in the absence of traditional intermediaries (Fisch, 2018; Howell et al., 2020).

New types of funding mechanisms have also emerged, operating on the foundation of ICOs, such as the Initial Exchange Offering (IEO), conducted through cryptocurrency exchanges, and the Security Token Offering (STO), which offers regulated investment opportunities akin to traditional securities. These novel models contribute to enhancing transparency and investor protection, while simultaneously imposing stricter compliance and legal requirements on startups (Hacker & Thomale, 2017).

Furthermore, the lack of standardized investor rights and the presence of significant information asymmetry in the ICO market necessitate a closer examination of project-specific disclosures, as these serve as the primary basis for investment decisions in a largely unregulated environment (Zhao et al., 2020).

While most prior studies have examined ICO mechanisms more generally, this study makes a niche contribution by focusing specifically on the Play-to-Earn (P2E) segment. The novelty of the research lies in the fact that, going beyond a mere technological description, it quantifies the impact of resource allocation between marketing, product development, and human capital on market value, revealing strategic correlations within the specific P2E ecosystem. A unique element of the methodology is the dual-currency-based analysis, which measures performance in Bitcoin and USD, allowing the decoupling of project-specific success from general crypto market trends. This approach scientifically reinforces the primacy of sustainable development capability over marketing-driven growth models in the long-term lifecycle of Web3 projects.

2. Literature review

2.1. Blockchain Technology and Smart Contracts

Blockchain is a distributed ledger technology (DLT) that enables network participants to share, record, and validate data without a central authority (Nakamoto, 2008). This approach is particularly significant in the realms of financial technologies, data security, and smart contracts, but it is also finding increasing application in logistics, healthcare, education, and public services (Swan, 2015).

The advantages of this technology include its transparency, the trust derived from decentralization, and the minimization of reliance on third parties. Conversely, the challenges associated with blockchain encompass high energy consumption, regulatory issues, and interoperability problems across different blockchain networks. The emergence of Bitcoin not only created a novel digital asset but also contributed to the birth of an entire industry, the blockchain ecosystem (Yermark, 2017).

Another significant milestone in blockchain technology was the launch of the Ethereum platform in 2015 (Castor, 2023). Ethereum is capable of not only processing transactions but also enabling the execution of so-called smart contracts. A smart contract is a self-executing code snippet that automatically performs a transaction or other operation on the blockchain when specific conditions are met (Buterin, 2014). This approach allows for the decentralized implementation of complex business logic, such as the automation of insurance payouts, digital rights management, or the operation of decentralized exchanges. The benefit of smart contracts is that transactions are deterministic and immutable, thus eliminating the need for legal intermediaries to guarantee execution (Wright & De Filippi, 2015).

2.2 Distinctive Attributes of Blockchain-Native Startup Ventures

Startup ventures represent one of the most dynamically evolving segments of the modern economy. These companies are innovative organizations that develop novel products, services, or business models, with the aim of rapid market growth. The operation of startups is characterized by significant uncertainty, high risk, and an experimental business approach (Kézai, 2024). By definition, a startup is a temporary organization in search of a repeatable and scalable business model (Blank & Dorf, 2020).

Key players in the startup ecosystem include venture capitalists, angel investors, accelerator programs, incubators, and universities. These actors not only provide financial support but also assist startups with strategic guidance, mentorship, technological infrastructure, and social capital (Wonglimpiyarat, 2015). Successful startups typically build upon multiple resources and actively participate in local or international innovation communities. As Benedek et al. (2018, p. 12) state in their study, ‘innovation is closely linked to technological development’.

Technology startups – particularly in the digital, IT, and fintech sectors – evolve in extremely rapid cycles. These ventures often work with artificial intelligence, data mining, blockchain technology development, or Software-as-a-Service (SaaS) models. Scalability, infrastructure flexibility, and the maintenance of technological competence are particularly important for such startups. The emergence of blockchain technology has ushered in a new era in the startup ecosystem, offering opportunities for the creation of decentralized systems and novel business models. Blockchain-based startups are enterprises whose business processes, services, or products are built on blockchain infrastructure. These companies leverage the key advantages of the technology – transparency, security, decentralization, and programmable contracts – to create new, often disruptive solutions (Adhami et al., 2018).

2.3 Capitalization Approaches for Blockchain-Based Projects

A prominent example of business innovation is the emergence of the previously mentioned Initial Coin Offering (ICO). The ICO stands as one of the most well-known and widely adopted fundraising methods for blockchain projects. This mechanism enables a newly established venture or decentralized project to issue digital tokens, which investors can purchase – typically using established cryptocurrencies such as Bitcoin (BTC) or Ethereum (ETH). The objective of an ICO is to directly raise the capital necessary for project implementation from investors, without the need for traditional financial intermediaries. This method gained significant popularity as it provided an avenue for the rapid financing of projects; however, it also entailed considerable risks for investors due to regulatory and transparency deficiencies. Among the successful ICO projects is Ethereum itself, which raised USD 18 million in 2014, thereby laying the foundation for a new era of decentralized applications (Tapscott & Tapscott, 2016).

2.4 Resource Allocation as a Critical Factor in Blockchain Project Success

The analysis of budgetary plans is indispensable for understanding the financial underpinnings and operational frameworks of blockchain-based projects. International literature distinguishes three prominent cost factors: resources allocated to marketing, funds dedicated to technological development, and the token share reserved for team members (Zetzsche et al., 2017). Each of these factors indirectly provides information about the project's strategic priorities and its market positioning (Fisch, 2018).

The theoretical role of marketing expenditure is paramount in the early stages of blockchain projects, as community recruitment and public attention are crucial elements in decentralized systems (Chen & Bellavitis, 2020). However, excessive marketing costs can also indicate increased speculation and the neglect of the technical foundation (Mougayar, 2016).

Examining development expenditures is an important indicator of whether a project possesses a functional infrastructure or a suitable development roadmap (Buterin, 2014). Blockchain projects can ensure a technologically stable platform if a significant portion of their budget is allocated to development (Tapscott & Tapscott, 2016).

The third factor examined – the team's token share – reflects the project's internal incentive system (Zetzsche et al., 2017). The amount of resources allocated to team members can influence commitment and the extent of long-term participation (Fisch, 2018). However, excessive resource allocation to the team may reflect short-term interests, while a gradual release system (vesting) is theoretically considered a more effective incentive (Chen & Bellavitis, 2020).

The positive correlation between expenditures on the team and long-term token performance can be interpreted through the lens of signaling theory. In the high-uncertainty environment of Web3 startups, the quality and expertise of the founding team and advisors serve as a crucial signal of project legitimacy and future viability to potential investors. As noted in the literature, the allocation of resources to human capital acts as a commitment mechanism; it indicates that the project possesses the necessary technological competence and strategic leadership to navigate the post-ICO development phase. Furthermore, expert advisors not only provide social capital but also reduce information asymmetry by validating the project’s technical roadmap, which is essential for building digital trust in decentralized ecosystems. Consequently, a well-funded team is perceived not merely as a cost factor, but as a guarantee of sustainable development capability, which stabilizes investor expectations and contributes to long-term price performance.

According to a recent systematic literature review by Moxoto et al. (2025), human and social capital are among the most critical determinants of ICO success. Their analysis confirms that the expertise, technical skills, and reputation of the founding team serve as vital signals that reduce information asymmetry and build community trust.

A common characteristic of the examined resource elements is that, according to professional assumptions, they inherently contribute to the project's transparency, strategic coherence, and technical feasibility (Mougayar, 2016). The literature considers the examination of such structures important for reducing investor information asymmetry (Fisch, 2018).

Moreover, the inherent risks associated with the lack of standardized legal frameworks in the ICO process necessitate a robust internal governance structure, as project-specific risk management becomes the primary safeguard for investor capital (Karpenko et al., 2021).

3. Material and methods

Our background research for this study aimed to understand which factors, among those discussed in the theoretical section, influence the price performance of newly launched Web3 and Play-to-Earn based startup projects and in what manner. To this end, we examined a cohort of 504 projects. However, comprehensive information was obtainable for only 54 of these ventures, utilizing data disclosed during their Initial Coin Offerings (ICOs). This limitation arose due to the prevalent issue of incomplete information provision to investors during the pre-sale phase by a significant number of projects. Furthermore, the price data for numerous projects became unavailable on cryptocurrency tracking platforms within one year of their launch, further restricting our analytical

scope. Despite the reduction in sample size to 54 projects with complete ICO data, this number can still be considered substantial. According to data from the CryptoRank portal, the initial cohort of 504 projects represents the entirety of publicly listed Web3 and Play-to-Earn based startup projects launched between January 1st, 2017, and the end of 2022.
We hypothesized that the proportion of marketing costs, the amount allocated to the development budget, and the role of the team and advisors could all serve as important indicators of a project's long-term viability.
During data collection, we primarily utilized the CoinGecko and CoinMarketCap databases, which are two of the most well-known, regularly updated, and community-audited platforms in the cryptocurrency market. Throughout the data collection process, we verified the official website and business plan for each project, which contained detailed technical and financial information. These primary documents provided a basis for understanding the projects' budgetary structure: where cryptocurrency price tracking platforms did not provide sufficient information, the examination of business plans allowed for the accurate determination of the proportion of marketing, development, and team costs.
For each project, data pertaining to budgetary structure, tokenomics, team composition, and token performance were recorded in an Excel spreadsheet. The price fluctuations of the projects were recorded in Bitcoin (BTC) and US dollars ($) at 3-month and 12-month intervals, and the data were subsequently evaluated using the JASP statistical software. The projects included in the sample were launched between 2017 and 2022.
To validate the data sources, we employed cross-verification using multiple databases to filter out misleading or false information. Where discrepancies were found between different sources, the data from the official whitepapers were considered primary.
Prior to commencing data processing, we normalized the data to eliminate differences arising from varying launch dates, as timing can significantly influence the short-term success of projects in the Web3 P2E market. This was achieved by converting dollar values to Bitcoin units. Based on the normalized data, we calculated relative performance for each project after both 3 and 12 months. During the data preparation phase, projects for which budgetary data or performance indicators were not fully available were excluded.
The normalization of price performance into Bitcoin units is consistent with recent empirical literature, which suggests that the optimal timing of an ICO and its subsequent valuation are heavily influenced by broader cryptocurrency market cycles and Bitcoin’s price trajectory (Drobetz et al., 2024). This approach allows for the mitigation of timing-related biases and isolates project-specific performance from systematic market movements.
To ensure the robustness of the comparative analysis, all financial data were normalized to both USD and BTC. It is important to emphasize that the conversion process does not introduce significant bias into the results for several reasons. Firstly, a substantial portion of the project data was originally recorded in BTC on the respective monitoring portals. For the remaining data points, conversions were executed using the spot exchange rates on the specific observation dates. Regarding the pre-sale phases, the exchange rates from the final day of each stage were applied; since these phases typically spanned only 2–3 days, the impact of intra-period Bitcoin volatility remained negligible. This rigorous approach effectively isolates project-specific performance from broader market fluctuations, thereby enhancing the reliability of the long-term valuation metrics.

4. Results

4.1. Average performance of Web3 P2E projects

Figure 1 illustrates the average performances in both US dollars and Bitcoin, clearly demonstrating the discrepancies in the short-term and long-term value generation capabilities of Web3 P2E projects. The initial part of Figure 1 presents the performances measured in US dollars,

where it is evident that the average 3-month performance (USD 6.2301) significantly surpasses the 12-month value (USD 0.5474). This suggests that many projects were capable of achieving high value increases in the short term, but this performance was not sustainable in the long run.
The difference is greater than tenfold, reinforcing the assertion that the life cycle of most projects exhibits a strongly short-term orientation. It can also be inferred from the data that the average 12-month performance is disproportionately low, which raises questions about the long-term investment value of these projects.

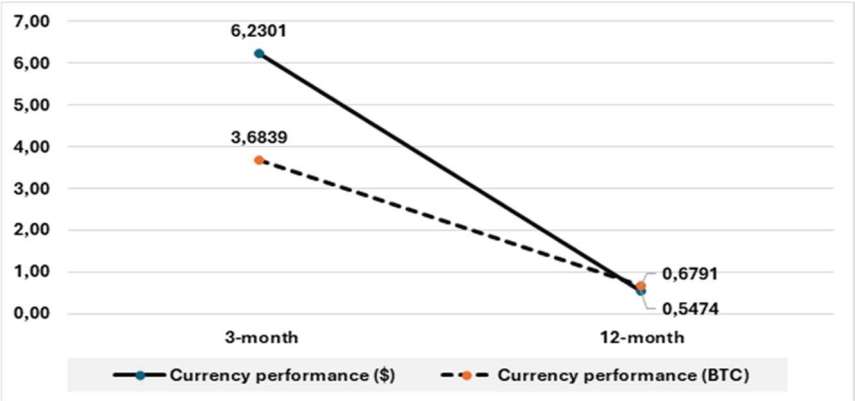

Fig. 1. Average performance of Web3 P2E projects in BTC and dollars
Source: edited by authors

Similarly, when examining the performance measured in Bitcoin, the average performance over the 3-month period (3.6839 BTC) is also considerably higher than the 12-month average (0.6791 BTC). The returns measured in Bitcoin further suggest that the projects' tokens were able to strengthen in the short term, even amidst cryptocurrency market volatility, but they could not keep pace with market expectations in the longer term.
The parallel observed between the two diagrams reinforces the conclusions drawn from the preceding quantitative and correlation analyses. These graphs suggest that the initial price surges characteristic of the early "hype" period should not be interpreted as genuine long-term success if they are not sustained by subsequent stability. Nevertheless, our results indicate that projects exhibiting stronger performance within the first 3 months tend to maintain a higher level of performance over a 12-month period as well.

4.2 Descriptive statistics

Table 1 presents key statistical indicators for three primary budgetary categories: marketing, game development, and team and advisors. The average values indicate that most projects allocated the largest proportion of resources to development (19%), followed by the team (16%), and finally marketing (12%). This distribution in itself suggests that a significant portion of Web3 P2E projects prioritize the development of their ecosystem.
The median values – 14% for marketing, 17% for development, and 15% for the team – indicate that the distribution of marketing costs is slightly right-skewed, meaning many projects remain at the lower end, but a few high values pull the average upwards. The mode – the most frequently occurring value – is 15% for all three categories, suggesting a somewhat standardized structure or that many projects allocate resources in a templated manner.
The standard deviation is highest for the development budget (0.126), indicating the greatest variance among projects in this area: some allocate almost nothing, while others exceed 50%. The standard deviations for marketing and team costs are smaller (0.065 and 0.062, respectively), suggesting more stable proportions for these categories.

Table 1. Descriptive Statistical indicators

	Marketing	Development	Team and advisors
Mode	0.150[a]	0.150[a]	0.150[a]
Median	0.140	0.172	0.150
Mean	0.117	0.188	0.160
Std. Deviation	0.065	0.126	0.062
Minimum	0.000	0.0009	0.002
Maximum	0.250	0.510	0.300

([a] The mode is computed assuming that variables are discreet.)
Source: edited by authors

The minimum values are 0% for all categories, implying the existence of projects that allocated no resources to marketing, development, or the team at all – this could be concerning, given that these pillars are arguably essential for long-term sustainability.
The maximum values are also revealing: 25% for marketing, 51% for development, and 30% for the team. These extreme values demonstrate that some projects have allocated their resources in a highly lopsided manner, which could represent a significant risk factor. Such concentrated budgetary structures often backfire, especially if they cannot support the project's long-term growth strategy.

4.3 Correlation

The examination of correlation is one of the most fundamental statistical tools that allows us to explore the direction and strength of the relationship between two variables. During the calculation of the correlation coefficient, it is important to recognize that it does not indicate a cause-and-effect relationship, but rather a covariation, that is, the direction and extent to which a change in one variable coincides with a change in another. Correlation calculation constituted the first step of our analysis, and we expected it to provide a more comprehensive picture of which types of budgetary structures are more likely to contribute to successful, sustainable projects.

Pearson's Correlations

Variable		Marketing	Development	Team and advisors	IN CP ($)	3-M CP ($)	12-M CP ($)
1. Marketing	Pearson's r	—					
	p-value	—					
2. Development	Pearson's r	0.183	—				
	p-value	0.181	—				
3. Team and advisors	Pearson's r	0.099	0.071	—			
	p-value	0.474	0.604	—			
4. IN CP ($)	Pearson's r	−0.325*	−0.160	0.092	—		
	p-value	0.015	0.244	0.503	—		
5. 3-M CP ($)	Pearson's r	0.232	0.193	0.088	−0.145	—	
	p-value	0.088	0.157	0.521	0.292	—	
6. 12-M CP ($)	Pearson's r	−0.195	−0.068	0.316*	−0.117	0.417**	—
	p-value	0.153	0.624	0.019	0.394	0.002	—

* p < .05, ** p < .01, *** p < .001

Fig. 2. Correlation matrix between budgets and performance in $
Source: edited by authors

Figures 2 and 3 show the correlation matrix between fiscal resource targets and exchange rate performance at different points in time. The correlation calculations also assisted us in determining which factors' relationships were worth testing with a linear regression model in the subsequent step.
The Web3 P2E sector is particularly dynamic and often unpredictable, making any measurable relationship that can provide guidance for investor and developer decisions especially valuable. Therefore, we also hoped that the correlation analysis would help filter out factors that appear superficially favorable but do not actually contribute to long-term value creation.
Based on the correlation values, it was determined that only the performance measured in US dollars had a significant ($p < 0.05$) relationship with the examined resource allocations. The relationship with the price performance measured in Bitcoin was not statistically significant in this study.
Figure 2 provides a more precise understanding of the significant impact of each budgetary type on project performance. In the case of 3-month performance, marketing costs showed a positive correlation with the results measured in US dollars ($r = 0.232$), suggesting that in the short term, investment in marketing can increase a project's visibility and initial market value, but this is not considered a significant effect. However, over the 12-month period, this effect reverses, and a weak negative correlation emerges ($r = -0.195$), indicating that marketing-based strategies do not prove sustainable in the long run.
Regarding the development budget, a nearly significant short-term correlation with the 12-month performance is only observed when measured in Bitcoin terms. The correlation between team and advisor costs and 3-month performance shows a weak positive ($r = 0.088$) but non-significant relationship. In contrast, the strongest positive correlation is measurable with the dollar-denominated 12-month performance ($r = 0.316$). This suggests that expenditures on the team yield their effects over a more extended period, contributing to the project's sustainability and stable operation.

Pearson's Correlations

Variable		Marketing	Development	Team and advisors	3-M CP (BTC)	12-M CP (BTC)
1. Marketing	Pearson's r	—				
	p-value	—				
2. Development	Pearson's r	0.183	—			
	p-value	0.181	—			
3. Team and advisors	Pearson's r	0.099	0.071	—		
	p-value	0.474	0.604	—		
4. 3-M CP (BTC)	Pearson's r	0.071	0.060	0.066	—	
	p-value	0.605	0.664	0.634	—	
5. 12-M CP (BTC)	Pearson's r	−0.078	0.259	0.044	0.393**	—
	p-value	0.574	0.056	0.750	0.003	—

* p < .05, ** p < .01, *** p < .001

Fig. 3. Correlation matrix between budgets and performance in BTC
Source: edited by authors

Based on the results, it can be established that the rapid ascent of marketing-dominant projects is often only superficial, and their market value decreases or stagnates in the long term. Marketing strategies may work in the short term, but their impact diminishes or even turns negative over a longer horizon. In contrast, projects that allocated more significant resources to team costs and, to some extent, development performed better in the long run. The most significant long-term positive impact is observed in the USD-based performance of team and advisor costs. Thus, the data clearly indicate that resource allocation towards the team and advisors can be the foundation

for sustainable Web3 P2E projects. At the same time, excessive reliance on marketing does not result in stable long-term value growth. This information can be useful in formulating new startups' budgetary strategies and making informed investment decisions.
Overall, the data highlight that an increase in the proportion of marketing costs was rather weakly negatively correlated with project performance. In contrast, development and team costs showed a positive or neutral relationship. It is important to note that the low correlation coefficients observed across the examined factors align with existing literature, suggesting that a multitude of variables influence the price fluctuations of cryptocurrency projects (see theoretical sub-sections). It is essential to emphasize that while budget allocation metrics offer valuable insights, they explain only a limited fraction of price dynamics (as indicated by the reported R^2 values). The valuation of Web3 P2E projects is a complex phenomenon influenced by a multitude of external factors, including overall cryptocurrency market sentiment, regulatory changes, technological shifts, and broader macroeconomic conditions, which are beyond the scope of this budgetary analysis.

4.4 Linear regression

The results indicate that none of the three examined budgetary factors exhibited a strong, significant relationship with market performance, yet their impact, albeit to varying degrees, is discernible. To further understand the connection, we conducted regression analysis in those relationships where the correlation matrix showed a significant association. Using the R^2 indicator, we quantified the proportion to which each factor explains the price fluctuations in the short term (3 months) and longer term (12 months).

Table 2. Linear regression analysis between marketing and initial exchange rate (in $)

Model Summary - IN CP ($)

Model	R	R^2	Adjusted R^2	RMSE
M_0	0.000	0.000	0.000	0.075
M_1	0.325	0.106	0.089	0.072

Note. M_1 includes Marketing

ANOVA

Model		Sum of Squares	df	Mean Square	F	p
M_1	Regression	0.033	1	0.033	6.277	0.015
	Residual	0.275	53	0.005		
	Total	0.308	54			

Note. M_1 includes Marketing
Note. The intercept model is omitted, as no meaningful information can be shown.

Coefficients

Model		Unstandardized	Standard Error	Standardized	t	p
M_0	(Intercept)	0.058	0.010		5.707	< .001
M_1	(Intercept)	0.102	0.020		5.079	< .001
	Marketing	-0.376	0.150	-0.325	-2.505	.015

Source: edited by authors

As depicted in Table 2, marketing expenditures account for 10.6% of the variance in the dependent variable (IN CP). This represents a weak but significant explanatory power. The costs allocated

to marketing showed a weak relationship with the issue price. This short-term marketing effect highlights that while initial hype can facilitate an increase in the token's value, fundamental factors take precedence in the long run. As we also established following the correlation calculations, the impact of marketing may still be relevant in the short term, but it cannot sustain the price if the project lacks genuine development activity. Marketing is important for generating initial attention, but it cannot substitute for actual value creation. The impact of individual factors can also differ over time: what is perceived as positive in the short term (e.g., marketing) may become irrelevant in the long term. Therefore, when evaluating projects, investors should consider not only the proportions but also their evolution over time. Due to the nature of the decentralized economic ecosystem, long-term sustainability and continuous development remain key factors.

Table 3. Linear regression analysis between Team & Advisors usage target and 12-month performance (in $)

Model Summary - 12-M CP ($)

Model	R	R^2	Adjusted R^2	RMSE
M_0	0.000	0.000	0.000	1.543
M_1	0.316	0.100	0.083	1.477

Note. M_1 includes Team and advisors

ANOVA

Model		Sum of Squares	df	Mean Square	F	p
M_1	Regression	12.820	1	12.820	5.873	0.019
	Residual	115.683	53	2.183		
	Total	128.503	54			

Note. M_1 includes Team and advisors

Note. The intercept model is omitted, as no meaningful information can be shown.

Coefficients

Model		Unstandardized	Standard Error	Standardized	t	p
M_0	(Intercept)	0.547	0.208		2.632	0.011
M_1	(Intercept)	-0.707	0.555		-1.275	0.208
	Team and advisors	7.852	3.240	0.316	2.424	0.019

Source: edited by authors

The regression analysis presented in Table 3 examines the relationship between "Team and advisors" costs and the 12-month dollar-based performance (12-M CP $). The "Team and advisors" expenditures have a significant positive impact on the 12-month token performance, explaining 10% of its variance. This result is statistically reliable and the relationship is also commercially interpretable. Allocations toward human capital show a positive correlation with 12-month performance, suggesting that a strong team may be one of the contributing factors to project stability. Similarly, marketing expenditures are associated with short-term price movements, although this relationship does not imply a guaranteed outcome or a direct causal

link. This finding aligns with the literature, which suggests that the presence of a working product or prototype strengthens the project's credibility and increases investor confidence (Chen & Bellavitis, 2020).
The extent of development expenditure carries somewhat greater weight, as the infrastructure being built and the technological implementation indirectly contribute to the project's long-term viability. The research confirms that the amount of resources allocated to development can be a critical factor from the perspective of investor confidence. However, the low R^2 values also indicate that there is no deterministic relationship between the cost structure and market performance. Therefore, budgetary factors should be interpreted more as qualitative than quantitative filters. Based on the results, developers should focus on strengthening the technical foundation and communicating product development effectively.

Table 4. Linear regression analysis between 3 and 12 months performance (in $)

Model Summary - 12-M CP ($)

Model	R	R^2	Adjusted R^2	RMSE
M_0	0.000	0.000	0.000	1.543
M_1	0.417	0.174	0.158	1.415

Note. M_1 includes 3-M CP ($)

ANOVA

Model		Sum of Squares	df	Mean Square	F	p
M_1	Regression	22.368	1	22.368	11.170	0.002
	Residual	106.135	53	2.003		
	Total	128.503	54			

Note. M_1 includes 3-M CP ($)

Note. The intercept model is omitted, as no meaningful information can be shown.

Coefficients

Model		Unstandardized	Standard Error	Standardized	t	p
M_0	(Intercept)	0.547	0.208		2.632	0.011
M_1	(Intercept)	0.286	0.206		1.386	0.172
	3-M CP ($)	0.042	0.013	0.417	3.342	0.002

Source: edited by authors

The linear regression analysis presented in Tables 4 and 5 examines the extent to which 3-month performance (independent variable) can predict 12-month performance (dependent variable). This analysis is displayed in a multi-part table: Model Summary, ANOVA, and Coefficients (Figures 6 and 7). This analysis reveals a statistically significant positive association between 3-month and 12-month performance. However, while the 3-month token performance provides some explanatory value for the subsequent price trajectory, the majority of price variance remains unexplained by this factor alone (it is certainly not the sole determining factor). This also implies that projects enjoying better investor perception in the short term typically manage to maintain that trust over the first year, hence in the longer term. This finding appears to contradict previous assumptions regarding the "pump and dump" phenomenon. These assumptions suggest that a significant portion of microcap crypto projects are designed for substantial and artificial short-

term price surges, often at the expense of long-term financial sustainability. (For the pump and dump assumptions and results, see: Friedhelm & Hagemann, 2019; Xu & Livshits, 2019; Kamps & Kleinberg, 2018.)
Although the results for team expenditures are statistically significant ($p = 0.019$), their economic significance is moderate, as budget structure accounts for approximately 10% of the long-term price variance. This suggests that while team composition is a relevant strategic signal, investors must weigh it alongside other fundamental and market-driven variables.

Table 5. Linear regression analysis between 3 and 12 month performance (in Bitcoin)

Model Summary - 12-M CP (BTC)

Model	R	R^2	Adjusted R^2	RMSE
M_0	0.000	0.000	0.000	1.607
M_1	0.393	0.154	0.138	1.492

Note. M_1 includes 3-M CP (BTC)

ANOVA

Model		Sum of Squares	df	Mean Square	F	p
M_1	Regression	21.485	1	21.485	9.657	0.003
	Residual	117.918	53	2.225		
	Total	139.404	54			

Note. M_1 includes 3-M CP (BTC)

Note. The intercept model is omitted, as no meaningful information can be shown.

Coefficients

Model		Unstandardized	Standard Error	Standardized	t	p
M_0	(Intercept)	0.679	0.217		3.135	0.003
M_1	(Intercept)	0.252	0.244		1.033	0.306
	3-M CP (BTC)	0.116	0.037	0.393	3.108	0.003

Source: edited by authors

5. Practical Implications

The empirical findings of this study offer several strategic insights for both founders of Web3 startups and prospective investors by clarifying the link between capital allocation and market performance. Regarding project founders and developers, the results suggest that a balanced budgetary structure is a prerequisite for long-term viability, where human capital and technical development receive a prioritized share of initial funding. While marketing is essential for generating initial visibility and short-term price increases, an over-reliance on promotional spending often signals a lack of long-term substance and can negatively impact token performance after the first year. Therefore, establishing a competent team with reputable advisors should be viewed not merely as an operational necessity but as a critical strategic signal that supports long-term valuation and investor trust.

For the investor community, these findings imply a need to look beyond initial "hype" and short-term price surges, as such performance is frequently unsustainable if not backed by continuous product development and a stable infrastructure. The data indicates that the allocation for "Team and Advisors" serves as a more reliable indicator of 12-month performance than marketing expenditures, providing a more grounded basis for long-term investment decisions. Furthermore, investors should evaluate project performance in both USD and BTC terms to accurately distinguish between a project's idiosyncratic success and broader market movements.
Ultimately, budgetary structures can serve as vital qualitative filters during the due diligence process. Projects that allocate nearly zero resources to essential pillars like development or human resources should be treated with significant caution, as the lack of these foundational elements is strongly associated with a failure to maintain value over time. A judiciously balanced resource allocation strategy, prioritizing technical and human capital over aggressive short-term marketing, appears to be the most efficacious approach for achieving sustainability within the Web3 sector.

6. Conclusions

Based on the aggregated interpretation of the results, it becomes evident that the majority of Web3 Play-to-Earn projects exhibit a strong short-term focus, with only a smaller fraction demonstrating sustainable long-term value creation. The sharp contrast between the 3-month and 12-month performance data indicates that while most projects may be capable of showing initial growth, this does not translate into long-term sustainability. This is particularly true for the dollar-denominated performance, where the average values decrease drastically after the initial period.
The relationship between marketing expenditure and performance further corroborates the theoretical proposition that excessive marketing dominance diminishes long-term effectiveness. This supports the investor perspective that technological foundation, rather than marketing intensity, is the determining factor for sustainability. Here, marketing specifically refers to promotional activities.
We were unable to demonstrate a significant relationship between development costs and 3-month and 12-month performance in the current sample.
The correlation between team and advisor costs and 12-month dollar-denominated performance showed the strongest positive association. This indicates that investing in appropriate human resources and external expertise plays a crucial role in the long-term survival and success of a project. This is less noticeable in the short term but becomes decisive over time, a trend consistent with classical startup theories.
The budgetary statistical indicators also reinforce the above conclusions. The proportion allocated to development showed the highest variance, suggesting that projects employ very different strategic priorities. The median and mode values are relatively close to the mean, which, in turn, may indicate similarities among the projects in the sample. However, this apparent consistency is misleading, as the extreme values, especially for development and team costs, point to significant discrepancies.
The interpretation of the 3-month and 12-month performance charts clearly shows that short-term price increases do not guarantee a project's long-term viability. The initial "hype" phase is often not based on real value creation, and in many cases, the price falls to a fraction of its initial value within 12 months. In contrast, projects that allocate a larger proportion to team costs tend to exhibit more stable performance.
Based on the combined interpretation of the data, a balanced budgetary structure is one of the main characteristics of successful and sustainable Web3 P2E projects.
The results largely confirmed our hypotheses. Marketing expenditures positively correlated with project performance over the 3-month period; however, this correlation turned negative over the 12-month period. This reinforced the idea that while the immediate impact of marketing can be favorable, it does not guarantee long-term value retention.

While development costs measured in dollars did not show a strong positive long-term effect, a clear positive relationship emerged with Bitcoin-denominated performance. This implies that the significance of product development is more pronounced within the decentralized economic space.

The hypothesis regarding team costs was also confirmed: the strongest positive long-term correlation with dollar-denominated performance was observed in this category. This suggests that maintaining competent human resources and incorporating the knowledge of external experts support a project's viability. The analysis of statistical variance and minimum and maximum values also showed that although there are significant differences between individual projects, higher proportions of development and team costs resulted in more stable performance.

The research highlighted that marketing-based strategies tend to support short-term price increases, but the key to long-term success lies in development and a strong team. Based on while simultaneously, a balanced budget allocation is recommended: increasing the proportion of resources allocated to development and the team can positively contribute to project performance in the long run. Excessive marketing expenditures may yield short-term results but do not provide a stable long-term foundation.

Regarding development costs, it is recommended to support technological innovation and product development, especially introducing features that create long-term value for users. Furthermore, ensuring the team's competence is crucial: expert background, active advisors, and well-structured management.

In aggregate, our results indicate that a judiciously balanced resource allocation strategy may prove to be the most efficacious for enterprises within the Web3 sector. Concurrently, price performance may be subject to a multitude of potential determinants, the comprehensive understanding of which necessitates additional inquiry.

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Tamás Faludi[5]

Strategic issue of outsourcing logistics processes involving dangerous materials: a decision support model for selecting the right logistics provider

This study examines the outsourcing of dangerous goods logistics. Its objective is to investigate the set of criteria that can be established in a decision-making situation where a company intends to outsource logistics processes related to dangerous goods. Based on the criteria framework, a potential decision-making process can be visualized, illustrating the possible decision paths through which optimal alternative can be selected. Through a structured review of the relevant literature, the risk factors associated with activities involving dangerous goods can be identified, providing the basis for the development of the decision criteria framework. This framework subsequently serves as the foundation for the service provider selection criteria system, through which a decision-making process can also be visualized.
Keywords: dangerous goods, dangerous materials, outsourcing, decision-supporting, logistics
JEL-codes: D21, L21, M10, R40, R41

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1. Introduction

The logistics processes associated with the handling and transportation of dangerous goods or materials constitute a domain characterized by elevated risk exposure and a pronounced requirement for specialized expertise. A wide range of risk sources must be systematically identified, assessed, and evaluated in order to ensure the safe and incident-free execution of logistics operations. When a material classified as dangerous enters a firm's material flow, the organization is required to implement specific technical, organizational and regulatory measures to ensure full compliance with the applicable dangerous materials framework.
In many cases, firms lack the appropriate infrastructure, technological capabilities, certified personnel or risk-bearing capacity necessary for the safe management of dangerous goods. Consequently, the outsourcing of dangerous goods logistics processes emerges as a viable strategic alternative. Such decisions are typically embedded in a boarder make-or-buy context and involve considerations related to regulatory compliance, liability allocation, operational risk exposure and transaction costs.
The primary objective of the paper is to develop a decision support model, operationalized through a decision tree-based framework, to assist firms in systematically identifying and evaluating the risks associated with specific dangerous goods logistics processes. The proposed model aims to support managerial decision-making by determining on a risk-informed basis, under which conditions the outsourcing of a given logistics activity is justified.
The outsourcing of dangerous goods logistics processes represents a critical decision context in which regulatory compliance and the maturity of risk management practices are of paramount importance. While numerous studies have examined the risk factors associated with dangerous goods, and the role of logistics service providers as distinct sources of risk has also been widely addressed, there is a lack of research that integrated these two domains into a unified analytical framework. The objective of this paper is to bridge this research gap by investigating the risks associated with dangerous goods logistics within a service outsourcing context. Based on prior research and expert judgment, the identified risks are systematically weighted, thereby enabling the development of a decision-support model grounded in a prioritized and relevant set of criteria. This model aims to assist companies in determining the key attributes, certifications, and

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infrastructure requirements that a logistics service provider must possess in order to ensure the safe and compliant handling of dangerous goods.

2. Literature review

The problem addressed in this study is inherently complex. The timeliness and relevance of the research are driven by the continuously increasing demand for the production and utilization of dangerous materials. In this context, the transportation, storage, and handling of such materials as dangerous goods constitute a significant logistics challenge, requiring strict adherence to an extensive and multifaceted regulatory framework. When combined with outsourcing considerations, this results in a highly complex decision-making scenario.
The literature review focuses on the conceptual and operational characteristics of logistics processes involving dangerous goods. In addition to outlining the structural features of dangerous goods logistics, this section reviews the relevant regulatory frameworks and synthesizes the risk factors identified in the extant literature.

2.1. Conceptual framework of dangerous goods and materials

Dangerous goods are defined as substances or materials that required heightened attention and specialized expertise throughout logistics operations, as improper handling may results in hazards to human health, property, safety or the environment (Güner-Özbek, 2008; Fattahi & Behnamian, 2021; Gholamizadeh et al., 2026). The integration of any dangerous material and goods into the supply chain necessitates comprehensive documentation ensuring its safe and compliant management across all stages of the logistics process.
A central document in this context is the Safety Data Sheet (SDS), which accompanies the material throughout the supply chain. The SDS provides detailed information regarding transportation, storage, handling and regulatory classification. It specifies the inherent hazards of the material or goods, potential sources of risk, prescribed risk mitigation measures, and the required emergency response protocols in the event of an incident (Mannan, 2012; Ho & Tenkate, 2024). While the SDS is traditionally paper based, the digitalization of compliance documentation has led to the widespread adoption of electronic SDS (Balázs-Kalázs & Rostás, 2026), thereby enhancing accessibility, traceability and integration into logistics information systems.
According to the logistics literature, core logistics processes may be conceptualized as loading, transportation and storage, complemented by ancillary activities such as packaging, warehousing, inbound storage, outbound handling, internal material handling, order picking, and dispatching (Sadjady, 2011; Gutiérrez et al., 2023). When dangerous goods or materials enter the material flow, the regulatory and operational requirements governing these processes are substantially modified. All logistics activities – including loading, transportation, storage, packaging, warehousing, inbound and outbound handling, material movement, order picking and dispatch – must be executed strictly in accordance with the specifications, hazard classifications, and handling instructions set forth in the applicable SDS and relevant regulatory provisions.
Given that dangerous materials logistics materials logistics necessitates dedicated risk management procedures, specialized infrastructure, certified personnel, and compliance assurance mechanisms, a growing number of logistics service providers have developed specific capabilities in this domain. Firms may opt for comprehensive dangerous materials logistics services, encompassing the full spectrum of activities, or alternatively outsource selected subprocesses to external providers. The following subsection examines the characteristics and risk profiles associated with individual logistics activities in the context of dangerous goods or materials.

2.2. Summary of risks associated with individual logistics activities

Logistics service providers may assume responsibility for the end-to-end management of supply chain activities, complex freight forwarding operations or selectively outsourced logistics subprocesses (Jharkharia & Shankar, 2007; Beckers et al., 2023; Abbasi et al., 2024). Within the conceptual framework of advanced logistics service models – up to the fifth-party logistics (5PL) configuration – it is necessary to identify and categorize the tasks and processes that constitute dangerous materials logistics (Hosie et al., 2012; Langley et al., 2016; McDonald & Ngo, 2025). Figure 1 illustrates the structural positioning of dangerous goods-related activities within the multi-level logistics service provider model and serves as the basis for the subsequent risk-oriented process analysis.

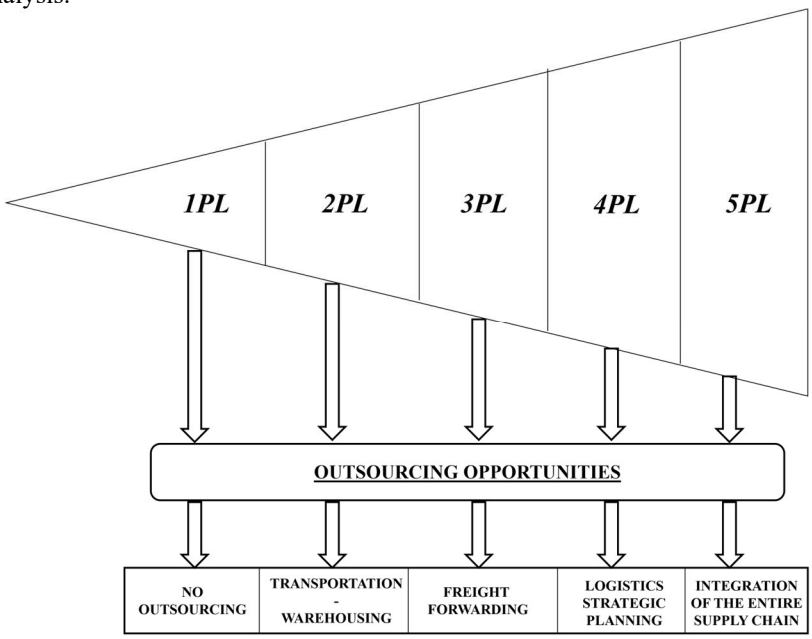

Figure 1: The outsourcing opportunities according to the 5PL model (source: own construction based on Hosie et al., 2012; Langley et al., 2016; McDonald & Ngo, 2025)

Figure 1. illustrates the 5PL model of logistics service providers, demonstrating the range and complexity of services that companies can offer to their client organizations. As depicted by the progressively expanding pyramid structure, higher PL levels correspond to an increasing breadth and integration of services provided by the logistics operator, as well as a greater extent of service utilization by the contracting company.

At the first level of the logistics service structure, no outsourcing takes place; the firm performs logistics activities using its own assets and internal resources (it means, it is an in-house logistics). At the second level, basic logistics functions – such as transportation and warehousing – are delegated to an external logistics service provider.

Building upon this, the third level encompasses not only transportation and storage but also complex freight forwarding and coordination activities. At this stage, the service provider assumes significant organizational and planning responsibilities. In many cases, the provider does not directly perform the physical carriage but subcontracts transportation tasks to specialized carriers, thereby acting as an integrative coordinator within the logistics network.

The fourth level further extends these capabilities by incorporating advanced information technology support and supply chain-level strategic planning.

At the apex of the logistics service hierarchy, the provider assumes responsibility for the integration of the entire supply chain, effectively achieving a form of virtual integration of the entire supply chain, effectively achieving a form of virtual integration (Langley et al., 2016; Nicoletti & Appoloni, 2024).

The 5PL framework is equally applicable to logistics service providers specializing in dangerous materials or goods. On this basis, the subsequent analysis identifies and evaluates the risks associated with individual dangerous goods related logistics activities.

In the context of transportation and carriage, a distinction must be made between different modes of transport. The harmonized classification system for dangerous goods in road transport is defined by the European Agreement concerning the International Carriage of Dangerous Goods by Road (in short ADR, but in originally Accord européen relative au transport international des marchandises Dangereuses par Route). Based on hazard identification criteria, the ADR categorizes dangerous goods into nine classes according to their primary risk characteristics (e. g. explosives, toxic substances). This classification framework is grounded in the intrinsic hazard properties of the material (UNECE, 2026a; Lukács & Veres, 2024).

In accordance with this classification system, standardized hazard labels (placards) have been develpod to visually communicate the nature of the risk. These consist of a square set on its vertex (diamond shape), featuring a background colour corresponding to the hazard class, a central hazard symbol, and the class number displayed in the lower corner. Such labels must be affixed to the packaging, while enlarged placards – where prescribed by the ADR – must also be displayed on vehicles and transport units in designated positions (DOT Chart, 2026; EUR Lex, 2026).

Dangerous goods and materials are further identified by four-digit UN number. In addition, certain substances are assigned two- or three-digit hazard identification numbers, sometimes preceded by the letter ‘X’, indicating specific risk characteristics. Vehicles transporting dangerous goods are required to display orange rectangular plates of prescribed dimensions, typically positioned at the front and rear of the vehicle, in accordance with ADR requirements. (UNECE, 2026b).

These plates may be blank, indicating the carriage of packaged dangerous goods (less-than-tank or general cargo transport), or may display numerical codes arranged in two rows separated by a horizontal black line. The upper row contains a two-digit hazard identification number indicating the primary and subsidiary risks of the goods or material, while the lower row displays the four-digit UN number identifying the specific material. Numbered orange plates are required in the case of tank transport, bulk transport, and exclusive carriage of packaged radioactive materials.

Hazard labels, placards and orange plates are applied in both road and rail transport. In maritime or waterway transport, the same hazard classes are recognized; however, marking and placarding requirements are subject to mode-specific technical standards (Carosso et al., 2012). Rail transport of dangerous goods or material is governed by the Regulations concerning the International Carriage of Dangerous Goods by Rail (in short RID, in originally Règlement concernant le transport international ferroviaire de marchandises dagereuses). Maritime transport by the International Maritime Dangerous Goods Code (in short IMDG Code). The inland waterway transport in Europe regulated by the European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (in short AND, in originally Accord européen relatif au transport international des marchandises dangereuses par voies de navigation intérieures).

Air transport of dangerous goods or materials represents a comparatively smaller volume due to stringent regulatory constraints and only materials or goods meeting specific criteria are permitted for carriage by air. The applicable regulatory framework is defined by the IATA Dangerous Goods Regulations (in short IATA DGR). IATA is the International Air Transport Association, which is the trade association for the world’s airlines.

Beyond general hazard determinants, it is essential to identify mode-specific risk factors associated with each transport modality in the case of dangerous goods carriage.

Strict compliance with mode-specific regulatory frameworks significantly mitigates the risks associated with the transportation of a given dangerous good. Importantly, such regulatory adherence is not limited exclusively to the act of carriage itself. For instance, the ADR provides a

comprehensive regulatory structure that governs the entire dangerous materials process, extending beyond transport to include classification, packaging, marking, documentation, loading, unloading and handling requirements. Accordingly, compliance with transport regulations should be interpreted not merely as authorization for carriage, but as an integrated compliance obligation applicable to the end-to-end logistics process.

The application of appropriate packaging – both terms of type and quality – constitutes a fundamental logistics principle, as it protects the goods from mechanical, chemical and environmental stress throughout logistics operations. In the context of dangerous goods, packaging must additionally meet certified performance standards aligned with the relevant hazard class and packing group, thereby serving as a primary risk containment mechanism.

Furthermore, the rolling stock, transport equipment and infrastructure associated with each mode of transport represent potential sources of risk. Vehicle condition, tank integrity, intermodal transfer points, terminal infrastructure and technological reliability may all contribute to operational vulnerability. Consequently, these elements must also be incorporated into a comprehensive risk assessment framework for dangerous material logistics (Erkut et al., 2007; Holeczek, 2019; Mejlingová & Pántya, 2021; Lukács & Veres, 2024).

In the case of warehousing, priority must be given to regulatory and technical requirements governing the storage of dangerous goods and materials. In warehousing operations, it is essential to determine – based on the chemical properties of the goods or material – the specific environmental conditions under which the material may be stored. This includes compliance with prescribed temperature ranges, humidity limits, ventilation requirements and, where applicable, explosion-proof or fire-resistant infrastructure standards.

Particular attention must be paid to incompatibility considerations. Substances, goods or materials that may react with one another must not be stored in proximity, nor even within the same storage compartment, if such co-location could trigger hazardous chemical interactions. (Cournoyer et al., 2005; ABS, 2025; Karkori & Olsen, 2025). Consequently, segregation rules and compatibility matrices constitue critical elements of dangerous materials warehouse management.

From a risk management perspective, systematic inspection of packaging integrity is likewise indispensable. In the regulatory and operational context, a distinction is drawn between single packaging and combination packaging. In the case of single packaging, the dangerous goods or material is in direct contact with the packaging material, which itself interfaces directly with the external environment. By contrast, the combination packaging involves placing the single packaging within an additional outer packaging unit – such as a box or crate – thereby providing an additional layer of mechanical protection (Park et al., 2014). These solutions are typically applied in the case of packaged dangerous goods (less-than-bulk consignments).

Where the intrinsic properties of the material preclude the us of either single or combination packaging, Intermediate Bulk Containers (IBSs) must be employed. IBCs are predominantly used for liquid and bulk dangerous materials and serve as standardized containment units designed to ensure structural stability, leak prevention and safe handling within logistics operations (Lüttgens et al., 2005).

When engaging complex freight forwarding services or higher-tier logistics service models (e. g. 3PL or 5PL configurations), the service provider itself increasingly constitutes a distinct risk factor. At elevated levels of outsourcing intensity, the focal firm becomes progressively dependent of the provider's regulatory compliance capability, risk management maturity, information systems reliability, and governance structures. Consequently, the provider's organizational competence, certification portfolio, subcontracting practices and liability management mechanisms must be incorporated into the overall risk assessment framework (Figure 2).

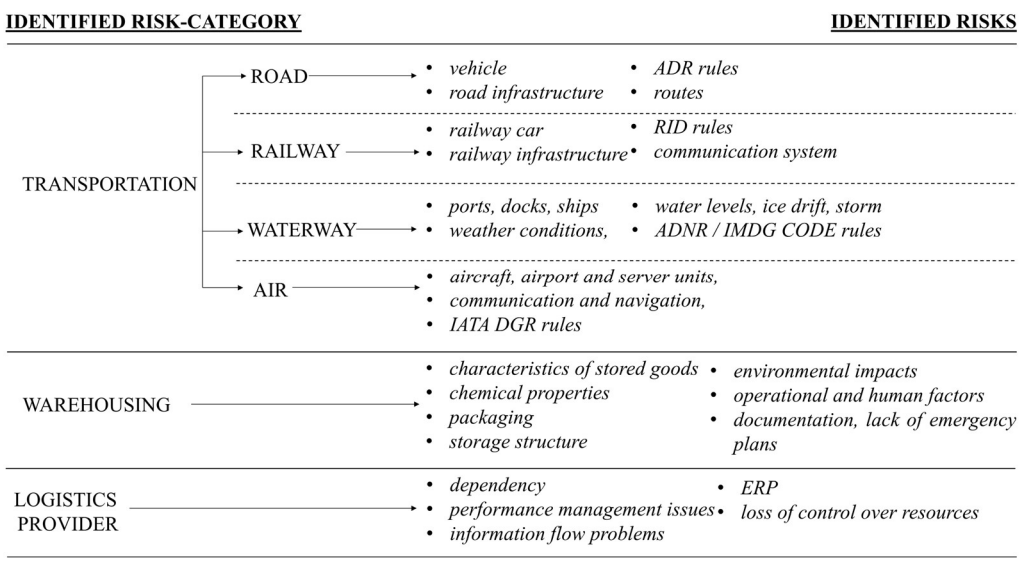

Figure 2: Summary of the identified risks (source: own construction based on the literature)

Figure 2. provides a structured overview of risk categories, followed by the identification of specific risk factors within each category. Accordingly, transportation and warehousing – representing the core logistics processes – are highlighted, alongside the logistics service provider as a primary source of risk. A more detailed breakdown of these categories reveals that, in the case of transportation, the key risk factors are predominantly associated with the availability and compliance of mode-specific regulatory frameworks and certifications. For warehousing, risks are primarily linked to facility structure, packaging practices, and documentation procedures. In relation to the logistics service provider, significant risks arise from dependency relationships induced by the level of integration, as well as from disruption and inefficiencies in information flow.

Across the previously examined, lower-tier service levels, the logistics service provider itself consistently emerged as an identifiable risk factor. The dependency relationship inherent in outsourcing arrangements substantially influences the focal firm's make-or-buy decision, particularly in the context of dangerous materials logistics. Beyond structural dependency, performance-related risks associated with the provider – namely, whether the service provider is capable of maintaining a consistently high level of operational excellence – carry considerable weight in managerial decision-making situations (Barata et al., 2024).

In addition to differentiation by transport mode, the risks arising during carriage may be generally identified on the basis of the intrinsic characteristics of the consignment, the provision of the transport service itself and human factors. A frequently observed source of disruption consists of administrative errors and deficiencies attributable to negligent handling, these are, in most cases, ultimately traceable to human factors within transport and logistics operations.

Beyond these aspects, packaging and its regulatory conformity may be defined as a general transport-related risk factor. In the context of dangerous goods logistics, packaging performance and compliance with applicable regulatory frameworks (e.g., ADR, UN approved packaging standards and modal-specific provisions) are of critical importance. In such cases, packaging does not merely serve to protect the goods from external environmental impacts; rather, it must also ensure the protection of the environment from the potentially hazardous effects of the goods or materials transported. This dual protective function is essential not only from an environmental risk mitigation perspective, but also with regard to occupational safety, public safety and asset protection considerations within the supply chain.

Based on the synthesized findings, the outsourcing of dangerous goods-related logistics activities to a logistics service provider represents a complex, multi-criteria decision problem. The overarching objective of this decision process is the minimization of provider-related and operational risks while ensuring regulatory compliance and supply chain continuity. The following section introduces the development of a structured decision criteria system designed to support firms in addressing the identified problem.

3. Method for developing the decision criteria system

The primary objective of the paper is to support corporate decision-makers in establishing an appropriate evaluation framework for outsourcing decisions. The analysis specifically focuses on the outsourcing of dangerous materials logistics processes and accordingly, develops a method applicable to decision-making among logistics service providers specialized in dangerous goods management.

3.1. Methodology

The study applies a case study methodology to stimulate a realistic decision-making situation. Given that the research question addresses a highly complex scenario characterized by multiple interdependent variables while concentrating on a specific decision context, the case study approach is methodology justified. This approach enables the simulation of real-world business conditions and facilitates the development of practice-oriented solutions (Gronhaug & Ghauri, 2016; Paparini et al., 2020; Correa et al., 2025).

A structured literature review provided a comprehensive understanding of dangerous materials logistics management and served as the conceptual foundation for constructing the case scenario. By synthesizing and comparing the identified risk sources, a structured criteria system supporting the outsourcing decision can be developed.

To visualize the proposed solution, the study constructs an adapted decision tree model based on the developed criteria system. Decision tree models allow for the structured representation of decision alternatives, conditional pathways and potential consequences (Mingers, 1989; Kalip et al., 2022). In the present study, the theoretical foundations of decision tree analysis are applied to model and visualize the outsourcing decision mechanism in a systematic and transparent manner.

In summary, the study integrates three methodological approaches, a structured literature review, a case study-based decision modelling framework.

3.2. Case description

The case involves a domestic small- and medium enterprise (SME) operating as a supplier within an international supply chain. A new raw material has been introduced into its procurement portfolio. This material qualifies as a dangerous good: sulfuric acid, which is classified under Class 8 of the ADR.

The company has acquired a new customer located in Portugal that requires sulfuric acid for PVC production. To fulfil this demand, the SME intends to procure the substance from a Hungarian sulfuric acid manufacturing facility, hold is in warehouse inventory (including a minimal safety stock buffer to mitigate demand fluctuation), organize and execute its transportation to the customer.

Although the firm has previously managed ad hoc procurement transactions involving dangerous materials, the newly established partnership implies a long-term contractual relationship. Consequently, the company faces a strategic decision: whether to internally develop the necessary capabilities for the transportation and storage of dangerous goods or to outsource the related logistics processes to an external service provider.

Preliminary cost calculations and managerial preferences indicate a predisposition toward outsourcing dangerous materials logistics activities. The firm aims to contract with a high-tier

logistics service provider, potentially at an advanced service level – e. g., 3PL or 5PL). To support this objective, a structured partner selection criteria system must be developed.

3.3. Development of the criteria system

The structured literature review enables the identification of key risk factors associated with both dangerous materials logistics processes and logistics service providers. In designing the decision criteria system, it is essential not only to account for direct provider-related risks – such as compliance capability, operational reliability and governance structure – but also to incorporate indirect risks arising from transportation and warehousing activities; e. g., mode-specific risks, storage incompatibility, infrastructure adequacy.
In accordance with managerial preferences and strategic priorities, the identified criteria should be weighted to reflect their relative importance in the decision context. The resulting criteria system – together with their assigned weights – forms the foundation of the proposed decision tree-based evaluation model. The figure below shows the criteria system and their relative weights in a hierarchical structure. The highest weight in the figure is 15%, which will be at the top of the structure, followed by factors with a relative weight of 10% in the middle level, and criteria with a relative weight of 5% at the bottom of the structure (Figure 3).

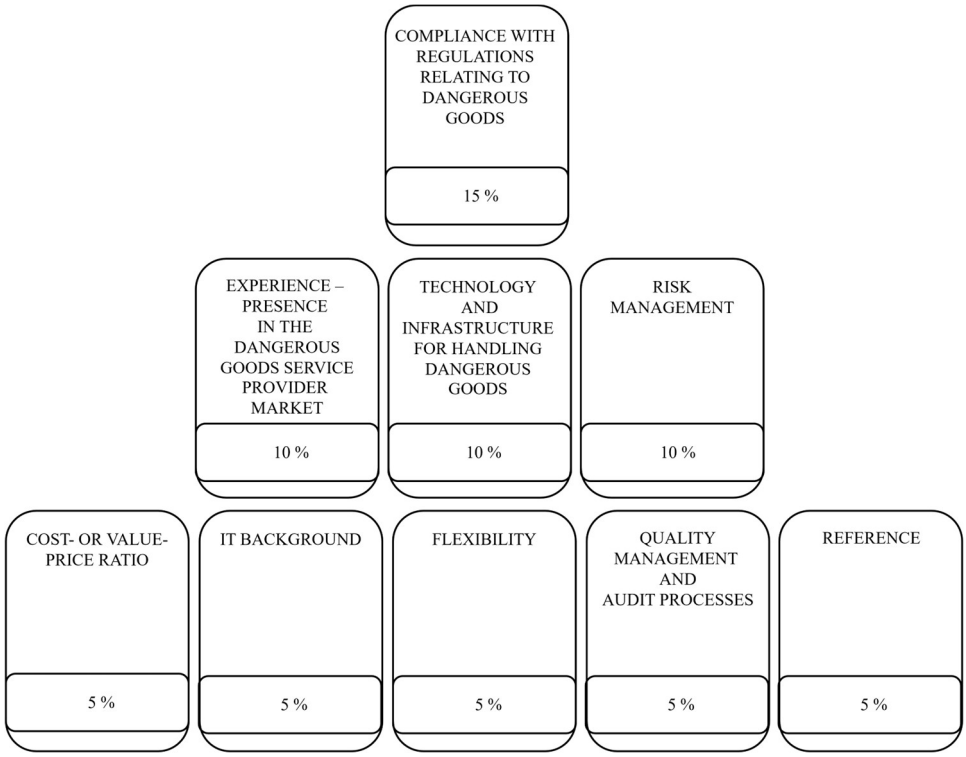

Figure 3: The criteria system (source: own construction)

In the determination of the weighting scheme, which is illustrated by the Figure 3, the researcher relied on findings and case studies identified in the relevant literature. Within these studies, expert judgement was frequently incorporated, for instance through the application of the Delphi method. Building upon the criteria established in the reviewed studies, and with particular emphasis on their underlying rationale, the evaluation criteria and their corresponding weights were further refined and developed. Overall, the existing literature demonstrates a clear trend toward the application of advanced MCDM techniques in dangerous materials logistics. The consistent use

of criteria weighting, risk prioritization, and alternative ranking underscores the importance of structured decision-support tools in this high-stakes domain (Sattayaprasert et al., 2008; Ebrahimi & Tadic, 2018; Yilmaz & Verter, 2022; Kitthiphovanoth et al., 2026)

The developed criteria system was derived directly from the previously identified risk factors. The risk elements associated – either directly or indirectly – with dangerous materials and logistics service providers were systematically transformed into measurable compliance and performance criteria.

Regulatory compliance with international dangerous goods frameworks constitutes the most critical factor in provider selection. In the absence of demonstrable compliance capability, the selection of a given provider becomes untenable. Accordingly, the highest weight was assigned to this criterion, reflecting the objective of achieving the highest attainable level of regulatory conformity.

Beyond compliance, the availability of dedicated infrastructure specifically designed to support dangerous materials handling represents a key evaluation dimension. Market experience likewise functions as a proxy for operational reliability and accumulated expertise, therefore, longer market presence is associated with higher service maturity and correspondingly assigned a greater weight in the criteria system.

Given the inherently high-risk nature of dangerous materials logistics, the presence of structured risk management procedures is indispensable. Potential providers are expected to demonstrate standardized risk management methodologies, relevant certifications and documented control mechanisms. Additional – though relatively lower-weighted – criteria include the robustness of IT systems (supporting information flow and traceability), organizational flexibility in a dynamic economic environment, service pricing, the existence of formal auditing procedures and the strength of professional references.

Together, these elements constitute the comprehensive evaluation framework.

3.4. Modelling the decision process

In structuring the decision model, the overall objective – selection of the most appropriate dangerous materials logistics service provider – must first be defined. Subsequently, decision nodes are arranged according to the relative importance of the criteria.

The model distinguishes between three outcome categories, represented visually:

green indicates the optimal solution;

- *yellow* denotes a conditionally acceptable alternative;
- *red* identifies an unsuitable provider.

The structured decision pathway facilitates the systematic identification of the most favourable alternative.

The first and most decisive criterion is regulatory compliance. This constitutes a primary screening factor in any outsourcing decision. If a provider lacks the necessary authorization to transport or handle the relevant dangerous goods, it must be immediately excluded.

It is essential to differentiate between transport mode-specific regulatory frameworks. In the present case, the primary modalities are road and rail transport. Therefore, compliance with the ADR for road transport and the RID for rail transport represent minimum eligibility requirements. Where a provider also holds certification for inland waterway or air transport, a broader service portfolio may be inferred. If a provider lacks ADR or RID compliance, it is deemed unsuitable (which means it goes to the red category). If it complies exclusively with ADR and RID, a limited but acceptable service scope may be assumed; which means this could be in the yellow path. Full multimodal regulatory compliance suggests a broader operational capability and position the provider within the optimal (green) category.

Only providers meeting at least ADR and RID requirements proceed to the next decision level, which concerns infrastructure adequacy. The absence of dedicated dangerous materials infrastructure constitutes a critical risk factor and results in immediate exclusion. The optimal

scenario is one in which the provider maintains its own purpose-built infrastructure. Reliance on subcontracted infrastructure introduces additional risk exposure and therefore yields a conditionally acceptable classification.

At the subsequent level, experiential factors are evaluated. Extended market presence is interpreted as an indicator of operational maturity. A minimum threshold of five years' market activity may be established, while ten or more years of experience represents the target value and optimal condition. Providers with between five and ten years of experience fall into the acceptable category, albeit with elevated partnership risk relative to highly experienced competitors

Given the elevated risk profile of dangerous materials logistics, the existence of formalized and standardized risk management procedures constitutes another critical decision node. The optimal pathway requires documented, structured and standardized risk management systems. Partially developed or ad hoc procedures result in a conditionally acceptable classification due to increased operational uncertainty. The absence of any formal risk management framework renders the provider unsuitable.

On the basis of the above criteria hierarchy, the decision tree model can be constructed as illustrated in Figure 4, providing a transparent and logically structured representation of the outsourcing decision mechanism.

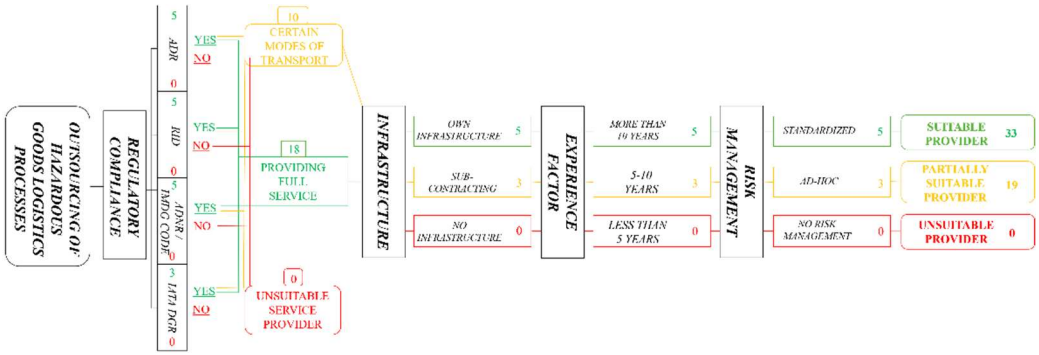

Figure 4: Provider selection model in terms of the outsourcing of dangerous goods and materials (source: own construction)

Due to space limitations, the model does not incorporate criteria assigned weights below 10%, instead, it focuses exclusively on the most significant evaluation dimensions. Consequently, the decision tree emphasizes the highest-weighted risk-derived criteria that exert the greatest influence on the outsourcing decision.

To ensure quantifiable and comparable outcomes, a simplified scoring system was incorporated into the decision tree. Given that regulatory compliance constitutes a fundamental prerequisite for logistics service providers handling dangerous goods, full compliance with the relevant legal frameworks was assigned a score of 5 points, while non-compliance was assigned 0 points. Considering that the transportation of dangerous goods by air is relatively infrequent, a lower score (3 points) was deemed acceptable in this modality. Based on this framework, a service provider may achieve a maximum of 18 points if it complies with regulatory requirements across all modes of transport. In cases where the provider holds authorization for at least one transport mode, it may be considered a partially acceptable alternative, corresponding to a score of 10 points. Conversely, if the provider lacks authorization for all transport nodes, it is excluded at this stage with a score of 0. Subsequently, the decision paths were evaluated using a color-coded scheme: green paths were assigned 5 points, yellow paths 3 points, and red paths 0 points. This approach yields a final, numerically comparable scoring outcome, whereby a fully compliant service provider attains 33 points, a partially suitable provider 19 points, a non-suitable provider 0 points. By applying the established scoring scheme in conjunction with the predefined weighting

factors, the weighted average scores corresponding to each decision path endpoint can be calculated. The aggregation of these weighted scores is presented in Figure 5.

	TOTAL WEIGHTED POINTS	POINTS	WEIGHTS	CRITERIA
SUITABLE PROVIDER	**3.7**	18	15%	*REGULATORY COMPLIANCE*
		5	10%	*INFRASTRUCTURE*
		5	10%	*EXPERIENCE*
		5	10%	*RISK MANAGEMENT*
PARTIALLY SUITABLE PROVIDER	**2.4**	10	15%	*REGULATORY COMPLIANCE*
		3	10%	*INFRASTRUCTURE*
		3	10%	*EXPERIENCE*
		3	10%	*RISK MANAGEMENT*
UNSUITABLE PROVIDER	**0**	0	15%	*REGULATORY COMPLIANCE*
		0	10%	*INFRASTRUCTURE*
		0	10%	*EXPERIENCE*
		0	10%	*RISK MANAGEMENT*

Figure 5: Weighted scores achieved by the service providers. (source: own construction)

Figure 5 consolidates the information obtained throughout the evaluation process. Accordingly, within the proposed scoring framework applied in the case study, a potential logistics service provider must achieve a minimum weighted score of 2.4 in order to be considered a viable alternative in the decision-making process.

4. Conclusions and future research directions.

The developed decision model generates three possible outcomes, thereby classifying potential logistics service providers into three categories. Providers that satisfy all high-weight criteria – namely, full regulatory compliance for dangerous materials and goods handling, availability of dedicated infrastructure, extended market presence and the application of standardized risk management procedures aimed at minimizing logistics-related hazards – are categorized as suitable providers, which will be the optimal alternative.
Service providers that demonstrate partial compliance – such as limited multimodal certification, incomplete infrastructure necessitating subcontractor involvement, moderate market experience, and ad hoc or partially formalized risk management practices – are classified as partially or conditionally suitable providers. Although these firms may be capable of performing the required services, the associated orientational and dependency risk remain comparatively higher.
Naturally, real-world decision-making is not restricted to the linear pathways depicted in the model. The decision tree outlines optimistic, moderately optimistic and pessimistic trajectories based on the weighted scoring structure. The established criteria system forms the structural

backbone of the provider selection framework, while the decision model represents one possible procedural pathway that decision-makers may follow. Through the application of weights, output values at each decision level can be determined, thereby enabling an objective and transparent basis for comparison among alternative providers.

As a direction for future research, the empirical testing of the proposed decision model within a specific corporate setting is recommended. Applying the weighted criteria framework in a real-world case would allow for validation of the model's practical applicability and robustness. To enhance the relevance of the criteria system and refine the weighting structure, the involvement of an expert panel is planned. A short online survey instrument is envisioned to validate and potentially extend the identified criteria. Subsequently, expert-based weighting of criteria – reflecting their perceived importance in dangerous materials logistics outsourcing decisions – would constitute the final step in the methodological refinement. Future research will target specialists from nationally operating companies engaged in dangerous goods logistics, thereby enabling empirical testing and further calibration of the developed decision model.

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HR as a Bridge Between Work and Life: An Empirical Study on Employee Well-Being and Flexibility

This study examines the challenges of work–life balance from a human resource management (HRM) perspective, with particular attention to changing labour market expectations and organisational culture transformation. The central assumption is that the integration of professional and personal life, together with the promotion of mental well-being, is becoming increasingly important for both manual and knowledge workers, with a significant impact on employee performance and commitment. The study used a mixed-methods approach. The quantitative phase was based on an online questionnaire completed by 131 active employees, of whom 69% worked full-time, 17% part-time, and 14% on a project basis. The analysis revealed that part-time and project-based employees reported lower stress levels and more favourable work–life balance perceptions compared to full-time workers. The qualitative phase drew on a semi-structured interview with an experienced HR professional, which provided deeper insights into internal HR practices and talent retention. The findings show that although 45% reported job satisfaction, organisational measures for well-being are often missing. The most common sources of stress include excessive job demands, lack of feedback, and rigid work organisation. The study highlights that supporting work–life balance should not be considered an additional benefit but rather a key element of sustainable HR strategy. By fostering trust, promoting flexibility, and prioritising well-being, organisations can gain long-term competitiveness and stronger retention.
Keywords: employee well-being; flexible employment arrangements; human resource management; organisational commitment; stress; work–life balance
JEL codes: J24, J81, M12

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1. Introduction

Amid the accelerated economic and technological changes of the 21st century, work–life balance has become a central theme in social discourse. The societal significance of this balance lies in its close connection to individual well-being, family life, and mental health.
Research shows that the prolonged disruption of work–life balance may lead to increased stress, burnout, and health deterioration (Molnár, 2023), which not only negatively affects the employee and their family but also generates broader economic consequences. For instance, the decline of mental health in the workplace results in measurable national economic losses: according to the World Health Organization (WHO, 2024), approximately 12 billion working days are lost globally each year due to depression and anxiety, corresponding to an estimated productivity loss of around USD 1 trillion.
Conversely, the harmonious alignment of work and private life has a positive impact on quality of life and job satisfaction – it supports the maintenance of overall employee well-being, enhances performance, and reduces turnover and absenteeism (Molnár, 2023). It is therefore unsurprising that for younger generations, the opportunity to achieve work–life balance is among the most important factors in choosing an employer (Guti et al., 2023; Farkas, 2025).
In parallel, the role of human resource management (HRM) has gained new dimensions in supporting employee well-being. Modern organisations increasingly emphasise employee health

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and satisfaction in their strategies, recognising that HR, as a strategic partner, can play a pivotal role in creating a balanced working environment.
It is now a fundamental expectation that HR departments should not only perform administrative tasks but also actively initiate programmes and policies that promote work–life balance. In line with this, many companies have introduced flexible working hours, remote work opportunities, health and mental well-being programmes, and fostered organisational cultures that support the reconciliation of personal life and career (Kaur, 2023). The strategic shift in HRM is also evident in that employee well-being has become a core element of corporate culture: organisations are increasingly focusing not solely on productivity but also on holistic employee health and satisfaction (Maven Team, 2024). Against this backdrop, it is particularly relevant to examine how employees experience work–life balance in their everyday lives and which HR tools and strategies contribute to supporting their well-being. Accordingly, this study explores employees' experiences with work–life balance, with special emphasis on the role and impact of HR strategies. This study seeks to demonstrate how human resource management can facilitate more balanced and healthier working conditions for employees. In doing so, it shows how HR can also contribute to organisational effectiveness and sustainable employment.

2. Literature Review

Over the past two decades, the issue of work–life balance has become a prominent field of study not only in psychology and sociology but also in management and human resource research. The literature consistently emphasises that work–life balance is a multidimensional phenomenon affecting individual well-being, social networks, and organisational effectiveness (Greenhaus & Allen, 2011; Guest, 2002).
International comparative studies suggest that work–life balance has a positive impact on mental health and life satisfaction (Haar et al., 2014).
The classical notion of balance – defined as an individual's ability to meet both professional and personal obligations – has in recent years been complemented by an emphasis on flexible life management and the consideration of individual preferences (Kossek & Lambert, 2005). Strategies aimed at managing conflicts between workplace demands and family roles play a key role in reducing stress, increasing commitment, and maintaining health (Allen et al., 2000).
In Hungarian scholarship, Juhász (2011) and G. Fekete (2013) also highlight that the boundaries between work and private life are becoming increasingly blurred, particularly with the spread of digital technologies and remote work. This emerging work culture, however, represents not only opportunities but also challenges for both organisations and employees.
In recent years, the international discourse has increasingly addressed the dimension of mental health. Following Máté (2022), chronic stress arising in the course of work can lead not only to decreased performance but also to psychosomatic illnesses if employees lack sufficient internal or external support. Similar conclusions were reached by Chapman et al. (2021), who argue that organisational trust and psychological safety play a decisive role in preserving employees' mental health.
The HRM literature increasingly underlines that supporting employee well-being and work–life balance is not merely a welfare measure but also a factor of competitiveness. Flexible forms of work – such as telework, flexible start and end times, or hybrid models – significantly enhance employee satisfaction, while simultaneously creating new challenges regarding control and collaboration (Kaur, 2023; Kelliher & Anderson, 2010).
Well-designed HR strategies – including recognition systems, managerial support, and opportunities for participation – facilitate the achievement of balance and, in the long run, strengthen retention and loyalty (Maven Team, 2024). One of the keys to retention and employee loyalty lies in the evidence-based development of HRM systems aimed at improving well-being (Allen et al., 2013).

In summary, the literature indicates that achieving work–life balance depends on the interplay of complex organisational and individual factors, with HRM as a conscious strategic partner playing a significant supporting role.
The literature also highlights that certain social groups face particularly pronounced challenges in achieving work–life balance. Single parents, employees with caregiving responsibilities for elderly family members, and shift workers are frequently identified as especially vulnerable due to time constraints, emotional demands, and limited flexibility (Guest, 2002; Greenhaus & Allen, 2011). These groups often experience heightened stress and reduced opportunities for recovery, underscoring the importance of organisational and HR-level interventions. Situating work–life balance within this broader social context reinforces the argument that supportive HR strategies are not universally applied solutions but must be sensitive to diverse life circumstances.

3. Research Methodology

This study explores employees' experiences with work–life balance, focusing on the role and impact of human resource strategies. The research applied a mixed-methods approach, combining both qualitative and quantitative elements.

3.1 Sampling and data collection

The target population of the quantitative survey consisted of active employees. Data were collected using an online questionnaire created in Google Forms, which was publicly accessible during the data collection period. The survey link was initially distributed through the authors' professional and personal networks via social media platforms, primarily Facebook and LinkedIn. In addition, respondents were encouraged to share the link further within their own networks.
As a result, the study employed a non-probability sampling strategy, combining convenience sampling with elements of snowball sampling. Participation was entirely voluntary and anonymous; any individual who accessed the link and met the criterion of being an active employee was able to complete the questionnaire. While this sampling approach does not allow for statistical representativeness, it is appropriate for the exploratory aims of the present study and provides valuable insights into employees' experiences of work–life balance and organisational support.

3.2 Quantitative Data Collection

The quantitative phase was conducted through an online survey completed by 131 respondents between February and March 2025. The participants were active employees representing a variety of industries and sectors. The questionnaire included 20 closed and semi-open questions covering the following themes: overall job satisfaction, sources of workplace stress, subjective perceptions of work–life balance, availability and frequency of flexible work arrangements, and experiences of organisational support, recognition, and managerial attention.
The design of the questionnaire was informed by insights from relevant Hungarian and international literature in work psychology and HRM (Allen et al., 2000; Greenhaus & Allen, 2011). The data were analysed using descriptive statistical methods (frequency and mean analysis, percentage distributions).

3.3 Qualitative phase and sequencing of the mixed-methods design

The qualitative component of the research was conducted after the completion of the quantitative survey, following a sequential explanatory mixed-methods design. The online survey was open for five weeks, from 22 February to 29 March 2025. The semi-structured interview with an experienced HR professional was conducted subsequently, on 7 April 2025.
The primary purpose of the qualitative phase was to deepen and contextualise the findings of the quantitative survey. Accordingly, the interview questions were developed based on the preliminary analysis of the survey results. Particular attention was paid to themes that emerged as

especially salient among respondents, such as perceived work–life balance, mental well-being, flexibility expectations, and the role of organisational support.
The interview explored how these issues are interpreted and addressed from an HR professional's perspective, including differences between blue-collar and white-collar employees, the perceived impact of work–life balance on productivity, and its contribution to organisational competitiveness. This sequential approach allowed the qualitative findings to complement and explain the quantitative trends, thereby enhancing the overall interpretative depth of the study.

3.4 Research Limitations

The study did not aim to produce nationally representative conclusions but rather employed an exploratory approach to provide insights into the interrelations between employee experiences and HR practices. The voluntary nature of participation and the online format of the survey may have influenced the generalisability of the results. Nevertheless, the findings provide a valuable starting point for understanding the effectiveness of HR methods.
In addition, the survey did not include detailed questions regarding respondents' family status, parenthood, or caregiving responsibilities. Previous research suggests that such factors may significantly shape experiences of job satisfaction, stress, and work–life balance. The absence of these variables limits the possibility of more nuanced subgroup comparisons within the present sample. Future research would benefit from incorporating family-related and caregiving dimensions in order to provide a more comprehensive understanding of how work–life balance expectations and experiences differ across life situations.

4. Results

This section explores employees' experiences of work–life balance, with particular attention to the role of HR tools and organisational support. The findings presented below are based on the survey and the in-depth interview, together outlining the key dimensions of the employee experience.
The quantitative data provide insights into job satisfaction, employee well-being, and the need for organisational support, while the qualitative data complement and nuance the statistical trends. The findings provide a comprehensive picture of how employees perceive their work–life balance and the extent to which they attribute significance to HR practices in this regard.

4.1 Socio-Demographic Characteristics of Respondents

In total, 131 individuals participated in the survey, all of whom identified themselves as active employees. The socio-demographic analysis focused on age distribution, educational attainment, employment sector, and type of employment.
With respect to age, the majority of respondents (77%) fell within the 25–34 (45%) and 35–44 (32%) age groups. This suggests that the study primarily reflects the experiences of employees in the active stage of their careers. At this stage of life, work commitment, career development, and family responsibilities often coincide, making work–life balance particularly salient. A further 12% of respondents were aged 18–24, representing early-career entrants, while only 11% were over 45, meaning that the perspectives of older, more experienced employees were less represented in the sample. The distribution of respondents by employment type is presented in Table 1.

Table 1. Distribution of respondents by employment type (N = 131)

Employment type	Number of respondents	Percentage (%)
Full-time	90	68.7
Part-time	22	16.8
Project-based / contract	19	14.5
Total	**131**	**100.0**

Source: Authors' own compilation based on survey data.

4.1.1. Educational background and occupational distribution

While the majority of respondents reported holding a higher education degree, educational attainment alone does not necessarily determine the nature of the work performed. For this reason, conclusions regarding the type of work were not drawn solely on the basis of education level.

To gain a more accurate picture of respondents' work characteristics, the questionnaire included an open-ended question asking participants to specify their current occupation. Based on these responses, occupations were grouped into broader professional fields, such as education, human resources and administration, finance and accounting, information technology, logistics and procurement, engineering, commerce and hospitality, manufacturing and quality management, healthcare and pharmaceuticals, public administration and legal services, and skilled trades.

This occupational grouping suggests that the sample includes a diverse range of job roles across multiple sectors, encompassing both physically demanding and predominantly knowledge-based positions. Accordingly, the findings primarily reflect the experiences of employees working in heterogeneous organisational and occupational contexts, rather than assuming a direct correspondence between education level and type of work.

4.2. Job Satisfaction, Stress, and Perceptions of Work–Life Balance by Age Group

Employees' workplace experiences were examined through three key indicators: job satisfaction, stress, and perceptions of work–life balance, with particular attention to variations across age groups.

The data indicate that the 25–34 age group, which constituted the largest respondent group, reported job satisfaction averages ranging between 3.15 and 3.43, while their perceptions of work–life balance fell between 2.79 and 2.91. This indicates that although young adults are moderately satisfied with their current jobs, they report less favourable work–life balance. This may be due to greater workplace pressures and career-building expectations typically experienced at this stage of life.

Stress levels in this age group were higher (averaging 2.85–2.86) than in other cohorts, which may be related to job insecurity, difficulties in career advancement, or the challenges associated with starting a family.

Among respondents aged 18–24, job satisfaction was relatively high (average 4.0); however, their perceptions of balance and stress levels were less favourable. This implies that while early-career employees are motivated, they face difficulties in harmonising work and private life.

Interestingly, the few respondents under the age of 18 (likely interns or student workers) reported balanced perceptions of work–life harmony and low stress levels. Although these data are not representative, they nevertheless illustrate how age and level of work experience shape psychosocial assessments.

Overall, in both young and middle-aged cohorts, job satisfaction and stress levels appear strongly interconnected, while perceptions of work–life balance are heavily influenced by life circumstances (e.g., family formation, career orientation).

4.3. Job Satisfaction, Stress, and Perceptions of Work–Life Balance by Employment Type

The analysis of respondents by employment type clearly demonstrates that different forms of employment are associated with distinct workplace experiences and psychosocial outcomes. Four main groups were identified: full-time employees, part-time employees, project-/contract-based workers, and student workers. The comparative patterns across employment types are summarised in Table 2.

Among full-time employees (69%), the average level of job satisfaction was 3.36, reflecting a moderately positive perception. Scores ranged from 2 to 4, indicating neither extreme dissatisfaction nor complete satisfaction. Perceptions of work–life balance were weaker, with an average of 2.86 (range 1–4). This suggests that full-time employment often involves compromises at the expense of private life. Stress levels were relatively high in this group, with an average of 2.78 (minimum 1, maximum 4).

For part-time employees (17%), the average job satisfaction was 3.38, similar to that of full-time employees but with greater variation (range 2–4). Perceptions of work–life balance were more favourable, averaging 3.25 (on a 1–4 scale), indicating a more positive experience. Stress was still present (average 2.75) but slightly lower than among full-time employees.

Project-/contract-based respondents (14%) reported slightly higher satisfaction (average 3.4), though their balance perception did not exceed a 3.0 average (range 2–4). Stress levels averaged 2.6, somewhat more favourable compared to full-time employees. However, given the small sample size, these findings should be interpreted with caution.

The single student worker (0.7%) reported highly positive workplace experiences, with all indicators rated at 3 or above. While not statistically representative, this nevertheless provides an interesting complementary data point.

In summary, employment type appears to influence perceptions of work–life balance: part-time and project-based forms of work are associated with more favourable work–life balance perceptions, whereas full-time employment more often correlates with stress and imbalance. Lower stress levels and improved perceptions of balance in flexible and entrepreneurial work may be linked to more autonomous time management and adaptable work arrangements.

These findings reinforce the importance of increasing employment flexibility within HR strategies. Furthermore, it is noteworthy that gender-related data were missing for nearly one-third of respondents. This may reflect both sensitivities in data collection and the broader complexity of how gender identity is socially understood. Such cultural dimensions should not be overlooked in future HR and organisational well-being strategies.

4.4. Insights from the HR Expert Interview

The in-depth interview highlighted that work–life balance has become a matter of strategic importance in contemporary organisations. According to the HR expert, employees increasingly consider not only pay and benefits when evaluating job opportunities, but also attach great importance to human-centred leadership, individual flexibility, and a culture of recognition and respect.

The expert further emphasised that, particularly among younger generations, a lack of flexibility often leads to job changes even within a short period. In their view, HR tools are less effective if not accompanied by genuine, exemplary leadership attitudes. They stressed that “soft” elements—such as trust, feedback, and recognition—are at least as important as structural changes.

The results confirm a growing consensus in the literature that work–life balance is not merely a welfare issue but a key determinant of organisational functioning, employee commitment, and long-term competitiveness (Guest, 2002; Kelliher & Anderson, 2010).

Survey data further revealed that job satisfaction does not automatically translate into overall well-being. More than half of respondents reported feeling regularly overburdened, which is consistent with the findings of Molnár (2023), who argues that workplace stress is one of the fundamental challenges of modern organisational environments. This is particularly concerning given that the deterioration of mental health directly impacts productivity and turnover rates (WHO, 2024).

The distribution of preferred HR tools across age groups suggests that there is no universal solution to supporting balance. While younger employees (18–34 years) expressed particularly high demand for flexible working hours and remote work options, older employees placed greater value on stability and direct managerial support. This aligns with the generational analysis of Guti, Szilágyi, and Németh (2023), which found that workplace values vary significantly across age cohorts.

Table 2. Average job satisfaction, stress and work–life balance scores by employment type

Employment type	Job satisfaction (Mean)	Stress level (Mean)	Work–life balance (Mean)
Full-time	3.36	2.78	2.86
Part-time	3.38	2.75	3.25
Project-based / contract	3.40	2.60	3.00

Note: Higher values indicate greater job satisfaction, higher perceived stress, or more favourable work–life balance.

Source: Authors' own compilation based on survey data.

As shown in Table 2, part-time and project-based employees report slightly higher levels of job satisfaction and more favourable perceptions of work–life balance compared to full-time employees. At the same time, full-time employment is associated with higher perceived stress levels, suggesting that reduced working time and greater flexibility may contribute to improved well-being outcomes.

The HR expert interview reinforced this view: well-being initiatives are most effective when adapted to the cultural and structural characteristics of the organisation. From a practical perspective, it is notable that more than half of survey respondents did not perceive HR tools as being systematically integrated. Although many organisations have introduced formal well-being elements—such as home office arrangements or individual development programmes—their effectiveness is often limited when not supported by authentic leadership and cultural acceptance (Kaur, 2023; Chapman et al., 2021).

Taken together, both the qualitative and quantitative findings suggest that HR strategies can only exert meaningful impact if organisations:

- acknowledge the diversity of individual employee needs,
- provide opportunities for choice and flexibility, and
- strengthen the role and sensitivity of middle managers in supporting well-being.

Promoting balance is therefore not merely a matter of tools but of mindset. The interview underscored the notion that HR success depends less on the number of initiatives introduced than on their integration and credibility. As the importance of trust and psychological safety becomes increasingly emphasised in the international literature (Chapman et al., 2021), there is also a pressing need in the Hungarian context for HR to act not only at the operational level but also as a strategic advocate of well-being and sustainable employment.

The distinction between satisfaction and well-being highlights the complexity of the employee experience, which is not determined solely by job roles or benefit systems. Psychological well-being is closely linked to whether employees feel valued, perceive a sense of control, and are able to reconcile workplace obligations with private life needs.

The responses make it clear that satisfaction alone is insufficient: employees who lack opportunities for rest and recovery, and who do not receive meaningful managerial feedback, are at risk of emotional exhaustion, which in the long run may reduce both performance and commitment. In light of these insights, it becomes crucial to examine the role that opportunities for work–life integration play in shaping employee well-being experiences.

5. Conclusions

This study explores employees' experiences of work–life balance and the role of human resource strategies in shaping these experiences. Based on both quantitative and qualitative data, it can be concluded that many employees regularly experience the negative effects of overload, inflexibility, and lack of recognition. These factors directly influence overall job satisfaction, mental health, and organisational commitment.

One key finding is that work–life balance is not solely an individual responsibility but also an organisational one. Among respondents, demand was particularly high for flexible working hours, opportunities for remote work, recognition systems, and managerial support—in other words, HR tools that promote individual autonomy and psychological safety.

At the same time, the mere presence of HR tools is insufficient: their effectiveness largely depends on organisational culture and leadership attitudes.

The analysis of age-related differences also highlighted that HR strategies must take into account variations in employees' life stages and value orientations. While younger employees prioritise flexibility and development opportunities, older employees place greater emphasis on security, predictability, and interpersonal relationships. This finding supports the need for personalised, target group–oriented HR management.

The practical implication of this study is that supporting work–life balance is not an optional initiative but a key factor in sustainable employment and organisational effectiveness.

Organisations that integrate well-being considerations at a strategic level are more likely to reduce turnover, increase employee loyalty, and enhance their competitiveness in an increasingly dynamic labour market. These findings are consistent with earlier evidence that managing the work–family interface effectively benefits both employee health and organisational performance (Van Steenbergen & Ellemers, 2009).

6. Suggestions for Further Research

The limitations of this study include the non-representative sample and the voluntary participation of respondents, both of which may affect the generalisability of the findings. Nevertheless, the identified trends provide an important starting point for further, more targeted research. Future studies could:

- examine sectoral differences in greater depth (e.g. public vs. private sector),
- analyse more thoroughly the impact of generational differences on employee expectations, and
- conduct longitudinal research on the effects of introducing HR tools on employee well-being.

Work–life balance is therefore not only a guarantee of individual well-being but also a cornerstone of organisational sustainability. Strategic involvement of HR actors in this area is indispensable.

In summary, HR as a strategic partner plays a pivotal role in shaping work–life balance, and future research should continue to explore this multifaceted role—both from the perspective of practical applicability and organisational effectiveness.

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Artificial Intelligence and Chatbots in Patient Management

Artificial intelligence (AI) and chatbots are expected to play an increasingly important role in patient management systems worldwide. These technologies have the potential to support preliminary triage, reduce waiting times, and alleviate the administrative burden placed on healthcare professionals. At the same time, their application raises substantial challenges related to data protection, ethical accountability, clinical responsibility, and professional practice. The purpose of this study is to present the opportunities and limitations of chatbot applications in healthcare and to illustrate their regional relevance in Hungary through the example of Northern Hungary. Based on a structured literature review and secondary data analysis, the findings indicate that chatbot integration may contribute to enhanced system efficiency and reduced inequalities in access to outpatient care, provided that implementation is accompanied by appropriate regulatory, ethical, and institutional safeguards.
Keywords: Artificial Intelligence, Chatbot, Digital Health, Patient Management, Regional Inequality
JEL-code: I18, O33, R58

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Introduction

Healthcare systems across Europe and globally are facing persistent structural challenges related to workforce shortages, limited capacities, rising costs, and increasing patient demand. These pressures are particularly pronounced in outpatient care, where long waiting lists, administrative overload, and regional inequalities in access remain key policy concerns. In Hungary, outpatient specialist care has been characterised by significant territorial disparities, shortages of medical professionals, and prolonged waiting times, especially in socio-economically disadvantaged regions (Boncz et al., 2021; Fernandes et al., 2021). In response to these challenges, the digitalisation of healthcare processes has become a strategic priority at both national and European levels. In Hungary, recent policy initiatives have focused on the development of digital patient management tools, including the Outpatient Routing System (ORS) and the continuous expansion of the National eHealth Infrastructure (EESZT). These systems aim to improve transparency, coordination, and efficiency in patient pathways while supporting more equitable access to care (Döbrössy et al., 2024). Within this context, artificial intelligence (AI)-based chatbots have emerged as a potentially valuable component of digital patient management. Chatbots are computer programs designed to simulate human interaction through text- or voice-based communication, typically relying on natural language processing (NLP) and machine learning techniques (Adamopoulou & Moussiades, 2020). In healthcare settings, chatbots may support preliminary symptom assessment, appointment scheduling, patient information provision, and administrative tasks, thereby reducing the workload of healthcare staff and improving patient flow. Despite these potential benefits, the implementation of AI-based chatbots also raises important concerns. Issues related to data protection, ethical accountability, algorithmic bias, cybersecurity, and patient safety remain highly relevant, particularly in healthcare systems that rely on sensitive personal and medical data. Furthermore, the effectiveness of chatbot applications

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depends on their integration into existing healthcare infrastructures and regulatory frameworks, as well as on user acceptance and digital literacy.

The research problem addressed in this study concerns the extent to which Hungary's efforts to digitalise outpatient management—particularly through the ORS and the EESZT—can be complemented by AI-based chatbot solutions, and what benefits and risks their introduction may entail. The study has a dual objective: first, to review international and domestic experiences with chatbot applications in healthcare, highlighting opportunities and limitations; and second, to evaluate the regional relevance of chatbot-supported patient management in Hungary through an empirical analysis focusing on Northern Hungary.

The main research questions are as follows:

- How can chatbots contribute to the efficiency and patient safety of outpatient management?
- What lessons can be drawn from international practice, and to what extent are these transferable to the Hungarian context?
- What ethical, data protection, and cybersecurity challenges arise in the application of chatbots in healthcare?
- How may digital patient management tools contribute to reducing regional health inequalities in Northern Hungary?

The central hypothesis of the study is that AI-based chatbots in outpatient care – particularly through supporting pre-screening, appointment management, and the reduction of no-show rates – can measurably improve system efficiency, provided that they are properly integrated into the EESZT ecosystem and aligned with the Hungarian regulatory and institutional environment

Literature Review

The application of artificial intelligence (AI) and chatbot technologies in healthcare has become one of the most dynamically expanding fields of digital health research in recent years. The literature highlights a wide range of potential benefits, including improved access to care, enhanced efficiency of patient pathways, and reduced administrative burdens. At the same time, empirical findings remain heterogeneous, and concerns related to diagnostic accuracy, ethical accountability, and user acceptance persist. Based on the reviewed literature, three interrelated thematic areas are particularly relevant for the present study: international experiences and performance outcomes, domestic developments and implementation challenges in Hungary, and the regional relevance of chatbot-supported healthcare solutions.

Performance – International Experiences

International experience demonstrates that chatbots have primarily been implemented in healthcare as supportive tools rather than autonomous decision-makers. In the United Kingdom, the National Health Service (NHS) introduced chatbot-based applications in primary care pilot programmes to support patient pre-screening and reduce administrative workload. These systems were primarily designed to guide patients toward appropriate services rather than to provide diagnoses, thereby reinforcing patient safety through professional oversight (Hindelang et al., 2024). In the United States, large healthcare organisations such as Kaiser Permanente and the Mayo Clinic have implemented chatbot solutions to assist with appointment scheduling, symptom checking, and patient information provision. During the COVID-19 pandemic, similar tools were widely adopted in Canada to manage surges in patient inquiries and reduce pressure on call centres (Bhatt et al., 2024). Empirical studies evaluating diagnostic or triage performance present mixed results. For example, the health chatbot "August" achieved an accuracy rate of 81.8% for first-hit diagnoses under controlled conditions; however, performance declined substantially when patient input was incomplete or imprecise (Bhatt et al., 2024). These findings underline that chatbot effectiveness is highly dependent on data quality and system design. The most favourable

outcomes have been observed in hybrid models, where chatbot-generated recommendations are reviewed or supplemented by healthcare professionals (Pawellek et al., 2022). Research on user attitudes further indicates that patient acceptance is strongly influenced by ease of use, transparency regarding data processing, and trust in the underlying information sources. Conversely, limited digital literacy—particularly among older populations—may constrain adoption and exacerbate inequalities if not adequately addressed (Simon et al., 2024; Mihalicza & Boncz, 2021).

Implementation – Domestic Developments and Challenges

In Hungary, digital health development has been strongly shaped by institutional initiatives and national infrastructure projects. Key academic and professional actors include the Health Services Management Training Centre (EMK) and the Institute of Digital Health Sciences (DEI) at Semmelweis University, whose research focuses on the lifecycle management of AI-based healthcare applications, clinical validation, and system-level integration (Balogh et al., 2022). The cornerstone of Hungarian healthcare digitalisation is the National eHealth Infrastructure (EESZT), which serves as a central platform for the storage and exchange of health-related data. The system contains several hundred million medical documents and is accessible to citizens through the EgészségAblak mobile application (Joó, 2024; EESZT, 2024). In addition, the e-Jelentés system of the National Health Insurance Fund (NEAK) provides an important basis for monitoring healthcare performance and supporting financing mechanisms (NEAK, 2022; Horváthné Csolák, 2025). Hungarian literature emphasises several implementation challenges relevant to chatbot applications. These include linguistic and cultural adaptation to the Hungarian language, compliance with strict data protection and cybersecurity requirements, and the need for adequate user training among both patients and healthcare professionals (Palicz et al., 2020; Olar et al., 2021). Ethical concerns are also prominent, particularly with respect to algorithmic bias, unclear clinical responsibility, and potential psychological risks associated with excessive reliance on automated systems. For instance, emerging evidence suggests that overuse of conversational agents may, in rare cases, contribute to distorted perceptions of reality among vulnerable users (AP News, 2023; Rao, 2025).

Data Sources and Methodology

The empirical analysis focuses on outpatient specialist care utilisation in Northern Hungary, specifically in the counties of Borsod-Abaúj-Zemplén, Heves, and Nógrád. The analysis is based on secondary data obtained from the Hungarian Central Statistical Office (KSH), complemented by county-level statistics collected by the authors for the period 2021–2023. Historical reference data were also drawn from the KSH STADAT database (Table 4.1.2.4.) to ensure methodological consistency. The selected indicators include the total number of outpatient specialist care cases, population figures, case rates per 1,000 inhabitants, and each county's share of the national total. Using population-adjusted indicators allows for meaningful regional comparisons and helps to control for demographic differences across counties. Aggregated regional values are compared with national totals to assess relative utilisation patterns and potential territorial inequalities. It is important to note that access to detailed waiting list data at institutional and regional levels remains limited in Hungary. Consequently, the empirical analysis primarily reflects utilisation volumes and intensity rather than direct waiting time measures. As a result, findings must be interpreted with scientific caution, particularly when drawing conclusions about system efficiency and access constraints.

Table 1 Northern Hungary counties: cases, population, cases per 1000 inhabitants and national share (2021–2023)

Year	County	Cases	Population	Cases per 1000 inhabitants	National share (%)
2021	Borsod-Abaúj-Zemplén	3,036,894	635,644	4,775	5.5
2021	Heves	1,518,207	290,396	5,227	2.7
2021	Nógrád	828,032	185,153	4,474	1.5
2022	Borsod-Abaúj-Zemplén	3,394,366	629,621	5,392	5.9
2022	Heves	1,544,054	288,430	5,356	2.7
2022	Nógrád	828,032	183,318	4,517	1.4
2023	Borsod-Abaúj-Zemplén	3,629,928	624,219	5,814	6.0
2023	Heves	1,617,659	287,533	5,627	2.6
2023	Nógrád	868,348	182,038	4,770	1.4

Source: own editing

Outpatient Care Utilisation in Northern Hungary (2021–2023)

The total number of outpatient specialist care cases in the region increased by approximately 13.6% over the observed period, rising from around 5.38 million cases in 2021 to more than 6.12 million cases in 2023. During the same period, the population of all three counties declined slightly, reflecting broader demographic trends in Hungary. The most substantial absolute increase was observed in Borsod-Abaúj-Zemplén County, where the number of cases grew by nearly 593,000 (+19.5%). Heves County recorded a more moderate increase of approximately 99,000 cases (+6.6%), while Nógrád County experienced a smaller rise of around 40,000 cases (+4.9%). When adjusted for population size, utilisation rates increased in all three counties, with the strongest growth observed in Borsod-Abaúj-Zemplén, where cases per 1,000 inhabitants rose from 4,775 to 5,814 (+21.8%). By 2023, Borsod-Abaúj-Zemplén surpassed Heves County in terms of specific utilisation intensity, indicating a structural shift in service use within the region. Nógrád County consistently exhibited the lowest utilisation rates, suggesting persistent access and capacity constraints.

Regional Trends and National Comparisons

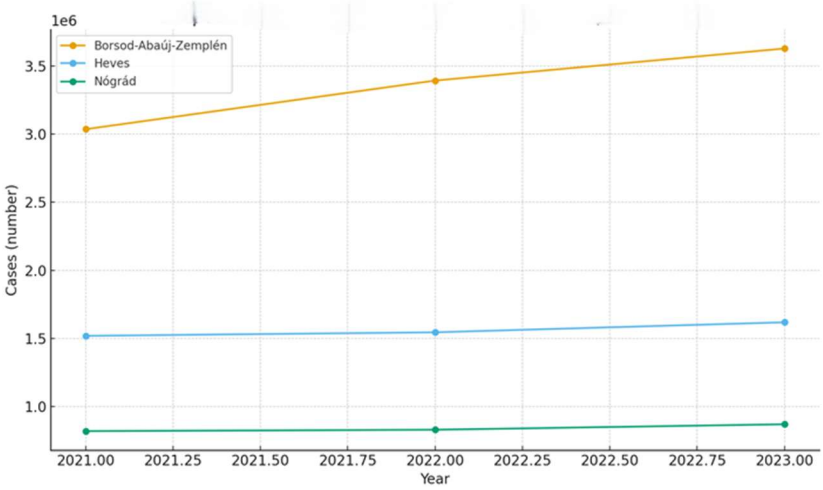

Figure 1 Outpatient visits in Northern Hungary counties (2021–2023)
Source: based on KSH.hu, own editing

Figure 1 illustrates the absolute number of outpatient specialist care cases in the three counties between 2021 and 2023. While all counties experienced growth, underlying differences in scale remained pronounced. Borsod-Abaúj-Zemplén consistently accounted for the largest share of cases, followed by Heves and Nógrád. The strongest growth dynamic was observed in Borsod-Abaúj-Zemplén, which acted as the primary driver of the regional increase.

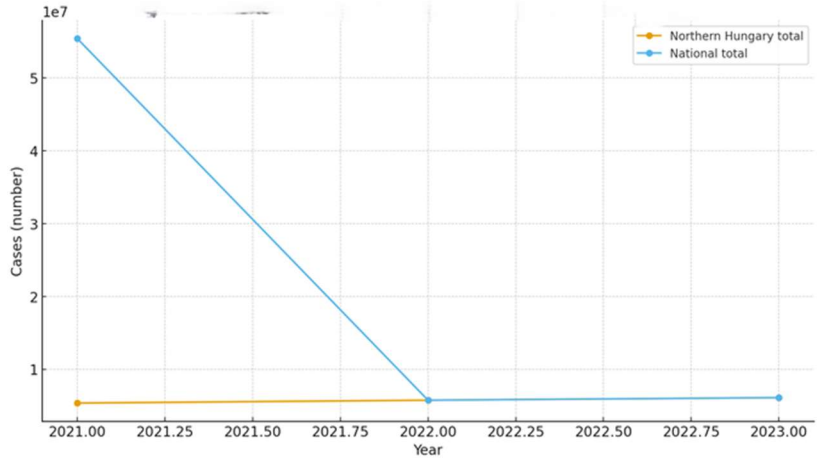

Figure 2 Outpatient visits – Northern Hungary vs National total (2021–2023)
Source: based on KSH.hu, own editing

Figure 2 compares the aggregated outpatient case volume of Northern Hungary with the national total. The region's share of national utilisation increased slightly from approximately 9.7% in 2021 to around 10.0% in 2023. This suggests that utilisation in Northern Hungary did not lag behind national growth trends during the study period, although absolute and relative disparities between regions persisted.

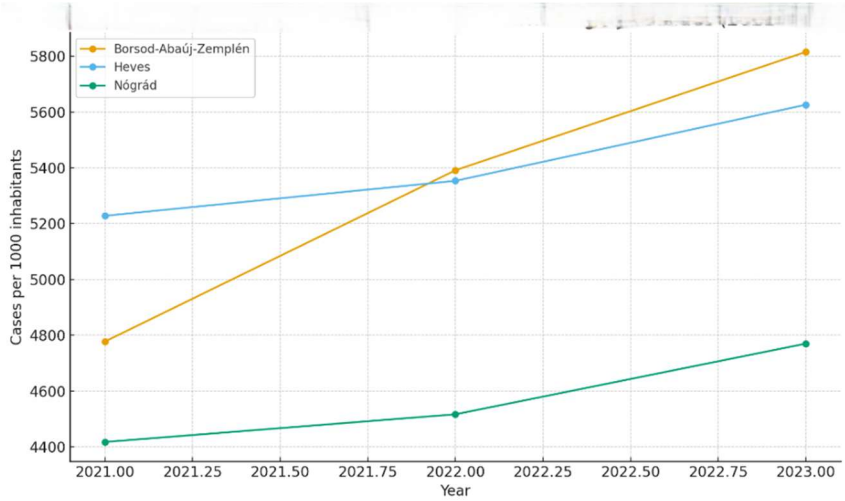

Figure 3 Outpatient visits per 1000 inhabitants – Northern Hungary counties (2021–2023)
Source: based on KSH.hu, own editing

Figure 3 presents outpatient specialist care utilisation rates per 1,000 inhabitants by county. The results indicate partial convergence among counties over time. While Heves County exhibited the highest utilisation rate in 2021, Borsod-Abaúj-Zemplén overtook it by 2023. Despite these shifts, all three counties remained below the national average in each year, highlighting a continued regional disadvantage in effective access to outpatient specialist care. Taken together, the empirical findings point to enduring territorial asymmetries in capacity and access within Northern Hungary. Although utilisation volumes increased substantially between 2021 and 2023, differences between counties persisted, and regional averages continued to lag behind national indicators. These patterns are consistent with post-pandemic readjustments as well as long-standing structural constraints in healthcare supply.

Opportunities in Hungarian Outpatient Management

Hungarian outpatient care is confronted with several interrelated challenges, including prolonged waiting times, shortages of healthcare professionals, high administrative burdens, and persistent territorial inequalities in access. Within this context, the integration of artificial intelligence (AI)-based chatbots into digital patient management systems—particularly the Outpatient Routing System (ORS) and the National eHealth Infrastructure (EESZT)—may offer relevant opportunities to improve both efficiency and equity.

Integration, Resource Optimisation and Financing

Effective patient management requires real-time information flow and coordinated decision-making across institutional boundaries. Close integration between the ORS and the EESZT is therefore essential for the successful application of chatbot-based solutions. In practical terms, chatbots may function as front-end interfaces that guide patients through preliminary symptom assessment, eligibility checks, and appointment requests, while relying on EESZT-backed data for verification and continuity. By accessing structured information on previous visits, referrals, and bookings—subject to strict access control and consent requirements—chatbots may help prevent parallel scheduling and reduce duplication of services. This can contribute to a more transparent allocation of outpatient capacities and support the prioritisation of patients based on clinical need rather than informal access mechanisms. Importantly, chatbot-generated outputs should be limited to administrative and pre-screening functions, with clinical decision-making remaining the responsibility of healthcare professionals.

Regional Inequalities and Empirical Opportunities

One of the most significant potential benefits of chatbot integration lies in the reduction of administrative workload. Chatbots can manage appointment confirmations and modifications, send reminders, provide standardised patient information, and answer frequently asked questions. These functions may substantially reduce the burden placed on call centres and administrative staff, allowing healthcare professionals to devote more time to direct patient care. From a system perspective, improved appointment management may also reduce no-show rates, which represent a major source of inefficiency in outpatient care. International evidence suggests that automated reminders and digital recall systems – including those implemented through chatbot platforms – can contribute to measurable reductions in missed appointments and more efficient use of available capacities (Laymouna et al., 2024).

Financing and Sustainability Considerations

The implementation of AI-based chatbots requires initial investment in software development, system integration, cybersecurity, and user training. However, these upfront costs must be evaluated against potential long-term savings resulting from reduced administrative expenditures, fewer unnecessary visits, and more efficient utilisation of specialist capacities. International experience indicates that the cost-effectiveness of AI-supported patient management tools is most pronounced when such systems are fully integrated into existing care pathways and supported by clear performance indicators (Laymouna et al., 2024). In the Hungarian context, alignment with financing mechanisms administered by the National Health Insurance Fund (NEAK) is essential. Transparent monitoring of performance indicators – such as waiting times, no-show rates, and utilisation intensity – may support evidence-based decisions regarding reimbursement and scaling. Without such alignment, the sustainability of chatbot-based interventions remains uncertain.

Regional Inequalities and Access

Digital patient management tools may be particularly relevant in regions characterised by limited healthcare capacity and workforce shortages. In Northern Hungary, patients frequently face longer waiting times and greater travel distances compared with national averages. Chatbots may serve as a primary digital entry point to the healthcare system, especially when combined with telemedicine solutions, thereby reducing access barriers for rural populations. The empirical findings presented in this study indicate that, despite increasing utilisation volumes, Northern Hungary continues to lag behind national averages in outpatient care access. In this context, chatbot-supported pre-screening and appointment management may contribute to more equitable distribution of available capacities and improved transparency in patient pathways. While digital tools alone cannot eliminate structural inequalities, they may form part of a broader strategy aimed at mitigating regional disadvantages.

Ethical, Data Protection, Accountability and Security Issues

The application of artificial intelligence (AI)-based chatbots in healthcare raises complex ethical, legal, and security challenges that extend beyond purely technical considerations. Given the sensitivity of health-related data and the potential consequences of erroneous or biased outputs, the implementation of chatbot solutions in patient management requires clearly defined ethical frameworks, regulatory safeguards, and institutional accountability mechanisms.

Data Protection and GDPR Compliance

Healthcare data belong to the most sensitive categories of personal information under European Union law. The General Data Protection Regulation (GDPR) establishes strict requirements for the collection, storage, processing, and transmission of personal and health-related data. In the context of chatbot applications, compliance with GDPR is not optional but a foundational prerequisite for lawful operation. From a practical perspective, chatbot systems must adhere to the principles of data minimisation, purpose limitation, and transparency. Only data that are strictly necessary for the intended administrative or pre-screening function should be processed, and patients must be clearly informed about how their data are used. Explicit and informed consent is essential, particularly when chatbots interact directly with patients and collect symptom-related information. Technical safeguards such as encryption, anonymisation or pseudonymisation, and secure authentication mechanisms are indispensable. In Hungary, integration with the EESZT further amplifies data protection requirements, as access to central health records must be logged, role-based, and auditable. Any chatbot accessing EESZT-linked data must therefore operate within clearly defined access boundaries and under continuous supervision.

Ethical Frameworks and Algorithmic Accountability

Beyond legal compliance, ethical considerations play a central role in the responsible deployment of AI in healthcare. One of the most critical ethical issues concerns accountability. Chatbots, regardless of their level of sophistication, cannot assume clinical responsibility. Medical decision-making must remain the exclusive responsibility of qualified healthcare professionals. To address this, ethical frameworks for chatbot implementation should explicitly adopt a “human-in-the-loop” approach. This means that chatbot-generated recommendations or classifications are used solely as supportive inputs, while final decisions are made by clinicians. Clear disclaimers and transparent communication are necessary to ensure that patients understand the limits of chatbot functionality and do not interpret automated outputs as medical advice. Algorithmic bias represents another major ethical challenge. AI systems are trained on historical datasets that may reflect existing inequalities or underrepresent certain population groups. In the Hungarian context, linguistic complexity and cultural specificities further increase the risk of biased outputs if training data are insufficiently representative. Regular auditing, validation, and recalibration of algorithms are therefore required to mitigate discriminatory effects and ensure fairness.

Patient Safety and Clinical Responsibility

Patient safety must remain a central consideration in any digital health intervention. While chatbots may enhance efficiency by supporting pre-screening and administrative processes, errors in symptom interpretation or inappropriate guidance may pose risks if not adequately controlled. For this reason, chatbot outputs should be restricted to low-risk functions and should never replace professional medical evaluation. Clear escalation protocols are essential. When chatbot interactions indicate potentially serious symptoms or uncertainty, the system should automatically redirect patients to appropriate professional channels. This approach not only safeguards patient safety but also reinforces trust in digital solutions.

Cybersecurity Risks

Healthcare systems are increasingly targeted by cyberattacks, including ransomware and data breaches, which can disrupt services and compromise sensitive information. The introduction of chatbot applications creates additional entry points into digital infrastructures, thereby increasing the attack surface. To mitigate these risks, robust cybersecurity measures must be implemented, including regular system updates, penetration testing, intrusion detection mechanisms, and staff training. In addition, contingency plans should be established to ensure continuity of care in the

event of system failures or security incidents. Without adequate cybersecurity governance, the potential benefits of chatbot solutions may be outweighed by operational and reputational risks.

Societal Implications and Trust

At the societal level, the widespread adoption of chatbot-based healthcare solutions raises concerns related to trust, acceptance, and inclusion. Excessive reliance on automated systems may, in rare cases, contribute to psychological risks, such as excessive attachment to virtual agents or distorted perceptions of reality among vulnerable users (Rao, 2025). Furthermore, digital health innovations risk widening the digital divide if they primarily benefit individuals with high digital literacy. Elderly patients and socially disadvantaged groups may face barriers to access, potentially exacerbating existing inequalities. To counteract these risks, chatbot implementation should be accompanied by user education, alternative access channels, and continuous evaluation of user experience. Building trust requires transparency regarding system capabilities, limitations, and performance. Public documentation, ongoing professional validation, and participatory design involving healthcare professionals and patients can support acceptance and sustainable use of chatbot technologies in healthcare.

Conclusions, Limitations and Future Research

Based on the reviewed international literature and the empirical analysis presented in this study, artificial intelligence (AI)-based chatbots have the potential to become a relevant component of modern outpatient patient management systems. Evidence from systematic reviews, pilot projects, and institutional case studies indicates that chatbot-supported solutions may contribute to improved efficiency in preliminary triage, appointment scheduling, patient information provision, and administrative processes. When appropriately implemented, these tools can reduce waiting times, alleviate workforce pressures, and enhance transparency in patient pathways. International experiences demonstrate that AI-based systems can deliver measurable improvements in patient flow and waiting time reduction when integrated into existing care structures. For example, studies report substantial reductions in average waiting times and improved utilisation of healthcare resources in settings where chatbot-supported patient management was combined with professional oversight and robust digital infrastructure (Li et al., 2021; Wah, 2025; Khare et al., 2025). These findings underline that the effectiveness of chatbots depends not on automation alone, but on their embedding within coordinated organisational and regulatory frameworks. In the Hungarian context, the integration of chatbots into the Outpatient Routing System (ORS) and the National eHealth Infrastructure (EESZT) presents particularly promising opportunities. The empirical analysis focusing on Northern Hungary confirms that, despite increasing utilisation volumes between 2021 and 2023, the region continues to face persistent capacity constraints and access inequalities. County-level outpatient care indicators consistently lag behind national averages, suggesting that digital patient management tools may be especially valuable in disadvantaged regions. Chatbot-supported pre-screening, appointment coordination, and patient information services could contribute to more equitable distribution of available capacities and improved transparency in access. At the same time, the study highlights several important limitations. First, the empirical analysis relies on secondary data sources and does not include primary patient satisfaction surveys or qualitative user experience assessments. Second, access to detailed institutional-level waiting list data remains limited, restricting the precision of regional comparisons. Third, the study does not empirically analyse the impact of Hungarian linguistic and cultural specificities on chatbot performance, although these factors are likely to influence accuracy and user acceptance. These limitations point to clear directions for future research. Further studies should focus on longitudinal monitoring of outpatient care indicators following the introduction of chatbot-based interventions, allowing for causal assessment of their effects on waiting times, no-show rates, and patient satisfaction. Pilot projects implemented in diverse

regional settings would provide valuable evidence on practical feasibility, acceptance, and cost-effectiveness. In addition, future research should examine the interaction between AI-based chatbots and healthcare professionals, with particular attention to accountability, trust, and the long-term implications for clinical workflows. In conclusion, AI-based chatbots may become an integral part of the Hungarian healthcare system if their introduction is accompanied by coordinated regulatory, ethical, and organisational development. Gradual implementation, continuous evaluation, and sensitivity to regional and societal differences are essential to ensure that digital innovations move beyond technological novelty and contribute meaningfully to improved quality, efficiency, and equity in patient care.

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Bridging Loyalty and Innovation: The Dual Challenge for Germany's Automotive Workforce

The study examines the relationship between employee loyalty and innovation within the framework of an empirical study conducted at a large German automotive company. The rapid technological development of the industry, sustainability goals, new market entrants, digitalization, and the rise of electric mobility demand continuous adaptation from both companies and employees. The research aims to explore how the automotive transformation and the associated innovation pressure affect employee loyalty and to identify key factors that promote loyalty. The research is based on a survey conducted among employees working in the company's development department. The analysis focuses on factors such as organizational culture, job security, brand significance, training opportunities, work-life balance, and job satisfaction. The findings aim to demonstrate that maintaining loyalty amidst the constant progress driven by innovation is a cornerstone of the company's long-term success. The research provides practical recommendations for human resource management on how to balance strengthening loyalty and fostering innovation.
Keywords: J53, M54, O32, L62, D23

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1 Introduction

In recent years, the automotive industry has faced unprecedented challenges resulting from the COVID-19 pandemic, the global semiconductor shortage, the Russia–Ukraine war, and the ongoing technological transformation of the sector. The rapid expansion of electric mobility, digitalisation, autonomous driving technologies, increasing sustainability requirements, and the emergence of new competitors—particularly from China and the United States—have fundamentally reshaped the competitive environment of the German automotive industry (European Automobile Manufacturers' Association [ACEA], 2025; Organisation for Economic Co-operation and Development [OECD], 2024). These developments require companies not only to adopt new technologies but also to transform their organisational structures and human resource management practices.

In addition to these external challenges, automotive companies are experiencing significant internal transformation, affecting organisational culture, leadership, and employee attitudes. While technological innovation has received considerable attention in previous studies, less emphasis has been placed on the organisational factors that help maintain employee loyalty during continuous transformation. Organisational culture, job security, work–life balance, employer branding, and professional development are recognised as important determinants of employee commitment and organisational performance (Schein & Schein, 2021; Meyer & Allen, 1991; Farooq et al., 2024).

Against this background, this study investigates the relationship between employee loyalty and organisational factors within the development department of a major German automotive company. The research examines how organisational culture, innovation pressure, job security, work–life balance, brand identification, and training opportunities influence employee loyalty. By providing empirical evidence from the German automotive industry, the study contributes to a better understanding of how organisations can strengthen employee commitment while maintaining innovation capability during periods of continuous organisational transformation.

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2 Theoretical background

2.1. Organizational culture

Organizational development is a continuous and dynamic process through which organizations adapt to changing internal and external environments while improving their long-term effectiveness. In an increasingly uncertain and technology-driven business environment, organizational development has become a strategic capability that enables firms to respond effectively to market disruptions, digital transformation, and increasing competitive pressure (Burnes, 2020; Cummings & Worley, 2019).

Organizational culture refers to the shared values, beliefs, assumptions, and behavioural norms that guide employees' decisions and interactions within an organization (Schein & Schein, 2021). These shared assumptions influence how employees perceive organizational goals, solve problems, collaborate with colleagues, and respond to change. A strong organizational culture aligns employees' behaviour with strategic objectives, strengthens organizational commitment, and facilitates the successful implementation of organizational change (Cameron & Quinn, 2011).

Since the 1980s, organizational culture has become one of the central concepts of management research. Early studies demonstrated that organizational culture represents a source of sustainable competitive advantage because it is difficult for competitors to imitate (Barney, 1986). More recent research confirms that adaptive organizational cultures enhance organizational resilience, employee engagement, innovation capability, and successful digital transformation, particularly in knowledge-intensive industries (Bogale & Debela, 2024; Wiese et al., 2024). Consequently, organizations operating in rapidly changing sectors such as the automotive industry must continuously develop organizational cultures that encourage learning, innovation, collaboration, and employee commitment.

2.2 Employee loyalty

Employee loyalty has become a strategic asset for organizations operating in highly competitive and innovation-driven industries. Loyal employees contribute not only to organizational stability and knowledge retention but also to higher productivity, stronger organizational commitment, and improved innovation performance (Meyer & Allen, 1991; Eisenberger et al., 1986).

Motivation is generally understood as the psychological process that initiates, directs, and sustains goal-oriented behaviour. Herzberg's Two-Factor Theory distinguishes between hygiene factors, which prevent dissatisfaction, and motivators, which foster intrinsic satisfaction and higher levels of performance (Herzberg, 1968). According to Herzberg, employees become genuinely motivated when they experience meaningful work, responsibility, opportunities for personal growth, and recognition for their achievements.

Similarly, Self-Determination Theory argues that sustainable motivation is primarily driven by the satisfaction of three fundamental psychological needs: autonomy, competence, and relatedness (Deci & Ryan, 2000). Organizations that support these needs are more likely to develop engaged and committed employees who willingly contribute to organizational success.

Employee loyalty extends beyond job satisfaction and reflects employees' long-term psychological attachment to their organization. Meyer and Allen (1991) conceptualize organizational commitment as comprising affective, continuance, and normative dimensions, each influencing employees' willingness to remain with the organization. In addition, Social Exchange Theory suggests that employees reciprocate organizational support with greater commitment and loyalty (Blau, 1964). This relationship is further explained by Perceived Organizational Support theory, which demonstrates that employees who feel valued and supported by their employer are more likely to develop stronger organizational commitment and lower turnover intentions (Eisenberger et al., 1986).

Recent studies further indicate that employee loyalty is increasingly shaped by leadership quality, career development opportunities, organizational justice, flexible working arrangements, and opportunities for continuous learning, particularly in knowledge-intensive industries undergoing rapid technological transformation (Farooq et al., 2024; Kim & Kim, 2023). Consequently,

fostering employee loyalty requires organizations to create supportive work environments that promote motivation, trust, professional development, and long-term organizational commitment.

2.3 Work-life balance

Work–life balance has become an increasingly important issue in contemporary human resource management, particularly in knowledge-intensive industries undergoing rapid technological change. It refers to the ability of individuals to effectively manage the demands of work and personal life while maintaining psychological well-being and job performance (Greenhaus & Beutell, 1985). Achieving this balance has become more challenging as digitalisation, flexible working arrangements, and continuous organisational change have blurred the boundaries between professional and private life (Clark, 2000).

Previous research demonstrates that work–life balance is positively associated with employee well-being, job satisfaction, organisational commitment, and retention. Employees who perceive that their organisation supports the integration of work and personal responsibilities are more likely to demonstrate higher motivation, lower turnover intentions, and stronger organisational loyalty (Allen et al., 2013; Haar et al., 2014). Consequently, family-friendly policies, flexible working arrangements, and supportive leadership have become important strategic tools for attracting and retaining highly qualified employees.

Recent studies further indicate that work–life balance is no longer primarily a gender-related issue but a broader organisational concern affecting employees across different demographic groups. The increasing participation of both parents in the labour market, demographic ageing, and changing family structures have expanded employees' caregiving responsibilities beyond childcare to include eldercare and other family obligations. Moreover, the COVID-19 pandemic accelerated the adoption of hybrid and remote working models, creating new opportunities for flexibility while simultaneously increasing the risk of work–family conflict, psychological strain, and employee burnout (Kniffin et al., 2021).

In innovation-intensive industries such as the automotive sector, maintaining an appropriate work–life balance has become particularly important. Continuous technological change, demanding project schedules, and increasing innovation pressure require organisations to develop human resource practices that support employee well-being alongside organisational performance. Therefore, organisations that successfully integrate flexible work arrangements with supportive organisational cultures are more likely to strengthen employee commitment, enhance motivation, and sustain long-term organisational competitiveness.

2.4 Innovation pressure

Innovation is a key component of competitiveness and corporate performance. Strengthening innovation capabilities has become a global priority, as international markets are increasingly driven by technological development, digital transformation, and changing customer expectations (OECD, 2024). Maintaining a competitive position requires organizations to continuously improve their products, services, and processes. An innovative mindset enables access to broader markets and enhances long-term competitiveness. Therefore, assessing a company's innovation capability has become an essential step in evaluating its strategic performance and future development (Chesbrough, 2003).

For many governments, innovation represents a central pillar of economic growth strategies and industrial competitiveness. Innovation policies increasingly focus on supporting research and development, encouraging collaboration between industry and academia, and creating effective incentive mechanisms that stimulate technological advancement (OECD, 2024).

However, innovation activities are associated with both costs and risks that organizations must effectively manage. Since the 1980s, innovation has gradually evolved from a closed organizational process toward more collaborative approaches. Chesbrough (2003) described this transformation as the shift from **closed innovation** to **open innovation**, where organizations

increasingly integrate external knowledge, technologies, and strategic partnerships into their innovation processes.

Although open innovation provides considerable benefits, organizations continue to face challenges related to knowledge protection, intellectual property management, and collaboration with external stakeholders. Consequently, many companies adopt hybrid innovation strategies that combine internal capabilities with external cooperation to balance innovation performance, organizational flexibility, and sustainable competitiveness (Chesbrough, 2003; OECD, 2024).

2.5 Brand loyalty and commitment

Employer branding has become a strategic area of human resource management and modern business research. Effective employer branding requires organizations to place employees and their competencies at the centre of strategic decision-making. Well-developed employer branding strategies improve organizational performance, strengthen talent attraction, and reduce recruitment and onboarding costs (Backhaus & Tikoo, 2004). Organizational culture, employee well-being, and work–life balance are widely recognized as essential components of a successful employer brand.

An employer's brand significantly influences the organization's external reputation by communicating what it is like to work for the company. Consequently, employer branding has become an important competitive tool for attracting and retaining highly qualified employees. Previous studies indicate that individuals with higher qualifications are more likely to choose employers with strong reputations and clearly communicated organizational values. Furthermore, Generation Z increasingly relies on digital communication and social media when evaluating potential employers (Farooq et al., 2024). Research also demonstrates a positive relationship between employer branding, employee satisfaction, and organizational commitment, suggesting that employees who feel valued by their organization develop stronger loyalty and are more willing to remain with the company over the long term (Kim & Kim, 2023).

Employer branding should encompass both employees' workplace experiences and the organization's reward and development opportunities. Its effectiveness depends on the alignment of external employer attractiveness with employees' internal experiences after joining the organization (Ambler & Barrow, 1996; Backhaus & Tikoo, 2004). Consequently, employer branding represents both the external image of the organization and an internal human resource management strategy that strengthens employee commitment, organizational identification, and long-term retention (Wang & Wang, 2024).

2.6 Industry and international perspective

A brand is more than a set of visual attributes; it represents customers' and employees' cognitive and emotional perceptions of an organization and its products. Strong brands contribute to organizational identity, strengthen stakeholder trust, and support long-term business sustainability. Previous research suggests that brand value is closely associated with customer loyalty, organizational reputation, and sustainable competitive advantage (Keller, 2013; Aaker, 1996).

In today's highly competitive business environment, innovation is not only a source of competitive advantage but also a strategic necessity. Organizations that continuously develop new products, services, and processes while responding to changing customer expectations are more likely to strengthen customer loyalty and maintain long-term market performance (OECD, 2024). However, innovation alone is insufficient to sustain loyalty. Long-term success also depends on product quality, organizational reliability, and the ability to build trust among both customers and employees (Chesbrough, 2003).

These challenges are particularly relevant in the automotive industry, where digitalisation, electrification, autonomous driving technologies, and increasing global competition require companies to simultaneously strengthen innovation capability and stakeholder loyalty. Consequently, organizations must integrate innovation strategies with strong organizational

cultures, effective employer branding, and continuous employee development to ensure sustainable competitiveness in rapidly changing international markets (European Automobile Manufacturers' Association [ACEA], 2025).

2.7 Theoretical synthesis of key factors derived from the literature

Component group	Related factors (examples)	Theoretical role in the system
Structural and organisational framework	organisational culture, HR systems, leadership practices	Provides the organisational context in which employee experiences and perceptions are formed
Managerial and organisational practices	communication, feedback, support, decision-making	Acts as a linking mechanism between organisational structures and employee attitudes
Employee perceptions	perceived fairness, perceived support, sense of security	Translates organisational factors into employees' subjective interpretations
Employee attitudes	job satisfaction, commitment, engagement	Develops based on perceptions and, in turn, influences organisational functioning
Behavioural outcomes	performance, cooperation, intention to stay	Behavioural expressions of attitudes that are visible at the organisational level
Organisational outcomes	retention, effectiveness, stability	Represents the long-term results of the overall system
Feedback mechanisms	experience, learning, adaptation	Enables continuous development and adjustment of the system

Source: own compilation

The table summarises the discussed theoretical components and their relationships, highlighting that the examined factors should not be interpreted in isolation but as part of an interconnected, system-level structure.

3. Methodology

3.1 Methodology and sampling

The literature review conducted in this study was complemented by empirical data collection, which took the form of a questionnaire-based survey. The questionnaire was distributed within a specific development department of one of Germany's largest and most well-known automotive companies. Although the questionnaire was initially made available to the department's 175 employees, it was subsequently shared through the internal network and reached other units within the company. The data collection period lasted from February 13 to March 23, 2025. During this time, a total of 236 individuals accessed the survey platform, of which 120 submitted valid responses. While the sample provides relevant insights into the attitudes of the target population, it cannot be considered statistically representative, as the proportion of respondents relative to the company's total workforce (3,500 employees) does not meet the 95% confidence level required for statistical representativeness. Nevertheless, the results offer valuable qualitative and quantitative information to guide future research directions and serve as a foundation for the in-depth analytical phase of the doctoral dissertation.

3.2. Data analysis procedures

Data processing and analysis were carried out using two different software applications. The questionnaire, which consisted of 23 closed-ended and 2 open-ended questions, was designed and initially analyzed using Survio, an online survey design and data processing platform. The questionnaire items are presented in detail at the end of this dissertation.

To test the hypotheses and explore the relationships between variables, the SPSS (Statistical Package for the Social Sciences) software was employed. SPSS is a widely used and respected

tool in the field of social science research. During the statistical analysis, correlation analysis was conducted to examine the relationships between factors influencing employee loyalty.
SPSS is commonly used not only in academic research but also in applied analyses. Due to its reliability and versatility, it is well-suited for uncovering complex interrelations. The results obtained contribute to a better understanding of organizational processes and help identify the key factors influencing employee commitment and loyalty.

3.3. Presentation of hypotheses

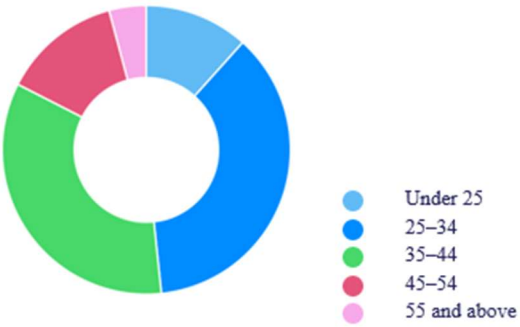
At the core of the research model is employee loyalty, conceptualized as the dependent variable. The model assumes that employee loyalty is influenced by multiple organizational and psychosocial factors within the innovation-driven environment of automotive companies.
Innovation-related pressure is assumed to have a direct negative effect on employee loyalty. In contrast, a supportive and innovation-oriented organizational culture, perceived job security, organizational practices supporting work–life balance, identification with the corporate brand, as well as access to training and professional development opportunities are assumed to have a positive effect on employee loyalty and long-term organizational commitment.

- **H1. Innovation pressure and employee loyalty**
  It is assumed that sustained and high levels of innovation-related pressure reduce employee loyalty.
- **H2. Organizational culture and employee loyalty**
  It is assumed that a supportive and innovation-oriented organizational culture enhances employee loyalty in automotive companies.
- **H3. Job security and employee loyalty**
  It is assumed that employees who perceive stable employment conditions and long-term job security demonstrate higher levels of loyalty.
- **H4. Work–life balance and employee loyalty**
  It is assumed that flexible work arrangements and organizational support for work–life balance strengthen employee commitment and loyalty.
- **H5. Brand identification and organizational commitment**
  It is assumed that employees who strongly identify with the company's brand and core values are more likely to remain committed to the organization over the long term, even during periods of innovation-driven transformation.
- **H6. Training and development opportunities**
  It is assumed that continuous professional development and access to training opportunities contribute to increased long-term employee loyalty.

4. Results

The presentation of the research results begins with an analysis of the first two questions from the questionnaire.
Based on the age distribution, the largest proportion of respondents belonged to the 25–34 age group, accounting for 36,7% of the sample. This was closely followed by the 35–44 age group, which represented 34,2% of respondents. The smallest group consisted of individuals over the age of 55 (4.2%), while those under 25 made up 11.7% of the sample. Respondents aged 45–54 represented 13,2% of the participants.
These figures indicate that the workforce composition of the examined company is predominantly made up of younger and middle-aged employees. This may suggest that the organization's dynamism and capacity for innovation are largely driven by younger generations.

Figure 1 Age groups



Source: own compilation

Regarding employment tenure, 48% of respondents had been working at the automotive company for more than seven years, while 14.2% had been employed for 4–7 years. Another 28.3% had been working for 1–3 years, and 9.2% had joined the company within the last year.

In response to the question *"Which factors contribute most to your loyalty toward the company?"*, the most frequently mentioned factor was **compensation and benefits** (67%), closely followed by **job security** (60.8%). **A positive working environment** was also highlighted as a key factor (59.2%), while **professional development opportunities** were cited by 40% of respondents. **Leadership** and **organizational culture** were each identified by 25% as influencing factors in employee loyalty.

These results suggest that employee loyalty is primarily shaped by financial compensation and perceived stability. However, the workplace atmosphere and opportunities for development also play an important role in fostering long-term commitment. The relationships between these factors will be further examined in subsequent sections of the research.

The fourth question of the questionnaire asked whether respondents had ever considered leaving the company. Results showed that 52% answered yes, indicating that a significant proportion of employees had contemplated resignation.

Those who answered yes were then asked to indicate their primary reasons for considering leaving. The most frequently cited factor was **dissatisfaction with leadership**, selected by 20% of these respondents. This was followed by **lack of opportunities for personal development** (10%) and **insufficient work–life balance** (7.5%). **Higher compensation available elsewhere** was mentioned by only 3.3%, as was the **"other"** category.

These findings suggest that employee dissatisfaction is primarily not rooted in financial issues, but rather in factors related to organizational culture, leadership decisions, and limited opportunities for professional growth. These insights can serve as important input for the company in designing strategies aimed at increasing employee loyalty.

The next section of the study focuses on testing the hypotheses, for which the detailed presentation of previous questionnaire responses is essential, as these are frequently referenced in the hypothesis analysis. The first hypothesis test involves examining the relationship between the following two questions:

Loyalty: *What factors contribute most to your sense of loyalty to the company?*

Innovation: *How often are employees encouraged to share new ideas and innovations?*

H1: Innovation pressure and employee loyalty: *It is assumed that sustained and high levels of innovation-related pressure reduce employee loyalty.*

The Pearson correlation coefficient calculated for this analysis was **r = 0.377**, with a significance level of **p = 0.81**, indicating that, based on the sample of 120 respondents, there is **no statistically significant relationship** between innovation pressure and employee loyalty.

Additional analyses were conducted to explore the relationship between specific loyalty-related factors and innovation encouragement. However, these results also failed to reveal any statistically significant correlations. Therefore, **the first hypothesis was not supported** by the current data.
It is also important to note that correlation does not imply causation. Employee loyalty is influenced by multiple factors, such as leadership support, job security, career development opportunities, and overall work environment. Innovation-related pressure might not necessarily be perceived negatively; employees may view it as a challenge, a learning opportunity, or a way to grow professionally. Such perceptions could counterbalance any potential negative impact of innovation pressure on loyalty.
In conclusion, the current findings suggest that innovation pressure alone is not a sufficient predictor of employee loyalty. Contextual and organizational factors likely play a significant role in shaping how employees experience innovation demands and whether these demands affect their long-term commitment to the organization.
Next, we examined the second hypothesis (H2):

H2: Organizational culture and employee loyalty: *t is assumed that a supportive and innovation-oriented organizational culture enhances employee loyalty in automotive companies.*

To test this hypothesis, the following questions were analyzed:

- **Loyalty** *What factors contribute most to your sense of loyalty to the company?*
- **Organizational Culture:** *How would you describe the company's organizational culture?* and *Do you feel that the company values and respects employee contributions?*

The results **confirmed the second hypothesis**: a supportive organizational culture positively impacts employee loyalty and is a key determinant of long-term employee commitment.
The statistical analysis revealed a **correlation coefficient of r = ,297**, indicating a **statistically significant relationship** between supportive organizational culture and employee loyalty. Recognition of employee contributions also showed a **positive but weaker** correlation with loyalty. In both cases, the level of statistical significance supports the conclusion that improving organizational culture can enhance loyalty.
To initiate such organizational changes, companies must develop a clear corporate strategy and define specific innovation goals. Depending on the company's structure, this process can proceed in two directions: by creating a new organizational unit or by implementing changes internally. In the case of establishing a new unit, organizational design must be undertaken, with characteristics differentiated from the parent company to effectively foster innovation—an approach that may prove successful in the long term (Csedő & Zavarkó, 2019).

Table 1: *Analysis of Hypothesis H2*

		Loyality	How would you describe the company's organizational culture?	Do you feel that the company values and respects employee contributions?
Loyality	Pearson-correlation	--		
	N	120		
How would you describe the company's organizational culture?	Pearson-correlation	.297 **	--	
	Sig.(2- sided)	<.001		
	N	120	120	

Do you feel that the company values and respects employee contributions?	Pearson-correlation	-.185*	-.650**	--
	Sig.(2- sided)	.044	<.001	
	N	120	120	

Source: SPSS – own compilation

The objective of testing the third hypothesis was to examine the strength of the relationship between job security and employee loyalty. The loyalty-related questions used in the analysis were the same as those applied in the evaluations of the first two hypotheses. These were compared with the questionnaire: *"Do you feel secure in your current job position?"*
The results supported the hypothesis. The statistical analysis revealed a correlation coefficient of r = 0.297, indicating a moderate but statistically significant positive relationship between a supportive organizational culture and employee loyalty. Additionally, recognition of employee contributions demonstrated a positive, albeit slightly weaker, correlation with loyalty. These findings suggest that employees are more likely to remain committed to organizations that foster an environment of support, open communication, and appreciation for individual contributions.
From a causal perspective, while correlation alone does not establish direct causality, the observed relationship is consistent with theoretical frameworks in organizational behavior. A supportive culture likely strengthens loyalty through multiple mechanisms: it enhances employees' psychological safety, increases job satisfaction, and fosters a sense of belonging and alignment with the company's mission. Employees who feel recognized and valued are more motivated to invest effort in their work and maintain long-term engagement. Conversely, in organizations lacking support or recognition, employees may experience disengagement, lower motivation, and a higher likelihood of turnover, even if other factors such as job security or compensation are adequate.
Implementing changes to promote a supportive, innovation-friendly culture requires deliberate organizational planning. Companies may establish new units or adapt existing structures to encourage innovation and employee involvement. Such interventions, when accompanied by clear strategic goals, transparent communication, and consistent recognition of contributions, can create an environment where loyalty naturally develops as a byproduct of positive organizational experiences. In summary, the data indicates that cultivating a supportive culture is not only associated with higher employee loyalty but can also serve as a causal driver for enhancing long-term commitment within automotive organizations.

H3: Job security and employee loyalty: *It is assumed that employees who perceive stable employment conditions and long-term job security demonstrate higher levels of loyalty.*

To test this hypothesis, the previously analyzed loyalty indicators were compared with responses to the question measuring perceived job security. The analysis revealed a **statistically significant relationship** between the two variables, supporting the validity of the hypothesis.
The results suggest that the more secure employees feel about their long-term employment, the stronger their loyalty toward the company. Conversely, when job insecurity is high, employees tend to select fewer loyalty-related factors from the available options in the questionnaire.
The calculated **correlation coefficient** was **r = -0,215**, indicating a **negative correlation** between job security and loyalty: the greater the perceived uncertainty, the lower the level of loyalty.
Beyond the observed statistical association, the findings point to an underlying **psychological and organizational mechanism** linking perceived job security to employee loyalty. When employees experience stable employment conditions, they are more likely to develop a sense of predictability, trust, and psychological safety, which fosters stronger emotional attachment to the organization. This perceived stability reduces uncertainty-related stress and allows individuals to invest more

cognitive and emotional resources into their work and organizational relationships, thereby reinforcing loyalty-related attitudes and behaviors. Conversely, heightened job insecurity can trigger defensive coping strategies, such as reduced organizational identification or emotional withdrawal, which may weaken long-term commitment to the employer. From an organizational perspective, perceived insecurity may also signal a lack of reciprocity in the psychological contract, diminishing employees' motivation to demonstrate loyalty. Although the correlation does not imply direct causation, the results are consistent with theoretical models suggesting that job security functions as an important antecedent of employee loyalty through its impact on trust, well-being, and perceived organizational support.

Table 2: *Analysis of Hypothesis H3*

			Do you feel secure in your current job position?
Loyality	Pearson-correlation	--	
	N	120	
Do you feel secure in your current job position?your work and personal life?	Pearson-correlation	-.215*	--
	Sig.(2- sided)	.018	
	N	120	120

Source: SPSS- own compilation

The fourth hypothesis aimed to examine the relationship between **work–life balance** and **employee loyalty**. The hypothesis was formulated as follows:

H4: Work–life balance and employee loyalty: *It is assumed that flexible work arrangements and organizational support for work–life balance strengthen employee commitment and loyalty*

To test this hypothesis, the previously applied loyalty-related question served as the baseline variable, which was analyzed in relation to responses to the following work–life balance–related items:

- *Do you feel you have a good balance between your work and personal life?*
- *How often do you feel stressed about work affecting your personal life?*
- *Does the company provide flexible working options (e.g., remote work, flexible hours)?*
- *How motivated do you feel in your current role?*

According to the statistical analysis, **no significant correlation** was found between overall work–life balance and employee loyalty. The **Pearson correlation coefficient** was **r = -0.037**, indicating **no strong or meaningful relationship** between the two variables in the current sample.

This suggests that, in this case, the perceived level of work–life balance does not exert a direct influence on employee loyalty. However, it is important to consider that other factors—such as leadership support, organizational culture, and job security—may have a more substantial impact on loyalty. These should be further investigated in future research.

Nevertheless, the work–life balance–related questions were examined in greater depth. Further analysis confirmed that a **balanced work–life dynamic positively influences workplace motivation**, which clearly contributes to employee performance and the long-term success of automotive companies. The results show that **work–life balance has a direct effect on employee motivation**, thereby supporting the achievement of corporate objectives.

Table 3: *Further Analysis of Hypothesis H4*

		How motivated do you feel in your current role?	Do you feel you have a good balance between your work and personal life?	How often do you feel stressed about work affecting your personal life?
How motivated do you feel in your current role?	Pearson-correlation	--		
	N	120		
Do you feel you have a good balance between your work and personal life?	Pearson-correlation	-.224*	--	
	Sig.(2- sided)	.014		
	N	120	120	
How often do you feel stressed about work affecting your personal life?	Pearson-correlation	-.172	-.554**	--
	Sig.(2- sided)	.061	<.001	
	N	120	120	120

Source: SPSS- own compilation

These findings indicate that work–life balance may function less as a direct antecedent of employee loyalty and more as an indirect or mediating factor within the broader organizational context. A balanced work–life dynamic appears to primarily influence employees' motivational states and psychological energy, which in turn shape performance-related outcomes rather than immediate attitudinal loyalty. In highly demanding and transformation-driven industries such as automotive manufacturing, employees may tolerate temporary imbalances in exchange for job security, meaningful work, or strong leadership support, thereby weakening the direct link between work–life balance and loyalty. Furthermore, loyalty may be more strongly anchored in relational and structural factors—such as trust in leadership, perceived organizational support, and long-term career prospects—than in day-to-day balance perceptions. Consequently, work–life balance should be understood as a supportive enabling condition that strengthens motivation and sustainable performance, while loyalty emerges from a more complex interaction of organizational, psychological, and contextual variables.
The penultimate hypothesis tested in this research is as follows:

H5 Brand identification and organizational commitment: *It is assumed that employees who strongly identify with the company's brand and core values are more likely to remain committed to the organization over the long term, even during periods of innovation-driven transformation*.

To validate this hypothesis, the following survey items were used:

- **Commitment:** *Have you ever considered leaving the company in the past year?*
- **Brand Loyalty:** *Do you feel proud to work for this company?*, *Does the company's brand inspire trust and confidence in employees?*

The SPSS-based correlation analysis produced the following results: Employees who feel a stronger emotional attachment to the company's brand and express pride in the products it manufactures are more likely to remain loyal over time. The **correlation coefficient** indicated a **moderate-strength relationship** (as defined by Cohen), confirming a **positive association** between brand loyalty and employee commitment.
Based on these results, the hypothesis was **confirmed**. Identification with the corporate brand and positive attitudes toward the brand significantly reinforce long-term employee commitment.

Furthermore, employee commitment has a notable impact on **innovation performance**, of which **employer branding is a foundational element** (Wang & Wang, 2024).

Table 4: *Analysis of Hypothesis H5*

		Do you feel proud to work for this company?	Does the company's brand inspire trust and confidence in employees?	Have you ever considered leaving the company in the past year?
Do you feel proud to work for this company?	Pearson-correlation	--		
	N	120		
Does the company's brand inspire trust and confidence in employees?	Pearson-correlation	-.383**	--	
	Sig.(2- sided)	<.001		
	N	120	120	
Have you ever considered leaving the company in the past year?	Pearson-correlation	-.248**	-.317**	--
	Sig.(2- sided)	.006	<,001	
	N	120	120	120

Source: SPSS- own compilation

The results provide strong empirical support for the assumption that **brand loyalty functions as a key psychological driver of employee commitment**. Employees who identify with the company's brand and perceive it as trustworthy and value-consistent are more likely to internalize organizational goals as part of their own professional identity. This identification process strengthens emotional attachment and fosters a sense of belonging, which reduces turnover intentions and enhances long-term organizational commitment. From a causal perspective, a credible and value-driven employer brand can be understood as a symbolic resource that reinforces the psychological contract between employees and the organization, thereby increasing willingness to remain despite external job opportunities. Conversely, weakened trust in the corporate brand may erode this psychological bond, increasing the likelihood of withdrawal cognitions such as contemplating leaving the organization. Although the correlational design does not permit definitive causal conclusions, the findings are consistent with social identity theory and employer branding literature, suggesting that strong brand identification precedes and reinforces sustained employee commitment and indirectly contributes to innovation performance through higher engagement and discretionary effort.

H6: Impact of Training and Development Opportunities: *Continuous training promotes long-term employee commitment.*

For the correlation analysis of this final hypothesis, the following survey items served as the basis:

- **Employee Retention:** ***Have you ever considered leaving the company in the past year?***
- **Training Opportunities:** ***How satisfied are you with the training opportunities provided by the company?*** and ***Do you believe the training programs are effective in preparing employees for industry changes?***

According to the results of the SPSS correlation analysis, a **statistically significant relationship** was identified between training opportunities and employee retention. The findings suggest that the fewer training opportunities the company provides, the more likely employees are to consider leaving the organization.
This indicates that continuous professional development and the provision of adequate training opportunities are **key factors** in maintaining long-term employee commitment. Training also offers advantages from a **knowledge-sharing** perspective, supporting internal development and enabling companies to evolve in relation to their own performance benchmarks (Tajti et al., 2024).

Table 5: *Analysis of Hypothesis H6*

		Have you ever considered leaving the company in the past year?	How satisfied are you with the training oppurtinities provided by the company?	Do you believe the training programs are effective in preparing employees for industry changes ?
Have you ever considered leaving the company in the past year?	Pearson-correlation	--		
	N	120		
Do you believe the training programs are effective in preparing employees for industry changes ?	Pearson-correlation	-.168	--	
	Sig.(2- sided)	.066		
	N	120	120	
Do you believe the training programs are effective in preparing employees for industry changes ?	Pearson-correlation	-.119	-.540**	--
	Sig.(2- sided)	.196	<.001	
	N	120	120	120
Are there sufficient opportunities for professional growth within the company?	Pearson-correlation	-.309**	.315**	.311**
	Sig.(2- sided)	<.001	<.001	
	N	120	120	120

Source: SPSS- own compilation

*. The correlation is significant at the 0.05 level (2-tailed).
**. The correlation is significant at the 0.01 level (2-tailed).

The analysis demonstrates a clear causal link between the availability of training opportunities and employee retention. Employees who perceive fewer opportunities for professional growth are more likely to contemplate leaving the organization, suggesting that inadequate development initiatives directly undermine long-term commitment. Conversely, the provision of effective and relevant training programs appears to enhance employees' confidence in navigating industry changes, thereby fostering a sense of job security and loyalty. The strong positive correlations between satisfaction with training and perceived effectiveness of programs indicate that when employees experience meaningful skill development, they are more engaged and less likely to exit. From an organizational perspective, investing in continuous professional development not

only mitigates turnover risk but also facilitates internal knowledge transfer, which strengthens overall performance. Therefore, the findings support the hypothesis that targeted training initiatives are a pivotal mechanism through which companies can sustain both individual growth and strategic competitiveness.

Figure 2 Summary of Hypotheses and Relationships

Source: own compilation

The figure summarizes the hypothesized causal relationships between key organizational factors and employee loyalty in the automotive industry. It illustrates that organizational culture (H2), job security (H3), brand identification (H5), and training and development opportunities (H6) exert a significant positive influence on employee loyalty, whereas innovation pressure (H1) and work–life balance (H4) do not demonstrate a direct statistically significant effect. The model highlights that employee loyalty emerges from a complex interaction of structural, cultural, and developmental drivers rather than from innovation-related demands alone. Overall, the diagram provides an integrative framework that supports a holistic understanding of employee loyalty in innovation-driven organizational contexts.

5. Short Case Study: Enhancing Employee Loyalty in the Automotive Industry

A large German automotive manufacturer undergoing rapid transformation toward electrification and digitalization experienced increasing turnover intentions among engineers and technical specialists. Although innovation pressure was initially assumed to be the primary cause, internal analyses revealed that employee loyalty was more strongly influenced by organizational conditions than by innovation demands themselves.

In response, the company introduced leadership development initiatives to strengthen a supportive and innovation-oriented culture, alongside measures to enhance perceived job security through transparent career paths and reskilling programs. Internal employer branding was reinforced to foster identification with the company's innovation-driven mission and German engineering values, while continuous training opportunities were expanded to support long-term professional development.

Within one year, employee surveys indicated reduced turnover intentions and higher levels of organizational commitment. The case illustrates that innovation pressure does not inherently

undermine employee loyalty; rather, loyalty is sustained when innovation is embedded in a supportive organizational context characterized by trust, stability, and continuous development.
The case study provides qualitative support for the empirical findings of this research. Consistent with **H1**, innovation pressure alone did not undermine employee loyalty; instead, its impact depended on organizational context. The interventions implemented directly reflect the mechanisms confirmed by **H2** and **H3**, as supportive organizational culture and perceived job security proved central to restoring commitment. Measures related to internal employer branding align with **H5**, reinforcing brand identification as a driver of long-term loyalty. Finally, the expansion of continuous training and development opportunities mirrors the findings of **H6**, demonstrating that professional growth significantly reduces turnover intentions. In line with **H4**, work–life balance was not treated as a primary loyalty lever but rather as a supportive condition influencing motivation. Overall, the case study illustrates how the empirically tested hypotheses interact in practice within a real organizational setting.

6. Conclusion

6.1 Application of Findings and Recommended Actions

Based on the research results, we conclude that the following areas are of key importance for automotive companies: improving organizational culture, enhancing job security, strengthening brand loyalty, and expanding training and development opportunities. Taking these factors into account, we propose the following measures, which—according to both academic literature and empirical findings—can significantly contribute to the retention and enhancement of employee loyalty.

6.2 Developing Organizational Culture

The findings indicate that reinforcing a supportive and innovation-friendly organizational culture promotes employee loyalty. An open, inclusive, and creativity-driven environment positively influences employee engagement (Hogan & Coote, 2014). Fostering a corporate culture that embraces innovation contributes to sustained competitiveness, as well as to long-term employee motivation and commitment.

Recommended actions:

- Review leadership styles and communication practices to promote innovation and open dialogue (Eisenbeiss et al., 2008).
- Strengthen core organizational values that emphasize respectful workplace behavior and a commitment to continuous improvement.

6.3 Enhancing Job Security

Measures that ensure job security directly contribute to increased employee loyalty. Stable employment conditions and a sense of long-term security enhance trust in the company (Getahun Asfaw & Chang, 2019). Ensuring job security not only improves employee satisfaction but also boosts overall company performance, as loyalty is closely linked to perceived workplace stability.

Recommended actions:

- Develop internal agreements that support long-term employment and outline stable career paths for employees. It is essential to provide multiple career track options, including not only traditional vertical advancement but also horizontal career development opportunities.
- Design benefit and insurance programs that enhance employee security, including reskilling and retraining options that reassure and motivate staff.

6.4 Strengthening Brand Loyalty and Commitment

To reinforce the connection between brand loyalty and organizational commitment, employees must develop a strong identity with the company's brand—one that aligns with their personal

values and goals. Identification with the brand is closely tied to employee engagement, particularly during periods of innovation-driven transformation (Kim & Kim, 2023).

Recommended actions:

- Continuously communicate the company's brand and mission; offer opportunities for employees to test company products (e.g., vehicles), participate in automotive exhibitions and competitions, and ensure that every employee understands and supports the company's values.
- Shape a brand image that resonates personally with employees—for example, by fostering pride in the company's products and services. For a German automotive manufacturer, this can be achieved by emphasizing innovation, future orientation, and promoting German standards of safety and quality.

6.5 Expanding Training and Development Opportunities

Improving the effectiveness of training programs and providing clear paths for employee development directly contribute to sustaining employee loyalty. Based on our findings, continuous learning and development increase motivation, better prepare employees for industry changes, and improve workplace performance (Kuvaas & Dysvik, 2009). Training not only enhances engagement but also supports organizational success.

Recommended actions:

- Provide personalized training and development programs aligned with industry trends and individual career aspirations. These may include advanced training in automotive software, electric motor and battery technology, as well as professional visits to suppliers across different linguistic and geographic regions.
- Continuously update educational offerings by integrating the latest industry knowledge into internal training structures, and include personal development modules focused on adaptability and resilience to support adjustment to changing environments.

For automotive companies, it is essential to invest in the development of organizational culture, enhancement of job security, strengthening of brand loyalty, and expansion of training opportunities. Implementing the recommended measures may significantly increase employee loyalty, which in turn contributes to the company's long-term competitiveness and sustainability.

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Manufacturing Development and Regional Socioeconomic Outcomes in the Context of Hungary's Battery Industry Expansion

This paper examines the association between regional manufacturing development intensity and socioeconomic outcomes in Hungary in the context of the country's recent battery-industry expansion, using an EU27 NUTS2 benchmark panel over 2013–2022. Using a two-way fixed effects framework, it analyses employment, compensation per employee, and the tertiary employment share, while also testing the conditioning role of regional innovation capacity. The results show limited evidence of broad-based employment expansion, clearer wage upgrading, and no systematic upgrading in the tertiary employment share. Wage gains are stronger in regions with higher human capital and R&D effort, suggesting that innovation capacity strengthens the association between manufacturing development intensity and local wage outcomes. The findings suggest that manufacturing deepening in the context of Hungary's battery-industry expansion is associated with real but uneven regional socioeconomic outcomes.
Keywords: battery industry; manufacturing development; innovation capacity; *socioeconomic outcomes; Hungary*
JEL codes: R11, R12, J31, F21

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1. Introduction

The rapid diffusion of electric vehicles (EVs) has repositioned battery manufacturing as a strategic segment of industrial transformation and green transition (Foley et al., 2020; Barbosa et al., 2022). Batteries are central not only to EV performance and cost, but also to broader efforts aimed at decarbonizing transport and strengthening industrial competitiveness (Siebenhofer et al., 2021). Within the European Union, this transformation is closely linked to policy initiatives such as the European Green Deal and the European Battery Alliance, which treat batteries as key enabling technologies for low-carbon growth and industrial renewal (Haas & Sander, 2020).
However, at the same time, the geographic distribution of battery manufacturing indicates a highly concentrated and asymmetric industry, predominantly situated in East Asia; in contrast, Europe and North America remain underrepresented despite rapid growth (Yang et al., 2022). In 2023, China accounted for over two-thirds of global EV battery cell production, while South Korea and Japan held significant shares (IEA, 2024). Within the EU, notable disparities exist, where a select few member states—namely Germany, Poland, Sweden, and Hungary—dominate current and planned battery plant capacities, whereas others primarily engage in upstream material processing or downstream pack assembly (Asaba et al., 2022; Győrffy, 2024). The regional dynamics indicate a pronounced shift in investment patterns, particularly in CEE, identified as pivotal regions for new investments, where countries like Poland and Hungary are rapidly evolving into critical production hubs for traction batteries and their components (Kostecka-Tomaszewska & Czerewacz-Filipowicz, 2019; Ferraro & Garofalo, 2025).
Hungary, in particular, holds a prominent position in this evolving battery production landscape (Pavlínek, 2022). Leveraging its historical integration into the German automotive supply chain,

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the country has become a leading site for large-scale EV battery production since the late 2010s (Lechowski et al., 2025). Major investments such as Samsung SDI's factory in Göd and CATL's gigafactory in Debrecen highlight this shift, and the Hungarian government is actively positioning the country as a prospective European battery hub (Csomós et al., 2025; Ricz & Éltető, 2025; Kronstein, 2026). At the same time, the regional socioeconomic consequences of this manufacturing transformation remain uncertain.

Although existing studies document investment patterns, supply-chain shifts, and the strategic relevance of battery manufacturing, there is still limited evidence on the within-country socioeconomic consequences of manufacturing deepening in the context of battery-industry expansion, especially in Central and Eastern Europe. Employment, wage, and skill-composition outcomes are rarely analyzed jointly, and the moderating role of regional innovation capacity is more often assumed than directly tested.

This paper addresses these gaps by examining how regional manufacturing development intensity is associated with socioeconomic outcomes in Hungary during the period of battery-industry expansion, using an EU27 NUTS2 benchmark panel over 2013–2022. Because harmonized battery-specific employment and investment data are not available at this regional scale for the full study period, the analysis does not directly measure battery-sector effects. Instead, the battery industry provides the substantive context, while the empirical analysis focuses on broader regional manufacturing development intensity. The paper examines employment, compensation per employee, and the tertiary employment share, and tests whether these relationships vary with regional innovation capacity. It argues that the associated regional socioeconomic outcomes are uneven: compensation upgrading is more visible than employment expansion or increases in the tertiary employment share, while innovation-capable regions capture stronger wage-related benefits.

The remainder of the paper is structured as follows. Section 2 presents the theoretical framework and literature review. Section 3 introduces the data and methodology. Section 4 reports the empirical results. Section 5 discusses the main findings. Section 6 concludes.

2. Theoretical framework and literature review

2.1. FDI-led manufacturing development and regional upgrading

The relationship between manufacturing development and regional socioeconomic upgrading is often discussed through the lens of FDI-led industrial development. Foreign investment may contribute to productivity growth, export expansion, wage upgrading, and technological learning through capital inflows, supplier linkages, and knowledge transfer (Yao & Wei, 2007; Fu et al., 2011; Gyamfi et al., 2022; Tóth et al., 2024). However, these benefits are rarely automatic or spatially uniform. In transition and emerging economies, including Hungary, the local gains from foreign-led manufacturing expansion depend on the depth of domestic linkages, the position of local actors in value chains, and the capacity of regions to absorb external knowledge (Halpern & Muraközy, 2007; García et al., 2022; Liu et al., 2022).

A more critical strand of the literature emphasizes that FDI-led industrialization may also generate uneven or limited upgrading. Foreign manufacturing projects can create employment and wage gains, but they may also reinforce dependent development, production-oriented specialization, weak domestic supplier integration, and limited local control over strategic functions. These concerns are particularly relevant in Central and Eastern Europe, where manufacturing expansion has often been closely linked to multinational production networks. From a home-country perspective, foreign investors may locate production in Hungary not only because of host-country advantages, but also to access the EU market, reduce supply-chain risks, and serve European automotive producers. Therefore, the regional outcomes of manufacturing expansion should be assessed cautiously rather than assumed to be automatically inclusive.

2.2. Battery-industry expansion and manufacturing deepening in Hungary

Battery manufacturing represents a new phase of manufacturing transformation in Hungary. The country's historical integration into the German automotive supply chain has facilitated its recent positioning as a major location for battery-cell, component, and related manufacturing investments. This development reflects both EU-level green industrial transformation and Hungary's national strategy to become a battery-industry hub. However, the battery industry is not spatially or functionally homogeneous. Battery and EV value chains are geographically concentrated and functionally differentiated, with some regions specializing in innovation-intensive activities and others in large-scale production and assembly (Ferloni et al., 2024).

In this paper, Hungary's battery-industry expansion is therefore treated as the substantive context in which regional manufacturing development is examined. The empirical analysis does not directly measure battery-specific employment, investment, or output. Instead, it uses regional manufacturing development intensity as a broader indicator of manufacturing deepening during the period in which battery-related investments have become increasingly important in Hungary's industrial strategy. This approach is also supported by previous evidence from Hungary showing dynamic interactions between manufacturing production and battery-industry exports, suggesting that battery-sector expansion is embedded in broader manufacturing dynamics (Yang, 2024).

2.3. Regional absorptive capacity and heterogeneous socioeconomic outcomes

The socioeconomic outcomes of manufacturing development are likely to vary across regions. The literature on absorptive capacity and regional innovation systems argues that local benefits from industrial expansion depend on existing stocks of human capital, R&D effort, institutional capability, and the quality of local linkages (Rodríguez-Pose & Bilbao-Osorio, 2004; Rodríguez-Pose & Crescenzi, 2008; Grillitsch & Nilsson, 2015). Regions with stronger innovation capacity may be better able to translate manufacturing deepening into wage upgrading and higher-value activities, whereas regions with weaker capabilities may experience more limited or production-oriented gains.

This framework suggests that employment, wage, and skill-composition outcomes should not be expected to move uniformly. Manufacturing deepening may increase compensation without necessarily generating broad-based employment growth or a higher tertiary-educated employment share. In this sense, regional innovation capacity may condition the relationship between manufacturing development intensity and socioeconomic outcomes. The empirical analysis therefore examines three outcomes—employment, compensation per employee, and the tertiary employment share—and tests whether human capital and R&D effort moderate these relationships.

3. Data and methodology

3.1. Data

The empirical analysis uses an annual EU27 NUTS2 regional panel for 2013–2022. Although Hungary is the substantive focus, Hungarian regions are embedded in the broader EU benchmark to provide a reference distribution and increase panel variation. All variables are compiled from Eurostat regional datasets and harmonized by region and year.

The study period is determined by the availability of comparable EU27 NUTS2 data. It captures the early phase of Hungary's battery-industry expansion and related manufacturing restructuring, rather than the full post-operation effects of all major battery investments. Since some projects were announced, constructed, or expanded near the end of the period, their labour-market effects may appear only with a time lag.

Three socioeconomic outcomes are analysed: total employment, compensation per employee, and the tertiary employment share. Employment and compensation are used in logarithms, while skill composition is measured as the share of tertiary-educated employment in total employment. The key explanatory variable is regional manufacturing development intensity (ManuDev), measured as the share of manufacturing employment (NACE Rev. 2 Section C) in total employment.

ManuDev is not interpreted as a direct measure of battery-sector employment, investment, or output. Rather, it captures the broader manufacturing intensity of regional economies during the period in which Hungary has increasingly positioned itself as a battery-industry hub. Accordingly, the results are interpreted as associations between regional manufacturing development intensity and socioeconomic outcomes, not as direct causal effects of battery-sector activity.
To test whether regional innovation capacity conditions the socioeconomic associations of manufacturing expansion, the analysis uses two moderators: human capital and gross domestic expenditure on R&D (GERD) per inhabitant. Both variables are standardised for the interaction analysis. Baseline controls include GDP per capita, population, population density, and unemployment. Table 1 reports the definitions and sources of all variables.

Table 1. Variable definitions and data sources

Abbrev.	Variable full name	Definition / construction	Unit	Source
Emp	Total employment	Total employed persons of all NACE activities	thousand persons	Eurostat LFS
Wage	Compensation per employee	Compensation per employee (all NACE activities)	EUR	Eurostat
Skill	Tertiary employment share	Employed (ISCED 5–8) / total employed	%	Eurostat LFS
ManuDev	Regional manufacturing development intensity	Manufacturing employment share (NACE C) / total	%	Eurostat LFS
HC	Human capital	Tertiary attainment	%	Eurostat
GERD	R&D expenditure	Total gross expenditure on R&D per inhabitant	EUR	Eurostat
GDPpc	GDP per capita	GDP per capita (Purchasing power standard) per inhabitant in percentage of the EU27 (from 2020) average	%	Eurostat
Pop	Population	Total population	persons	Eurostat
Dens	Population density	Persons per square kilometre	persons/ km²	Eurostat
Unemp	Unemployment rate	Unemployment rate	%	Eurostat

Source: Own construction.

3.2. Methodology

To examine how regional manufacturing development intensity is associated with socioeconomic outcomes in the context of Hungary's battery-industry expansion, the paper applies a two-way fixed effects (TWFE) panel model. This approach exploits within-region changes over time while controlling for unobserved time-invariant regional heterogeneity and common year shocks.
The baseline specification is:

$$Y_{it} = \beta_1 ManuDev_{it} + X_{it}\gamma + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

where Y_{it} denotes one of the outcomes (log employment, log compensation per employee, or tertiary employment share), ManuDev_it is regional manufacturing development intensity, X_{it} is the vector of controls, μ_i are region fixed effects, and λ_t are year fixed effects.
To test whether innovation capacity conditions the association between industrial expansion and socioeconomic outcomes, the following specification is estimated:

$$Y_{it} = \beta_1 ManuDev_{it} + \beta_2 Innov_{it} + \beta_3 (ManuDev_{it} \text{ x } Innov_{it})$$

$$+X_{it}\gamma + \mu_i + \lambda_t + \varepsilon_{it} \quad (2)$$

where $Innov_{it}$ represents either standardised human capital or standardised R&D effort. The interaction coefficient β_3 indicates whether the marginal relationship between industrial development intensity and the outcome varies systematically with innovation capacity.

Moreover, to highlight Hungary within the EU benchmark, a heterogeneity specification is also estimated:

$$Y_{it} = \beta_1 ManuDev_{it} + \beta_2 (ManuDev_{it} \text{ x } HU_i) + X_{it}\gamma + \mu_i + \lambda_t + \varepsilon_{it} \quad (3)$$

where HU_i is an indicator for Hungarian regions. Because HU_i is time-invariant, it is absorbed by region fixed effects, but the interaction term remains identified.

Table 2 reports descriptive statistics for the EU27 NUTS2 panel over 2013–2022. The variables display substantial cross-regional variation, while GERD has more limited coverage, reducing the effective sample size in some interaction models. For descriptive purposes, percentage-based variables are reported in percentage terms in Table 2. In the regression analysis, share variables such as ManuDev and the tertiary employment share are expressed as shares ranging from 0 to 1.

Table 2. Descriptive statistics

Variable	Obs	Mean	Std. dev.	Min	Max
Emp	2,412	787.98	680.42	13.8	5578.4
Wage	2,370	33,597.64	14,521.18	5,100	80,800
Skill	2,388	29.86	9.58	11.4	62.1
ManuDev	2,357	18.04	7.67	3.26	43.16
HC	2,380	29.80	9.53	11.4	62.1
GERD	1,585	457.20	596.77	4.16	5,776.65
GDPpc	2,369	94.48	37.24	27	282
Pop	2,420	1,840,384	1,610,715	28,501	1.24e+07
Dens	2,397	346.91	849.12	3	7,660
Unemp	2,385	8.67	6.19	1.2	36.2

Source: Own construction.

4. Empirical analysis

This section presents the empirical results on the associations between regional manufacturing development intensity and its socioeconomic outcomes. Using the two-way fixed effects framework introduced in Section 3, the analysis proceeds in three steps. First, it estimates the baseline association between ManuDev and regional labour-market outcomes. Second, it examines whether these relationships vary with regional innovation capacity. Third, it benchmarks Hungarian regions against the broader EU27 distribution.

4.1. Employment outcomes

Total employment is measured as the logarithm of total employed persons (ln_emp), and ManuDev is defined as the manufacturing employment share (NACE Rev.2 C) in total employment at the NUTS2 level. All models include region fixed effects and year fixed effects, with standard errors clustered at the NUTS2 level. Results are reported in Table 3.

Before turning to the regression estimates, it is useful to position Hungary within the EU benchmark. Over 2013–2022, Hungarian NUTS2 regions display substantially higher manufacturing development intensity than non-Hungarian EU regions. The average value of ManuDev is 0.253 for Hungary, compared with 0.178 for the others, consistent with Hungary's increasingly manufacturing-intensive development path. As shown in Figure 1, Hungarian regions also exhibit a visibly higher distribution of ManuDev relative to the EU benchmark.

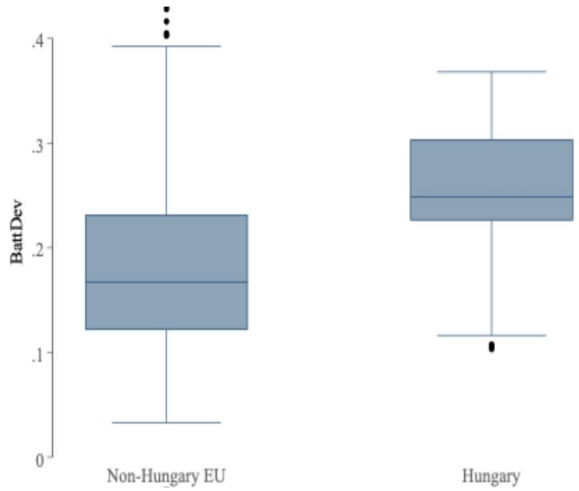

Figure 1. ManuDev distribution: Hungary vs non-Hungary EU regions (2013–2022)
Source: Own construction.

In the baseline specification shown in Column (1), ManuDev is negatively and significantly associated with total employment. In magnitude, a 0.10 increase in ManuDev, equivalent to a 10 percentage-point increase in the manufacturing employment share, is associated with approximately a 3.2% lower employment level in the baseline model. This suggests that rising regional manufacturing development intensity does not automatically translate into net employment expansion at the regional level. After introducing regional controls in Column (2), the coefficient on ManuDev remains negative but weakens in magnitude and statistical significance. This indicates that part of the baseline relationship reflects broader regional economic and demographic dynamics rather than a stable net job-creation effect of manufacturing development intensity.

Columns (3) and (4) test whether innovation capacity conditions the ManuDev–employment relationship. Human capital is positively related to employment, but the interaction term ManuDev × HC is statistically insignificant. Likewise, neither the main effect of GERD nor the interaction ManuDev × GERD is statistically significant. These results suggest that innovation capacity does not materially alter the employment association of regional manufacturing development intensity in the sample period.

Finally, Column (5) benchmarks Hungary against the broader EU27 distribution through the interaction ManuDev × Hungary. The interaction term is statistically insignificant, indicating that the within-region employment association of ManuDev does not differ significantly between Hungarian regions and the broader EU benchmark.

Taken together, the employment results provide limited support for a regional "job creation dividend" associated with rising regional manufacturing development intensity during 2013–2022. The ManuDev coefficient is negative and significant in the baseline specification, but the magnitude and statistical strength weaken after accounting for regional economic conditions and become indistinguishable from zero in the interaction models. These patterns are consistent with an interpretation in which manufacturing development in the context of Hungary's battery-industry expansion coincides with structural reallocation and increasingly capital-intensive production dynamics rather than broad-based net employment expansion. At the same time, this interpretation should remain cautious. The weak employment relationship may also be consistent with alternative mechanisms, including demographic change, sectoral crowding-out, broader regional restructuring, or measurement limitations associated with aggregate manufacturing employment shares.

Table 1. Employment outcomes and regional manufacturing development intensity

Variables	(1) Baseline FE	(2) + Controls	(3) + HC interaction	(4) + GERD interaction	(5) + Hungary interaction
ManuDev	-0.323** (0.158)	-0.173* (0.098)	-0.098 (0.100)	-0.080 (0.112)	-0.177* (0.101)
HC			0.027** (0.013)		
ManuDev × HC			0.000 (0.067)		
GERD				0.001 (0.008)	
ManuDev × GERD				0.026 (0.041)	
ManuDev × Hungary					0.094 (0.367)
ln GDPpc		0.080*** (0.025)	0.076*** (0.024)	0.110*** (0.031)	0.081*** (0.025)
ln Pop		0.851*** (0.128)	0.784*** (0.128)	0.771*** (0.141)	0.852*** (0.129)
ln Dens		0.270*** (0.057)	0.271*** (0.067)	0.321*** (0.082)	0.270*** (0.057)
Unemp		-0.01170*** (0.00070)	-0.01153*** (0.00069)	-0.01214*** (0.00070)	-0.01170*** (0.00070)
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Region fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	2,357	2,281	2,277	1,528	2,281
Regions (NUTS2)	240	232	232	218	232

Notes: Coefficients reported with standard errors in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.10.
Source: Own construction.

4.2. Wage upgrading outcomes

Wage upgrading is proxied by compensation per employee, expressed in logarithms (ln_wage). All specifications follow the two-way fixed effects framework with region and year fixed effects, and standard errors clustered at the NUTS2 level. Results are reported in Table 4.

Table 2. Wage outcomes and regional manufacturing development intensity

Variables	(1) Baseline FE	(2) + Controls	(3) + HC interaction	(4) + GERD interaction	(5) + Hungary interaction
ManuDev	0.632** (0.285)	0.212 (0.180)	0.205 (0.189)	0.114 (0.241)	0.201 (0.188)
HC			-0.087*** (0.025)		

ManuDev × HC			0.445*** (0.117)		
GERD				-0.066*** (0.024)	
ManuDev × GERD				0.318*** (0.120)	
ManuDev × Hungary					0.273 (0.456)
ln GDPpc		0.758*** (0.120)	0.749*** (0.121)	0.990*** (0.065)	0.759*** (0.120)
ln Pop		-0.534** (0.260)	-0.335 (0.288)	-0.050 (0.283)	-0.532** (0.261)
ln Dens		0.032 (0.170)	-0.013 (0.228)	0.054 (0.258)	0.030 (0.170)
Unemp		0.00923*** (0.00154)	0.00843*** (0.00152)	0.00778*** (0.00144)	0.00923*** (0.00154)
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Region fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	2,324	2,281	2,277	1,528	2,281
Regions (NUTS2)	234	232	232	218	232

Notes: Coefficients reported with standard errors in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.10.
Source: Own construction.

In the baseline model, ManuDev is positively and significantly associated with compensation per employee. In magnitude, a 0.10 increase in ManuDev is associated with approximately a 6.3% higher compensation per employee in the baseline model. This indicates that regions experiencing increases in regional manufacturing development intensity also tend to record stronger wage dynamics over time.

Once regional controls are included in Column (2), the ManuDev coefficient remains positive but becomes statistically insignificant. This attenuation suggests that part of the baseline wage association reflects broader regional development conditions rather than a uniform unconditional effect of manufacturing intensity alone.

The interaction specifications reveal a more differentiated pattern. In Column (3), the interaction term ManuDev × HC is positive and highly significant, indicating that the wage association of manufacturing development intensity is stronger in regions with higher human capital. However, the negative main coefficient of HC should be interpreted cautiously, as it is estimated in an interaction specification with region and year fixed effects. In this setting, the substantive interpretation should focus on the interaction term, which indicates that the ManuDev–wage association becomes stronger in regions with higher human capital. In Column (4), the interaction ManuDev × GERD is also positive and significant, suggesting that regions with stronger R&D effort obtain larger compensation gains from increases in ManuDev. These findings are consistent with an absorptive-capacity mechanism, according to which innovation-capable regions are better able to translate industrial expansion into higher wages.

To visualise the interaction effect, Figure 2 plots the marginal effect of regional manufacturing development intensity on regional compensation across the observed range of human capital. The figure shows that the wage association of ManuDev strengthens monotonically with human capital and becomes clearly positive in more human-capital-rich regions.

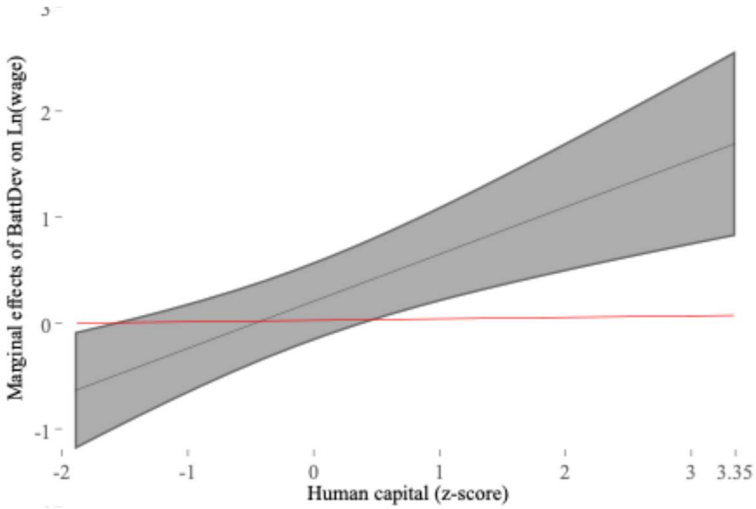

Figure 2. Marginal effect of ManuDev on ln(wage) across EU regional human capital (2013–2022)

Notes: The figure reports average marginal effects of ManuDev on ln(wage) estimated from the two-way fixed effects model with controls and year fixed effects (Table 4, human-capital interaction specification). Shaded areas denote 95% confidence intervals; the horizontal dashed line marks zero effect.

Source: Own construction.

The Hungary interaction reported in Column (5) is positive but statistically insignificant, indicating that the wage relationship between ManuDev and compensation does not differ systematically between Hungarian regions and the broader EU benchmark.

Overall, the wage results provide clearer evidence of upgrading than the employment results. While the unconditional association weakens after controls are included, both human capital and R&D significantly strengthen the ManuDev–wage relationship. This suggests that compensation gains from manufacturing development intensity are more pronounced in innovation-capable regions.

4.3. Skill composition outcomes

Skill composition is measured by the share of tertiary-educated employed persons (ISCED 5–8) in total employment at the NUTS2 level. All models include region and year fixed effects, and standard errors are clustered at the NUTS2 level. Results are reported in Table 5.

Table 3. Skill-composition outcomes and regional manufacturing development intensity

Variables	(1) Baseline FE	(2) + Controls	(3) + GERD interaction	(4) + Hungary interaction
ManuDev	-0.292*** (0.044)	-0.267*** (0.040)	-0.211*** (0.046)	-0.257*** (0.040)
GERD			0.015** (0.006)	
ManuDev × GERD			-0.074** (0.032)	
ManuDev × Hungary				-0.233 (0.260)

ln GDPpc		0.011 (0.010)	0.013 (0.012)	0.011 (0.010)
ln Pop		0.308*** (0.059)	0.276*** (0.062)	0.306*** (0.059)
ln Dens		-0.060 (0.051)	-0.011 (0.054)	-0.058 (0.052)
Unemp		-0.000992*** (0.000324)	-0.001075*** (0.000320)	-0.000996*** (0.000324)
Year fixed effects	Yes	Yes	Yes	Yes
Region fixed effects	Yes	Yes	Yes	Yes
Observations	2,353	2,277	1,528	2,277
Regions (NUTS2)	240	232	218	232

Notes: Coefficients reported with standard errors in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.10.

Source: Own construction.

In the baseline specification, ManuDev is negatively and significantly associated with the tertiary employment share. This indicates that increases in manufacturing development intensity are accompanied by a decline in the regional share of tertiary-educated employment. After controlling for regional economic and demographic conditions in Column (2), the coefficient remains negative and highly significant, suggesting that the result is not mainly driven by contemporaneous co-movement with income, population, density, or labour-market slack.

To examine whether innovation capacity conditions this relationship, Column (3) introduces an interaction with GERD. The coefficient on ManuDev remains significantly negative, while GERD itself is positively associated with the tertiary employment share. However, the interaction ManuDev × GERD is negative and significant, implying that the negative association between manufacturing intensity and the tertiary employment share becomes more pronounced in more R&D-intensive regions.

A plausible interpretation is compositional. Regions with stronger innovation capacity may still experience manufacturing expansion through production-oriented job creation, which increases total employment faster than tertiary-intensive employment and thereby lowers the tertiary share. In this sense, wage upgrading and tertiary-share upgrading do not necessarily move together.

The Hungary interaction in Column (4) is statistically insignificant. Thus, although Hungary exhibits higher average manufacturing development intensity, the within-region relationship between changes in ManuDev and changes in skill composition does not differ significantly from the broader EU benchmark.

To sum up, the skill results contrast with the wage findings. ManuDev is consistently associated with a lower tertiary employment share, suggesting that manufacturing expansion is linked more closely to production-oriented employment growth than to a systematic increase in the tertiary employment share. The negative GERD interaction further indicates that this compositional pattern can persist even in innovation-oriented regions.

5. Discussion

5.1. Uneven patterns of regional upgrading

The results point to a differentiated pattern of regional socioeconomic associations linked to manufacturing development intensity in the context of Hungary's battery-industry expansion. There is little evidence of a robust regional employment dividend. Although the baseline employment specification shows a negative and significant association between ManuDev and

total employment, this relationship weakens after regional controls are included and becomes statistically indistinguishable from zero in the extended models. This suggests that rising manufacturing intensity is better interpreted as part of structural reallocation and increasingly capital-intensive production than as a source of broad-based net job creation.

Wage upgrading emerges more clearly than employment expansion. ManuDev is positively associated with compensation per employee in the baseline model, and the broader pattern suggests that manufacturing deepening is linked to stronger income dynamics. However, the tertiary employment share does not increase in parallel. Instead, ManuDev is consistently associated with a lower tertiary employment share, indicating that manufacturing expansion is more closely linked to production-oriented employment growth than to a systematic increase in tertiary-intensive employment. Thus, upgrading in the context of Hungary's battery-industry expansion appears partial and multidimensional, with compensation effects more visible than employment expansion or increases in the tertiary employment share.

5.2. Innovation capacity and interpretation limits

Innovation capacity mainly conditions wage outcomes. The positive interaction terms between ManuDev and both human capital and GERD suggest that regions with stronger innovation-related capabilities are better able to translate manufacturing expansion into compensation gains. This supports the absorptive-capacity argument: where skill endowments and innovation effort are stronger, industrial deepening is more likely to be associated with higher-value tasks, productivity gains, and improved wage-setting conditions (Rodríguez-Pose & Crescenzi, 2008; Grillitsch & Nilsson, 2015).

At the same time, the results should be interpreted cautiously. ManuDev captures regional manufacturing employment intensity rather than battery-specific employment or investment. The estimated associations therefore cannot be read as direct evidence of the socioeconomic effects of the battery sector alone. Instead, they show how manufacturing deepening during a period of battery-related industrial transformation is linked to regional employment, wage, and skill-composition outcomes. This distinction is important because manufacturing employment may also reflect automotive, electronics, machinery, and supplier activities.

6. Conclusion

This paper examined the association between regional manufacturing development intensity and socioeconomic outcomes in Hungary in the context of the country's battery-industry expansion, based on the EU27 NUTS2 regional panel over the period 2013–2022. Using a two-way fixed effects framework, it analysed how within-region changes in manufacturing intensity are associated with employment, compensation per employee, and the tertiary employment share, and whether these relationships vary with regional innovation capacity.

The findings reveal uneven regional socioeconomic outcomes. ManuDev is not robustly associated with employment expansion, while wage upgrading is more visible, especially in regions with stronger human capital and R&D effort. By contrast, increases in manufacturing intensity are associated with a lower tertiary employment share, suggesting that industrial expansion is linked more strongly to production-oriented employment growth than to a systematic increase in tertiary-intensive employment.

The policy implication is that manufacturing development in the context of battery-industry expansion should not be treated as an automatic mechanism of inclusive regional upgrading. Policies should go beyond investment attraction and strengthen local skill formation, R&D capacity, supplier linkages, and cooperation between foreign investors, domestic firms, and regional institutions. Without such complementary measures, the benefits may remain uneven and concentrated in wage dynamics or production-oriented activities.

The paper has several limitations. ManuDev is based on the manufacturing employment share and does not directly measure battery-specific employment, investment, output, or plant-level activity; therefore, the findings should be interpreted as associations during Hungary's battery-related

manufacturing transformation rather than as isolated effects of battery-sector expansion. The use of aggregate NUTS2 indicators may also mask sectoral, firm-level, occupational, and worker-level differences, while limited regional R&D data reduce the effective sample size in some interaction models. Future research should use plant-level battery-specific data and case studies of major sites such as Göd and Debrecen, possibly combined with event-study designs around investment announcements or production start dates.

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Adrienn Bokányi[15]

Land-Use Transformation and the Prospects of Spatial Knowledge Concentration: The Case of the Northern Industrial Area of Szombathely

The use of space has changed over time, revealing not only physical characteristics but also ideologies, narratives, and economic and political interests. As a result, spaces go beyond their practical functions to serve as symbols of struggle, power, or visibility, often connected to these broader forces. This paper reviews the spatial characteristics and changes in the land use of the so-called Northern Industrial Area of Szombathely City since the mid-1970s. It explores the area's characteristics, future development plans and their historical antecedents, while studying the spatial concentration of knowledge and its impacts beyond the industrial zone, extending to the city and the wider region. The study indicates that knowledge concentration requires high-quality training and economy-integrated higher education, active stakeholder cooperation, a critical mass of intellectual resources capable of generating and implementing innovation, and an adequate quality of life. It argues that the city's industrial structure must shift from labour-intensive to knowledge-intensive ecosystem through coordinated development efforts, which may improve economic robustness, strengthen regional positioning, raise profitability and competitiveness, and contribute to the creation of a resilient knowledge economy.
Keywords: spatial theory, land use, Szombathely, Northern Industrial Area, industrial park, technology park, knowledge concentration, knowledge economy
JEL codes: O18, R11, O31, R14, R58

https://doi.org/10.32976/stratfuz.2026.18

Introduction

This study shows a case analysis of the spatial characteristics and land-use transformations of the Northern Industrial Area of Szombathely City with County Rights, a county seat with a resident population of 76,918 as of 1 January 2025 (Hungarian Central Statistical Office, 2025), from the mid-1970s onwards. It explores the area's characteristics, future development plans, and their historical antecedents, rooted in the past and present, while analysing the spatial concentration of knowledge and its impacts beyond the industrial zone, extending to the city and the wider region. The paper reviews the most relevant literature, analyses the historical and current transformation of the Northern Industrial Area, and evaluates future development plans through the lens of spatial transformation, knowledge concentration, and regional resilience.

Research Question and Objectives

This paper studies whether the transformation of the Northern Industrial Area of Szombathely can be interpreted as a progression from a former military land-use regime towards a knowledge-oriented innovation environment. Particular attention is given to the role of planned Technology Park developments, research and innovation capacities, and institutional cooperation in supporting spatial knowledge concentration and regional economic resilience.
The study defines the following research question: To what extent can the ongoing transformation of the Northern Industrial Area contribute to the emergence of a knowledge-based economic ecosystem in Szombathely and its wider region?
To answer this question, the paper analyses the historical transformation of land use in the area, examines current development processes, and evaluates the relevant future strategic plans.

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Methodology

This study uses a qualitative case study approach to examine the spatial transformation of the Northern Industrial Area of Szombathely and its possible role in fostering spatial knowledge concentration. Following Yin (2018), case study research is particularly fitting for examining complex territorial development processes in their real-world contexts, especially when historical, institutional, and planning-related dimensions are closely intertwined.

The empirical analysis is based primarily on document analysis. The examined sources include local and regional development strategies, urban planning documents, municipal committee materials, resolutions and minutes of the General Assembly of the Municipality of Szombathely City with County Rights (Szombathely CCR), investor-oriented development materials, and relevant press publications. These sources provide information on the area's historical transformation, current status, and planned development.

The analysis follows a thematic approach. Particular attention is devoted to three dimensions: (1) the historical transformation of land use, (2) the institutional and infrastructural conditions of current development processes, and (3) the strategic initiatives intended at strengthening knowledge-intensive economic activities and regional resilience. The empirical findings are interpreted through concepts derived from spatial theory, knowledge concentration, regional innovation systems, and regional resilience literature.

The study has several limitations. It does not rely on primary empirical data collection such as interviews, surveys, or statistical modelling. Consequently, the analysis primarily focuses on institutional intentions, planning documents, and observable development processes rather than on measuring the actual economic impacts of the initiatives examined. The findings should therefore be interpreted as an exploratory assessment of an ongoing territorial transformation process.

Literature Review

The issue of spatiality and territoriality in contemporary social sciences – as Faragó (2018) explains in detail – goes beyond the classical geographical interpretation of space as a physical entity. Spatial transformation can be interpreted as a socially constructed process rather than a purely physical change in land use. According to Lefebvre (1991), space is continuously produced and reproduced through social practices, representations, and lived experiences. Building on this approach, Soja (1996) emphasises the interaction between material, conceived, and lived dimensions of space. From this perspective, the transformation of former military areas into economic development zones can be understood not solely as a physical conversion of land use, but also as a redefinition of the social and economic functions attached to space (Varga, 2024).

Thus, the use of space is not fixed by physical conditions. Instead, it can be seen as a social construct determined by ideologies, economic interests, and political strategies. Harvey (2001) and Massey (2005) note that space is a key arena of the capitalist mode of production, where power relations are continuously reproduced through the interweaving of global and local processes. As a result, spaces frequently serve as symbolic tools for economic competition, visibility, and social control.

The spatial concentration of knowledge has become a key factor in regional competitiveness and innovation in recent decades. Castells (1996) describes contemporary development processes using the concept of the "space of flows", stressing the importance of knowledge networks and information exchange. The Triple Helix model (Etzkowitz & Leydesdorff, 2000; Asheim & Gertler, 2005) further emphasises the role of cooperation among universities, industry, and government in generating innovation and promoting knowledge-intensive economic activities. Regional innovation systems and learning-region approaches similarly stress the importance of institutional cooperation, collective learning, and knowledge transfer in supporting long-term development (Morgan, 1997; Asheim & Gertler, 2005).

In this context, the spatial distribution of knowledge-intensive services also exhibits a highly concentrated pattern, determined primarily by network/institutional connections, accessibility, and the quality of innovation ecosystems (Szakálné Kanó, 2009). Clusters, science and innovation parks, and technology parks – as institutionalised forms of the knowledge-based economy – play a key role in these processes, as they are highly capable of facilitating knowledge flow, collective learning, and the strengthening of innovation capacities (Porter, 1998; Barta, 2002).
From a regional development perspective, knowledge concentration is closely linked to economic resilience. Regions characterised by related variety, meaning the coexistence of industries with complementary knowledge bases, are generally more capable of generating innovation and adapting to external shocks (Frenken et al., 2007). Boschma (2015) argues that regional resilience depends not only on economic diversity but also on regions' capacity to renew and transform their knowledge structures. Consequently, diversification towards knowledge-intensive sectors can contribute to greater economic robustness and adaptive capacity in the long term.
In addition to the above-mentioned approaches, the literature on regional innovation and knowledge spillovers stresses the importance of geographical proximity and localised learning processes. According to Jaffe et al. (1993), knowledge spillovers are spatially bounded phenomena, meaning that innovation activities tend to concentrate geographically due to the tacit nature of knowledge and the high importance of direct interpersonal interactions. This argument is further developed by Audretsch and Feldman (1996), who demonstrate that innovative activities are highly concentrated in areas where knowledge-producing institutions and businesses are located, thereby bringing out the role of agglomeration economies in supporting innovation.

Defining the Northern Industrial Area

The Northern Industrial Area represents a particularly relevant case for exploring the relationship between spatial transformation, knowledge concentration, and regional development. Over the past five decades, the area has undergone multiple functional transitions, including military, agricultural, recreational, and industrial uses. More recently, it has become the focus of strategic efforts to foster knowledge-intensive economic development through the establishment of a Technology Park and a planned Research, Development and Innovation (R&D&I) Centre.
The entire Northern Industrial Area covers nearly 672 hectares and sits on almost completely flat terrain bordered by the municipalities of Szombathely, Söpte, and Gencsapáti. Figure 1 illustrates the location and boundaries of the Northern Industrial Area within the administrative territory of Szombathely and neighbouring settlements.

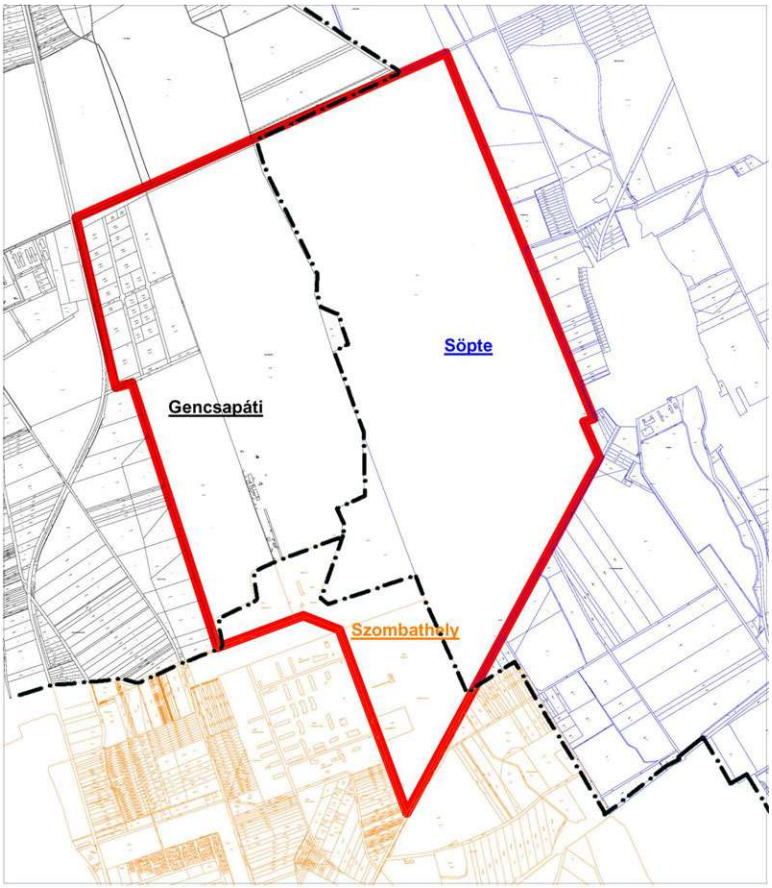

Figure 1: Action Area of the Northern Industrial Area
Source: Szombathely City's Urban Development Concept, Integrated Urban Development Strategy, Amendment No. 1 Consolidated into a Single Document (2017)

The area's large contiguous land reserve, flat topography, key location, and proximity to the urban core of Szombathely provide favourable conditions for industrial and innovation-oriented development. These characteristics help explain why the area has grown into a focal point of the city's long-term economic development strategy.

The Past of the Northern Industrial Area

Between 1975 and 1976, the Rudolf Garasin Barracks of the 15th Mechanised Infantry Regiment of the Hungarian People's Army were established in Szombathely as a greenfield investment. In addition to the barracks, the military complex included an 800-meter-long electrified shooting preparation track, a 100-meter-long shooting range, and a 1,500-meter-long, 800-meter-wide training area extending across the territory between Szombathely, Söpte, and Gencsapáti. After 1990, the military unit was renamed the Hungarian Defence Forces' 37th Savaria Mechanised Infantry Brigade, and the barracks were renamed Savaria Barracks, although their function remained unchanged. From 1 January 2000, the unit continued to operate as an independent military unit under the name Savaria Training Centre of the Hungarian Defence Forces until its

final dissolution on 31 December 2004. The area thus served as a military training ground from 1975 until 2004 (Jagadics, 2010).

As military activities involved mainly infantry training and vehicle manoeuvres rather than live-fire exercises, no significant contamination or hazardous residues remained after military use. After the closure of the training centre, the former Savaria Barracks was gradually converted into a penitentiary institution and has housed the Szombathely National Prison since 2008. The training grounds themselves, however, became largely unused, so the area between Söpte, Gencsapáti, and Szombathely remained undeveloped, with only scattered concrete surfaces serving as reminders of its former military function.

Recognising the key importance of the area, the Municipality of Szombathely began acquiring former military lands from the Hungarian State at an early stage. In 2000, the municipality purchased a 210,199 m² site in Söpte, formerly used as a military airfield, thereby securing the first substantial land reserve for future development and utilisation of the wider area.

Throughout the following decade, redevelopment progressed slowly. Ownership fragmentation, administrative boundaries, and the wider economic consequences of the global financial crisis delayed the implementation of industrial development plans. Although the establishment of an industrial park had been among the declared objectives of local development policy since 2007, the necessary institutional and territorial conditions for implementation were not yet in place.

During this transitional period, large parts of the area remained temporarily utilised for agricultural and recreational purposes. Livestock grazing became the dominant land use, while a smaller section was used for recreational activities, including paintball facilities. Consequently, the former military training ground underwent a temporary functional transformation towards agricultural and leisure uses. These activities represented an interim solution rather than a long-term development strategy, indicating limited investment resources and an unresolved territorial-administrative situation.

A decisive turning point occurred after 2020, when agreements were reached regarding the gradual transfer of additional land parcels into the administrative territory of Szombathely. This process created the prerequisites needed for coordinated development planning and utility infrastructure expansion. The phased territorial reorganisation enabled the municipality to begin preparing the area for large-scale economic development while simultaneously providing a compensation mechanism for the neighbouring municipality of Söpte.

Essentially, under a 2020 framework agreement, the area is being transferred to Szombathely's administrative jurisdiction in four phases, as shown in Figure 2. Following phase 1, each subsequent phase is initiated once at least 75% of the previous phase has been sold, or the Municipality of Szombathely has received a purchase offer that would affect the next phase(s). This arrangement enables Szombathely to finally begin utility infrastructure development in the area,[16]

[16] Based on the Proposal prepared for the meeting of the Committee Preparing for the Transfer of the Area (2021).

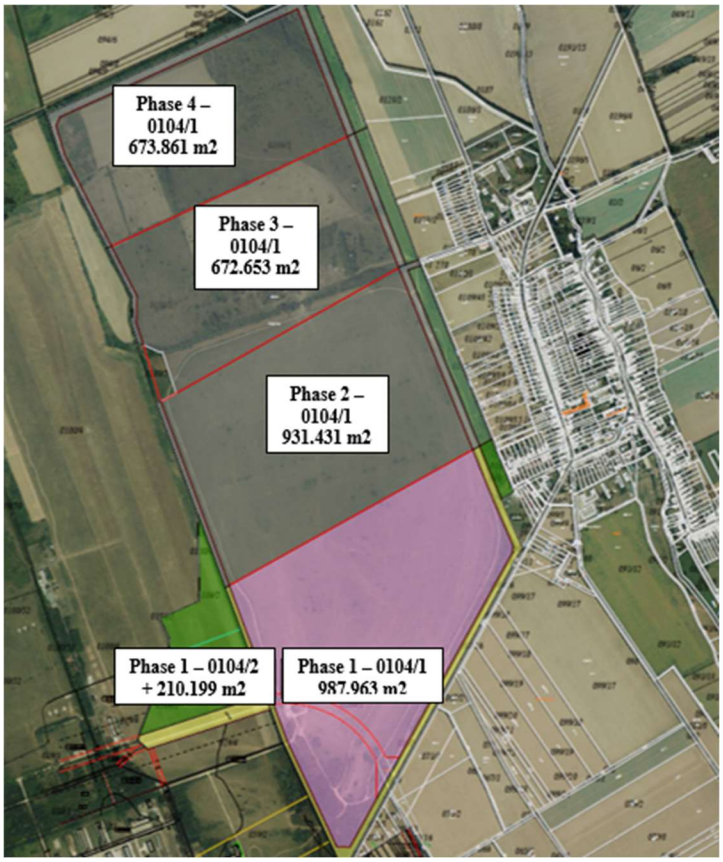

Figure 2: Schedule for the Transfer of Land

Source: Appendix to the Proposal prepared for the meeting of the Committee Preparing the Transfer of Land (2021)

The area also contains a small sports airfield and a waste-sorting facility. However, further developments will require major infrastructure investments and the construction of public utilities. As a first step, developments were carried out between 2016 and 2020 using European Union Territorial Operational Programme grant funds, but only within the administrative territory of Szombathely CCR. Therefore, the provision of public utilities to the areas recently transferred to Szombathely is an extremely important issue for the future.

Viewed through the lens of spatial transformation, the history of the Northern Industrial Area demonstrates how territorial functions can be repeatedly redefined in reaction to changing political, institutional, and economic priorities. The transition from a military training ground to agricultural and recreational uses, and subsequently to industrial and innovation-oriented development – as shown in Figure 3 – illustrates a long-term process of spatial reconfiguration rather than a simple change in land use. In this respect, the Northern Industrial Area demonstrates how formerly specialised military spaces can be integrated into broader urban and regional development strategies.

Figure 3: Functional evolution of the Northern Industrial Area since the mid-1970s Source: own compilation based on municipal development documents, land-use history, and the planned development path of the Northern Industrial Area

The Northern Industrial Area Today

The Northern Industrial Area is currently classified as an economic-industrial zone. It is entirely owned by the Municipality of Szombathely CCR, and the first phase of territorial transfer from Söpte has already been completed. However, more than 75% of the land transferred in the first phase has already been sold, and purchase offers have also been received for subsequent phases, which means that preparations for further land transfers are underway.

The first major successful investment in the area was the construction of Schaeffler Savaria Ltd's second manufacturing facility in Szombathely. The handover took place in September 2021. The new factory was built as a greenfield investment on 30 hectares, including a 15,000 m2 production hall and an e-mobility research and development centre, and created approximately 150 jobs.

In August 2021, Galambos Holding Ltd. from Vép purchased more than 14 hectares of land from Szombathely CCR to establish a multimodal logistics centre as a greenfield investment. As part of the investment, logistics warehouses with truck parking lots have been built, and according to plans, the site will also be connected to the industrial rail line to be constructed during the second phase of development. The 13.000 m² facility, completed in 2024, has become a major attraction for companies planning to invest in the Northern Industrial Area, as its complete logistics services can support businesses operating there.

In 2022, another logistics service provider, DOMINO Trans Ltd. from Viszák, acquired 7 hectares for another logistics facility. The 5,000 m² warehouse logistics centre, operational since 2025, offers state-of-the-art traditional and flexible storage and logistics solutions.

Infrastructure development – including road connections, railway access, and utility networks – is currently a top priority for the city leadership of Szombathely. Figure 4 shows that the M87 2x2-lane expressway heading toward Kőszeg/Vienna will pass directly alongside the industrial area. The expected completion date for construction is 2030, as is the case for the 2x1-lane Route 89 and the planned new interchange at their intersection, which will connect the Northern Industrial Area directly to the M86 expressway toward Győr and Budapest. The image also clearly shows the industrial railway line, for which a construction period of approximately 30 months should be anticipated, as well as the small electrical substation located in the lower-right corner of the area, from which the electrical supply to the plots can be established. Rainwater drainage is provided by the brooks Bogáca Stream and Kozárborzó, and the groundwater table in the area ranges from -3.5 to -5.0 meters.[17]

[17] Based on the non-public presentation prepared by the Municipality of Szombathely CCR for investors (2021).

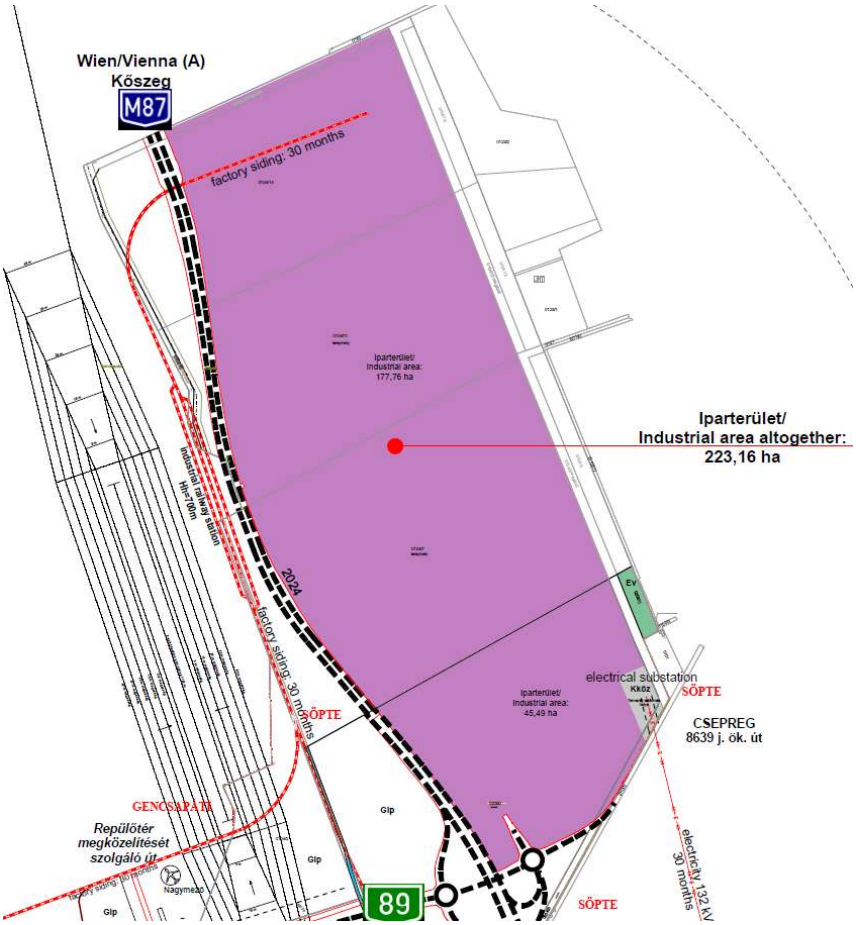

Figure 4: Planned infrastructure developments in the Northern Industrial Area

Source: own compilation based on the non-public presentation prepared by the Municipality of Szombathely CCR for investors (2021)

Access road
to the airport

Although the Northern Industrial Area cannot yet be considered a fully developed knowledge hub, several current developments indicate the emergence of knowledge-concentration processes, as shown in Table 1. The establishment of Schaeffler's highly automated production facility and e-mobility R&D centre represents a turn towards more knowledge-intensive industrial activities. At the same time, the Technology Park status and the preparation of an R&D&I Centre suggest an institutional effort to strengthen innovation capacities and facilitate cooperation among businesses, higher education institutions, and public actors.

Table 1: Key Development Projects Supporting the Transformation of the Northern Industrial Area (2021–2024)

Investment	Year	Function
Schaeffler Plant II + E-mobility R&D Centre	2021	Production + R&D
Galambos Logistics Centre	2021	Logistics
DOMINO Logistics Centre	2022	Logistics
Technology Park status	2024	Innovation infrastructure

Source: own compilation

From the perspective of the Triple Helix model (Etzkowitz & Leydesdorff, 2000), the area is gradually developing beyond a traditional industrial park. Current developments steadily integrate industrial production, research and development, higher education cooperation, and public-sector strategic planning. Although these interactions linger at an early stage, they provide the institutional foundations necessary for future knowledge concentration.
The ongoing diversification of economic activities is also relevant to regional resilience. The expansion of advanced manufacturing, logistics, and planned healthcare-related activities may help reduce the city's dependence on a single industrial sector and increase its adaptive capacity in the face of upcoming economic obstacles (Boschma, 2015; Frenken et al., 2007).
Recent developments indicate that the preconditions for knowledge concentration are gradually emerging in the area. While the area cannot yet be regarded as a fully developed knowledge-intensive innovation ecosystem, recent investments, planned institutional developments, and improving infrastructure indicate a gradual transition toward a more knowledge-oriented progression pathway.

The Potential Future of the Northern Industrial Area

The Municipality of Szombathely CCR applied for Science and Technology Park status for the Northern Industrial Area, together with the existing Claudius Industrial Park, initiating the preparatory phase in December 2020 with the explicit aim of establishing and sustaining a resilient knowledge economy in the long term. In the case of the Northern Industrial Area, the positive evaluation of the application simultaneously granted the Industrial Park status in a single step.
According to the 2016 report "Overview of Industrial Parks Operating in Hungary," a Science and Technology Park (STP) is a subtype of industrial park established primarily to promote the development of knowledge-intensive enterprises engaged in technological innovation and research and development.
However, Government Decree 799/2021 (XII. 28.) created two distinct categories by splitting the STP designation: Science and Innovation Parks (classical university-based science parks), eligible for application by universities, and Technology Parks (TP), that can be established by municipalities or municipally owned companies. The Northern Industrial Area obtained the TP status in 2024.
Barta (2002, p. 112) similarly characterises such formations – at the time still referred to as STPs – as "(…) enclosed or delimited spaces where offices, research institutes, laboratories and modern corporate buildings are concentrated in a high-quality environment." However, he additionally emphasises that an STP or TP can only be truly successful and fulfil its role in knowledge concentration within regional development if it does not operate in isolation or focus solely on its own profitability, but rather promotes the development of the prerequisites for collective learning in the region, and participates in this process itself.
Thus, the Northern Industrial Area represents a new development zone, which, according to the socio-economic programme of Szombathely adopted in 2020, could be driven forward by the Schaeffler investment in the same year, which has since become operational, and to the north of it, approximately 600 hectares of land are available for further development. A key objective of the city leadership is to attract companies operating outside the dominant automotive industry to settle alongside the major automotive manufacturers in Szombathely, whose knowledge-intensive activities could help diversify the city's industrial structure, thereby enhancing its economic stability and resilience.
The city's ten-year economic and urban development programme, "Szombathely2030 – Towards a Resilient Knowledge Economy" (Barta, Bokányi et al., 2021), goes a step further by explicitly stating that the dominance of large automotive manufacturers in the city has resulted in a single-pillar industrial structure, rendering the city's economy vulnerable. Its industrial structure is predominantly labour-intensive, making it highly exposed to processes of automation, digitalisation, and robotisation – i.e., industrial restructuring – as well as to the economic impacts

of the COVID-19 pandemic, which have even more accelerated this process. The Szombathely2030 programme was conceived precisely to respond to these challenges. It highlights, on the one hand, the cruciality of continuous, bidirectional communication with manufacturing companies to assess their needs, and, on the other hand, the need to provide high-quality R&D&I and educational support to facilitate their adaptation. This approach will enable the generation of high-quality, crisis-resistant jobs and allow knowledge-intensive elements to be integrated even into traditionally labour-intensive industries.

However, to improve the stability and knowledge intensity of the city's industry, diversification is critical, especially through the establishment of a strong second pillar to serve as a diversification sector. This role is assigned to the healthcare industry, based on the region's long-standing traditions of thermal baths and sports rehabilitation, the stable institutional system operating in the area, and its proximity to Austria, while also responding to European Union and national development priorities. To facilitate the settlement of healthcare industry manufacturers, it is necessary to provide a dedicated R&D&I and educational background focused on this sector, which has been incorporated into the relevant programme elements (Bokányi, 2021).

To realise these objectives, the planned key project of the Szombathely2030 is the establishment of a Research, Development, Innovation and Education Centre (R&D&I Centre) in the Northern Industrial Area. This project would serve as shared infrastructure and stimulate further development, meeting the knowledge-intensive demands of existing and future businesses. To ensure effective cooperation in the implementation phase, in September 2021, six organisations signed a cooperation agreement: the Municipality of Szombathely CCR, Eötvös Loránd University, the University of Pécs, Óbuda University, the Institute for Transportation Sciences, the Chamber of Commerce and Industry of Vas County, and the Pannon Business Network Association.

The institutional structure emerging around the proposed R&D&I Centre closely reflects the principles of the Triple Helix model (Etzkowitz & Leydesdorff, 2000). The planned cooperation among universities, public institutions, business actors, and intermediary organisations seeks to create an environment in which knowledge generation, knowledge transfer, and innovation can reinforce one another, as shown in Figure 5. It illustrates the planned institutional framework supporting knowledge concentration in the Northern Industrial Area. The proposed R&D&I Centre has a central position within the emerging network, linking higher education institutions, public actors, and private-sector organisations. In this respect, the Northern Industrial Area represents not only an industrial development project but also an attempt to establish a regional innovation ecosystem.

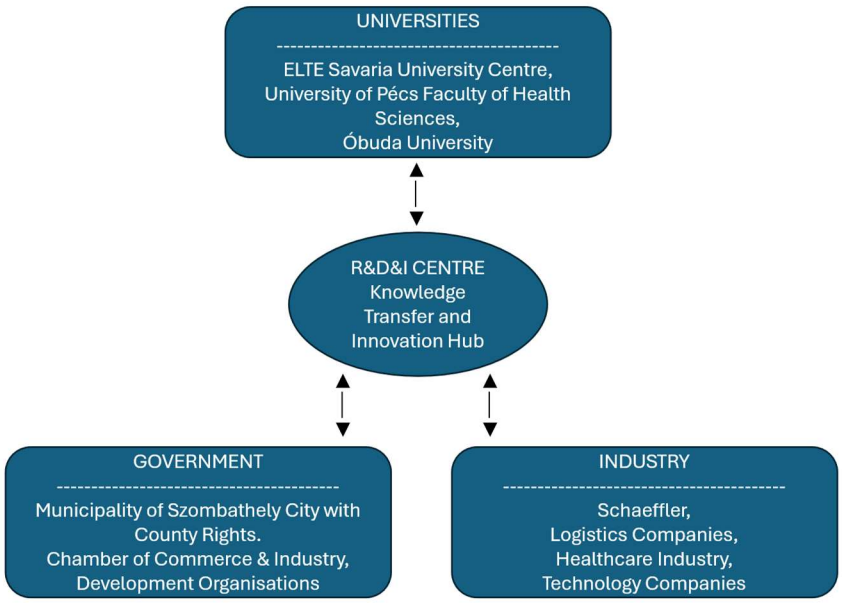

Figure 5: Conceptual model of the institutional framework supporting knowledge concentration in the Northern Industrial Area
Source: own compilation based on Etzkowitz and Leydesdorff's Triple Helix model and the planned R&D&I Centre partnership network

The participating universities contribute expertise in healthcare, digital technologies, advanced manufacturing, and workforce development, while creating a business-oriented educational environment and introducing programmes that offer dual Hungarian-foreign degrees.
The centre intends to place greater emphasis on R&D&I by establishing research and skills development labs, implementing applied research services, and creating a unique development, demonstration, and testing environment focused on the healthcare industry at the Central European level. The latter, focusing on complex rehabilitation, would integrate households, nursing homes, thermal baths, and virtual hospital infrastructure into a single, interconnected system. The project is planned to be implemented in multiple phases and is expected to provide shared infrastructure for research, training, and innovation-related activities.
The planned R&D&I Centre is expected to serve as a shared innovation infrastructure and may function as a driving force for further knowledge-intensive development. However, its long-term contribution to regional innovation performance will depend on the successful implementation of the project, the establishment of stable institutional partnerships, and the ability to attract both research-oriented companies and highly qualified human capital.
Current plans show a strategic effort to move beyond the traditional industrial park model towards a more knowledge-intensive development path. While many of the proposed initiatives remain in the planning phase, the institutional, infrastructural, and organisational foundations necessary for future knowledge concentration are gradually being established.

Conclusion

The analysis points out that the transformation of the Northern Industrial Area can be interpreted as a gradual transition from a military land-use regime to a knowledge-oriented development direction. Over the past five decades, the area has undergone several functional transformations, including military, agricultural, recreational, and industrial uses. More recently, the emergence of research and development activities, the acquisition of Technology Park status, and the planning

of an R&D&I Centre indicate a major shift towards knowledge-intensive economic development. All these major milestones are listed in Table 2.

Table 2: Major milestones in the development of the Northern Industrial Area

Year	Milestone
2000	First land acquisition
2007	Industrial Park concept
2009	Additional land acquisitions
2020	Framework agreement with Söpte
2021	Schaeffler Plant II + E-mobility R&D centre
2021	Galambos Logistics Centre
2022	DOMINO Logistics Centre
2024	Technology Park status
Planned	R&D&I Centre

Source: own compilation

Regarding the research question, the study shows that the ongoing transformation of the Northern Industrial Area could significantly contribute to the emergence of a knowledge-based economic ecosystem in Szombathely and the wider region. The contribution is currently indirect and preparatory rather than fully realised. While the establishment of a Technology Park, the planned R&D&I Centre, and the emerging network of institutional partnerships indicate a clear strategic direction, the long-term outcomes of these projects will depend on their successful implementation and the ability of local actors to sustain cooperation and attract knowledge-intensive activities.

From a spatial-theoretical perspective, the case illustrates how the functions attached to a specific territory can be continuously redefined through changing political, economic, and institutional priorities. The observed transformation supports the argument that space is not simply a physical container but a socially produced and continually reconstructed phenomenon (Lefebvre, 1991; Soja, 1996). The Northern Industrial Area, therefore, does not represent only a land-use transformation process but also an institutional and economic reconfiguration of territorial functions.

As Rechnitzer (2002) argues, industrial development can contribute to knowledge-based economic transformation only when it is embedded in a wider institutional environment characterised by higher education, innovation capacity, and active cooperation among economic and public actors. The case of the Northern Industrial Area supports this argument. The long-term success of the Technology Park and the planned R&D&I Centre will depend not only on physical investments but also on the ability of local stakeholders to maintain effective cooperation and generate synergies between industry, education, and innovation.

Current developments demonstrate the growing importance of institutional cooperation in supporting knowledge concentration. The planned cooperation among universities, businesses, public actors, and intermediary organisations reflects key elements of the Triple Helix model and the learning-region approach. Although a fully developed knowledge ecosystem has not yet emerged, the institutional foundations for future knowledge generation and transfer are gradually being established. This denotes a significant shift from the situation described by Szakálné Kanó (2009), when the Szombathely micro-region played only a marginal role in the spatial distribution of research and development activities in Hungary.

At the same time, the long-term success of the proposed development path cannot be taken for granted. International experience suggests that technology parks and innovation districts achieve sustainable outcomes only when infrastructure development is accompanied by continuous investment in human capital, research capacity, entrepreneurial activity, and institutional

cooperation. Consequently, the future performance of the Northern Industrial Area will depend not only on physical development projects but also on the ability of local and regional actors to attract and retain knowledge-intensive activities. Nevertheless, the case demonstrates how the coordinated transformation of a former military area can contribute to regional resilience, economic diversification, and the gradual emergence of a knowledge-based development path.

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The Stagnant Union: The Dual Division of Gulf Integration

The Persian Gulf region has gradually emerged from its peripheral position as a result of its rapid economic and political development. In line with the broader wave of regional integration that became a global trend during the second half of the twentieth century, the Gulf Cooperation Council (GCC) was established in 1981. The member states' shared historical, linguistic, religious, and ethnic characteristics, together with favorable economic prospects, created a unique set of conditions conducive to closer cooperation. Similar to the European Union, one of the GCC's principal objectives was the establishment of a highly integrated form of regional cooperation. In the decades following the signing of its founding charter, however, the Council faced both external and internal divisions, which significantly hindered the deepening of integration. The process of regional integration in the Gulf and the challenges accompanying it can be examined from several perspectives. One widely applicable and effective approach is chronological analysis, which follows the sequence of events over time. Another analytical framework focuses on decision-making processes, examining how individual decisions have shaped the dynamics of cooperation within the organization. This study centers on the key developments that have been most influential in shaping the evolution of Gulf integration, grouping these events according to different analytical criteria. Furthermore, the analysis adopts a comparative qualitative case study approach, highlighting the similarities and differences between Gulf regional cooperation and the European Union, which serves as the primary reference model.
Keywords: integration efforts, GCC, European Union, polarization
JEL-code: F02, O52, P16

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1.Integration of the Arabian Peninsula

The Gulf Cooperation Council (hereinafter GCC, Gulf, or Council) was established in 1981, two years after the Iranian Islamic Revolution. Its immediate precursor was the dialogue initiated in Jeddah in 1975 among the leaders of eight countries. In addition to the six countries that later formed the group, Iraq and Iran were among the participants. A year later, the dialogue continued in Muscat, with a focus on defense, security, and foreign policy. Subsequently, the 1979 Iranian Islamic Revolution, followed by the war with Iraq, led to the withdrawal of those two countries, thereby making military cooperation more urgent for the remaining six to avoid conflict. At the meeting held in Kuwait in 1981, the primary objectives were economic integration alongside the strengthening of collective security and military ties (Abdulla, 1999). The rushed pace resulted in the failure to establish the most critical institutional foundations during the negotiations, which later shaped the Gulf's overall functioning (Legrenzi, 2011). Deepened integration was hindered not only by the young nation-state status but also by territorial disputes predating independence and significant disparities in relative weight. The Gulf set ambitious goals aimed at achieving a level of integration comparable to that of the European Union (Alsowaidi, 2007). This justifies approaching the study's analysis of the Gulf's development through comparison with European integration.

At the moment of signing the founding charter in May 1981, the organization became the second subregional initiative in the Middle East (Worrall, 2021). By then, the broader-inclusion Arab League already existed, but the objectives differed; the young states of the Arabian Peninsula envisioned much closer cooperation. The signatories were Bahrain, the United Arab Emirates

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(hereinafter Emirates), Qatar, Kuwait, Oman, and Saudi Arabia. The countries aimed for strengthened and integrated relations based on Islam and historical identities. They expressed coordination in service of Arab nation goals. While emphasizing unity, each country insisted on preserving its own political role. The main decision-making body, the Secretariat, was not granted supranational powers; instead, the Supreme Council and the Ministerial Council became the primary responsible assemblies. Members could exercise veto rights against policies deemed unsuitable for them. They expressed the necessity of progressing toward unity and creating common rules (Gulf Cooperation Council, 1981).

Table 1: Chronological Milestones in the Development of the GCC

Year	Event	Significance
1975	Jeddah talks	Cooperation precursor
1976	Muscat talks	Security focus
1979	Iranian Revolution	Threat perception
1981	GCC founded	Formal integration
1981	Founding charter	Sovereignty preserved

Source: Author's own work.

The Council's developmental history has been examined from various perspectives, with both internal and external conflicts receiving significant attention. Turbulent regional events have recurrently posed challenges to the organization. Fault lines continually fluctuate, often with multiple influences acting simultaneously and reinforcing each other. This very dynamic provides the study's relevance, as deepening integration continually faces new or resurgent challenges. I present the obstructing factors grouped by category, highlighting the most important milestones in terms of integration progress. Since the initial goal-setting in the Gulf envisioned creating an organization similar to the European Union (hereinafter EU), comparing the two integrations sheds light on developmental shortcomings. This study examines the development of integration within the GCC through a comparative qualitative case study approach. It adopts a chronological perspective, highlighting the major turning points in the integration process while taking into account the most significant political, economic, and institutional factors that have directly or indirectly contributed to or hindered the deepening of regional integration. The European Union serves as the principal reference framework for the comparative analysis. In Bela Balassa's neoclassical framework, economic integrations were categorized into six stages in 1961: preferential trade area, free trade area, customs union, common market, economic union, and complete integration. The model is non-linear, allowing stages to be skipped, though this potentially poses risks to stability (Balassa, 1961). This model remains applicable in the 21st century, serving as a reference point when analyzing the unity of an international integration.

2.External Threats

It is expedient to commence the review of the Gulf's history by examining external factors. At the moment of the organization's establishment, the Iran-Iraq War was already underway, posing a grave security risk to the region, particularly during the tanker war phase beginning in 1984. Attacks on commercial vessels extended to regional countries supporting Iraq. Due to assaults on Kuwaiti and Saudi oil tankers, the United States intervened (Richer, 2024). Following the conflict's conclusion in 1988, the region remained calm for two years. In 1990, Saddam Hussein invaded Kuwait, and in early 1991, an international coalition led by the United States repelled the aggressor's Iraqi forces.

After the 2001 U.S. terrorist attacks, security pressures intensified in the Middle East, with American forces launching operations in both Afghanistan and Iraq. This exerted profound effects on the region's security approach. In the shadow of protracted wars, extremist ideologies gained

strength and proliferated following the 2011 Arab Spring. At that time, fears of regime change spread across the region, leading to a significant increase in defense spending amid the uncertainty (Dokos, 2019). Heightened threat perceptions fostered mutual distrust, which shaped the dynamics of foreign policy determination. In this context, cooperative coalitions were transient and interest-based (Soler i Lechna, 2017).

Table 2: Key External Pressures Affecting GCC Integration.

Period/Event	Key points	Significance
1980–1988	Iran–Iraq War; tanker war	Regional security shock
1990–1991	Kuwait invasion; U.S.-led coalition	Gulf vulnerability exposed
2001	9/11 attacks; U.S. wars in Afghanistan and Iraq	Heightened security pressure
2011	Arab Spring	Regime-change fears; defense spending
2010s	China's Belt and Road Initiative	Economic diversification; external balancing
2020	Abraham Accords	Uneven GCC responses
2023	Gaza war; Saudi-Iran rapprochement	Persistent rivalry; renewed polarization
2020s	Saudi-UAE tensions	Intra-GCC power competition

Source: Author's own work.

Beyond overt conflict situations, the pursuit of independent economic and foreign policy interests is equally telling. Individual countries, relying on their sovereignty, seek to bolster their external relations. An illustrative example is the deepening of economic ties with China. China's comprehensive geopolitical initiative in the 2010s (Belt and Road Initiative) encompasses this region, albeit unevenly (Kocsis et al., 2017). The great power pursued a modus vivendi with each regional state based on mutual benefits (Kovács, 2023). The GCC states exhibited no unity in the Abraham Accords; Bahrain and the Emirates established diplomatic-economic relations with Israel, while the remaining states adopted a cautious approach (Guzansky & Marshall, 2020). The initiative aimed to bolster regional stability through tension reduction and signaled that, within the Gulf, Iran is deemed the primary security threat over Israel. Following the signing of the agreements, further expansion—such as with Saudi Arabia—remained on the agenda. The topic receded from public discourse after the outbreak of the Gaza war in 2023, as Islamic societies firmly condemned the airstrikes on Palestinian territories. The previously marginalized Palestinian issue resurfaced, widening foreign policy fault lines among Gulf countries. That year, Saudi Arabia and Iran agreed to restore diplomatic relations, yielding modest results beyond the gesture. The two powers remain rivals, rendering the region a theater of mutual distrust and an arms race (Kovács, 2023). These processes have influenced the Council's operations, undermining its efficacy. A new chapter in power rivalry is marked by escalating geopolitical tensions between Saudi Arabia and the Emirates (Kabandula & Donelli, 2024).

3. Internal Disputes

The 20th century dramatically transformed the Arabian Peninsula, elevating it from the periphery of great powers to the center of global oil production. Nomadic tribes settled, and nation-state frameworks necessitated the delineation of borders. The discovery of oil fields enhanced the

significance of these borders, as each government sought maximum control over the peninsula to secure prospective oil reserves. By the time of the GCC's establishment, these disputes had largely been resolved, though border conflicts persisted to some extent. Lingering distrust from prior disagreements persisted, alongside an emphasis on sovereignty. By the 21st century, control over disputed territories resulted in minor border skirmishes, primarily addressed through diplomatic channels. Post-formation, tensions arose between Qatar and Saudi Arabia, Qatar and Bahrain, as well as Saudi Arabia and the Emirates (Okruhlik & Conge, 1999). Internal diplomatic disputes have accompanied the organization's existence throughout, with causes ranging from energy issues to security concerns.

In the early period, Qatar proposed a significant integration initiative in 1989 by outlining a gas pipeline plan among the Gulf countries. The initiative quickly failed, as Bahrain – strained by the dispute over the Hawar Islands – rejected the plan. Subsequently, Saudi Arabia also declined, citing its own production capacity, and denied permission for a pipeline to Kuwait. Between Qatar and the Emirates, the Dolphin pipeline became operational from 2008 (Dargin, 2008). Riyadh raised objections, arguing that permission should have been sought from its territory for the investment. Another energy project, the 2006 proposal for nuclear energy development within the framework of integration, also failed. Instead of a joint project, the Emirates announced its own development in 2008. The Barakah Nuclear Power Plant, after multiple delays, commenced operations in 2024 rather than the promised 2018 (Larsen et al., 2024). Saudi Arabia similarly announced its own project, with the other four member states contemplating independent implementations.

In 1995, the Qatari delegation protested against the Secretary-General by walking out of the GCC annual summit's closing session. The timing aligned with a bloodless coup in Doha that year, and the new emir adopted a markedly technocratic approach. The country envisioned an independent foreign policy to bolster its own capabilities. This shift was unfavorable to Saudi Arabia, escalating diplomatic tensions. In 1996, an unsuccessful coup attempt occurred in Qatar, with suspicions pointing to the influence of the neighboring kingdom (Kinninmont, 2019).

In 2014, three GCC governments deemed Qatar a threat to regional security, initiating a diplomatic dispute; Bahrain, Saudi Arabia, and the Emirates withdrew their ambassadors. Doha maintained its representation and sought dialogue. By the end of the year, at the GCC summit, agreement was reached to restore diplomatic relations (Hassan, 2015). The calm proved temporary: on June 5, 2017, several Arab countries abruptly severed ties, imposing an air, land, and sea blockade against Qatar. Bahrain, the Emirates, and Saudi Arabia from the Council joined, citing primarily Qatar's financing of terrorism, media messaging, relations with Iran, and the Turkish military base. Kuwait and Oman refrained from the isolation, instead acting as mediators. During the conflict, the GCC's institutional framework proved absent for mediating disputes among members. It failed to serve as a platform or assume a position-shaping role to influence events. Despite the blockade, the customary annual summit proceeded in December 2017 amid heated disputes (Ulrichsen, 2018). The tense diplomatic state and blockade persisted for approximately three and a half years. The situation concluded at the GCC's Saudi-hosted summit in Al-Ula in 2021, where parties signed an agreement to resolve diplomatic differences (Kabalan, 2021).

Table 3: Key Internal Disputes and Fragmentation within the GCC.

Period/Event	Key points	Significance
20th century	Border formation; oil discovery	Territorial disputes intensified
1989	Qatar gas pipeline proposal	First major failed integration project
1995	Qatar walkout at GCC summit	Diplomatic tension with Saudi Arabia

1996	Unsuccessful coup attempt in Qatar	Escalation of intra-GCC distrust
2006-2024	Nuclear energy initiatives	Parallel national projects; weak collective integration
2008	Dolphin pipeline begins operation	Selective bilateral energy cooperation
2014	Qatar diplomatic crisis	Ambassador withdrawal; temporary normalization
2017	Qatar blockade	Severe GCC fragmentation
2021	Al-Ula agreement	Blockade ends; partial reconciliation
2020s	Saudi-UAE rivalry	Hegemonic competition within GCC

Source: Author's own work.

Intra-organizational disputes gained a new chapter in the 2020s, as power struggles between Saudi Arabia and the Emirates intensified. The two largest economies have long been geopolitical rivals. According to Ulrichsen (2018), their relationship fundamentally determines the integration's future due to their sheer weight. Together, they account for nearly 76 percent of the Council's population (Saudi Arabia 57.3 percent, Emirates 18.3 percent) (De Bel-Air, 2025) and 77.5 percent of its economy (AGBI, 2025). This preponderance within the six-member Council results in perpetual rivalry for hegemony. For smaller states, this translates into sovereignty disputes. Conflicts among members undoubtedly hinder the organization's smooth functioning. Rivalry has impacted integration success, prioritizing individual interests over collective ones. Al-Hamadi (2020) argues that to counter internal Gulf oppression, smaller states seek external political-security ties that reinforce their sovereignty.

4. Stuttering Integration

The Council's primary economic integration goal at its establishment was achieving a monetary union. The development history of monetary unity and a common currency provides a diagnostic snapshot of issues surrounding the Council's cohesion. Upon independence, Gulf countries introduced independent national currencies, pegging their exchange rates to stable international currencies – de facto the U.S. dollar – in the 1970s. Within the GCC, discussions on introducing a common currency began in 2003, targeting 2010 as the deadline. At that time, the organization met basic criteria, including size, proximity, trade structure, and inflation performance (Berengaut & Elborgh-Woytek, 2006). Internal disputes stalled the process: Oman objected to the public debt limit, while the Emirates contested Saudi dominance in the proposed regional central bank, preferring Abu Dhabi as its headquarters. The former withdrew in 2006, the latter in 2009. In 2003, all countries except Kuwait formally pegged their currencies to the U.S. dollar. Five convergence criteria were established, though not as accession conditions. Parties met most by 2008. Institutional building and harmonization continually slipped (Khan, 2010). The Gulf Monetary Council (GMCO) was established in Riyadh in 2010, a year late, tasked with coordinating economic policies, harmonizing financial regulations—yet only modest progress occurred. In 2011, Arab Spring discontent waves sparked regional demonstrations; to mitigate impacts, countries adopted divergent strategies. The absence of collective steps highlighted divisions, prompting Saudi Arabia to propose deeper union, to be discussed at the Kuwaiti Gulf summit. Oman's leadership signaled non-participation, effectively torpedoing the initiative (Arab News, 2013). In 2014, Kuwaiti Finance Minister Anas al-Saleh urged reviving the monetary union

and sought to persuade withdrawn Oman and the Emirates to rejoin (Khan, 2014). Pinto (2018) identifies resistance to oil price shocks as the key rationale for deeper integration. From June 2014, oil prices plummeted from $115, posing severe fiscal challenges for oil-export-dependent states. Estimates indicate cumulative deficits exceeding hundreds of billions of dollars in budgets, current accounts, reserves, and sovereign funds across regional countries by 2018. Market conditions forced Bahrain and Oman to seek financial aid to defend their pegs; Saudi Arabia and Qatar faced difficulties too (Husain, 2015). Arguments for monetary union include stronger fiscal oversight, institutional frameworks, and intra-regional trade. These are less critical in economic models reliant on European and Asian exports, where intra-Gulf trade remains marginal (Kateb, 2024). By early 2026, introducing the common currency khaleeji has failed, and the Gulf no longer prioritizes it, signaling the goal's collapse. A minor advance: parties agreed to a unified visa system's pilot phase from 2026, dubbed a "Schengen-style visa," allowing foreign visitors access to all six states without separate paperwork per country.

A hallmark of phased integration progress is the unified railway, whose plan was approved at the Gulf's 2003 summit. Project challenges are evident in transport ministers' 2009 and 2023 calls for acceleration. Interim financing and diplomatic hurdles impeded advancement (Noureddine, 2024). Members re-approved the budget and timeline, targeting network completion by 2030. Its first segment between the Emirates and Oman launched in 2024, with joint country enterprises participating (Royal Decree No. 41/2023). The full 2,117 km network interconnects all members, estimated at $15 billion (Qatar News Agency, 2023). A key feature: states retain sovereign decision-making over lines on their territory, sometimes via binational solutions. The GCC Railway Company handles coordination, standards enforcement, and unified technical specifications. Progress serves national interests in infrastructure upgrades while cross-border lines deepen integration (Noureddine, 2024).

In 2016, the GCC resolved to uniformly introduce value-added tax (VAT) across member states, setting a 5 percent minimum – though countries may apply higher rates. The Emirates, Saudi Arabia, Bahrain, and Oman implemented from 2018; Bahrain and Saudi Arabia exceeded the minimum (raising to 10 and 15 percent in phases). Despite the decision, as of early 2026, Qatar has not introduced VAT though planning it, and Kuwait shows no prospects (GCC Accounting, 2025). No strict deadline was set, so non-implementation incurs no sanctions. Divergences create trade price inequalities. Gulf leadership bodies exert ongoing pressure via recommendations, exemplars, and economic diversification needs.

From January 1, 2003, parties introduced the common external tariff at 5 percent, achieving full harmonization only in 2015. Significant advances occurred in regulatory domains; the Gulf Standardization Organization is deemed the body's most effective unit. Industrial and economic coordination encompasses free labor and capital mobility. The common market emerged in 2008 but qualifies as a modest success due to segmentation limiting intra-trade. The Economic and Development Affairs Committee formed in 2016 to advance regional economic-financial stability and develop common frameworks.

At the Gulf's December 2025 session, numerous unity-supporting decisions were made. In 2026, the inaugural "Made in the Gulf" conference will showcase local industrial achievements. A Civil Aviation Authority will be established, alongside railway linkage details. Citizens gain property ownership facilitations (Gulf Cooperation Council, 2025).

Table 4: Integration Performance across Core GCC Policy Areas.

Period/Event	Key points	Significance
2003	Common currency talks; common external tariff	Deep economic integration agenda
2008	Common market launched	Partial success
2010	Gulf Monetary Council established	Institutional coordination
2014	Oil price collapse; monetary union revival failed	Fiscal pressure, setback
2016	VAT coordination; Economic Committee	Economic harmonization
2024	Railway first segment opens	Infrastructure integration
2026	Common currency collapses; U.S.–Iran war	Security shock; selective integration

Source: Author's own work.

The war that broke out in February 2026 between the United States and Israel on one side and Iran on the other may bring about fundamental changes to the achievements of Gulf cooperation and integration attained thus far. The military conflict has affected all member states of the Gulf Cooperation Council (GCC), both through direct attacks and through severe economic and political consequences. Although the conflict had not yet concluded at the time of writing, its likely implications can already be identified.

- The disruption of the regional security balance may increase the importance of defence investments and security cooperation. The GCC member states may become more inclined to pursue deeper integration with one another, thereby further strengthening institutionalized interconnectedness.
- From an economic perspective, greater emphasis may be placed on accelerating the achievement of diversification objectives. A potential closure of the Strait of Hormuz would affect one of the region's most vulnerable strategic chokepoints, prompting governments to reduce this dependency through economic restructuring and the development of alternative transportation and trade routes. This, in turn, could systematically strengthen regional cooperation and integration, particularly in the fields of logistics, infrastructure, and transport connectivity.
- Politically, the emergence of a common threat may foster temporary cohesion among the Gulf states. However, differing conceptions of regional roles and strategic priorities mean that their interests do not necessarily coincide. Consequently, individual states may adopt different approaches to peace processes and crisis management. These divergent national priorities may therefore also constitute constraints on deeper regional integration.

Overall, it can be concluded that, following the U.S.–Iran war, the Gulf states may be compelled to strengthen cooperation in certain areas, while the persistence of fundamental political fault lines is likely. As a result, the conflict is more likely to promote selective and partial deepening of regional integration than comprehensive integration.

5. The Role Model: European Union

It is worthwhile to briefly address the European Union, regarded as one of the Gulf's successful precursors. A cornerstone of the EU and its predecessors' success lies in the evolving integration objectives, to which member states remained open and adaptive. In the 1950s, continental security

was the primary concern, thus initially focusing on peace, stability, and reducing regional rivalries. Subsequently, establishing the single market—with free movement of goods, labor, services, and capital, alongside tariff-free trade—shifted priorities toward expansion and economic development. The EU advanced to economic union, lacking the final stage of complete integration. Elements of political union exist and function, rendering unity partial in this domain. The conflict-reduction approach increasingly tilted toward prosperity, accompanied by deepening integration. During this era, internal divisions and interest conflicts emerged as primary threats (Wæver, 1998). The organization's perspective shifted with the 2022 outbreak of the Ukraine war, re-elevating security concerns, with Russia as the principal threat. Wendt cited the EU as a prime example of collective identity formation, wherein individual states interpret the group as an extension of their own interests (Ruggie, 1993).

Numerous similarities and differences exist between the EU and the Council. Both were driven primarily by needs for security and stability at inception, envisioning deeper cooperation to mitigate intra-organizational rivalries. However, institutional frameworks, member states' openness to democracy, and interpretations of individual geopolitical interests exhibit marked divergences, accounting for disparities in integration depth. Both the EU and the Gulf confront external and internal tensions; alongside fears of fragmentation, external threats manifest differently. According to Rumelili (2004), a key to EU success resides in identity, emphasizing the downplaying of differences among member states. Another factor is the continuous review and, if necessary, revision of established systems (Kandrács, 2017). Equally vital is the integration's pursuit of reducing divergence and fostering cohesion (Szabó et al., 2025). This theme remains pertinent in the Arabian Peninsula's monarchies, where young nation-states labor to forge their identities. The Persian Gulf's unity challenges are underscored by the fact that, over more than 45 years since inception—despite opportunities—no expansion has occurred. Despite higher integration ambitions, a partial customs union was achieved, falling short of both original goals and EU-level integration.

Table 5: Comparative Overview of GCC and EU Integration.

Criteria	EU	GCC
Date of establishment	1957 (1951*)	1981
Number of Member States	27	6
Type of integration	Supranational, multi-level integration	Intergovernmental, state-to-state cooperation
Decision-making mechanism	Multiple network of institutions, including common institutions and involvement of Member States	Coordination among Member States, strong consensus-seeking approach
Key common policies	Single market and trade policy, environment and agriculture, economic, social and territorial cohesion, foreign and security policy (in certain areas)	More limited common policies; mainly economic coordination, regulatory harmonisation, customs and market integration
Level of intra-regional trade	Member State exports largely internal market-based: for most Member States between 50–80%	Mainly external markets: except for Bahrain, the level of intra-regional trade remains below 10%

Monetary union	Euro area, with 20 Member States	Was an objective, no common currency
Central bank	European Central Bank (ECB), the monetary authority of the euro area	Planned, not realised
Population (millions)	450.4	61.5
GDP	~€18 trillion	~€2.24 trillion
GDP per capita	~€40,000/capita, significant differences between Member States	~€36,500/capita, smaller dispersion among Member States
Area / Territory	4,101,000 km²	2,572,975.5 km²
*=Establishment of the European Coal and Steel Community, which is considered the direct predecessor of the Union		

Source: Author's own work.

Deeply integrated groups demand robust institutions, conflicting with the autocratic governance prevalent in monarchies. Leadership typically allocates key domains – interior affairs, defense and security, finance, and foreign policy – among ruling family members. This structure limits scope for international power-sharing and oversight, owing to fears of disrupting personalized arrangements. Hurrell (1995) posited that strong institutions offer no guarantee of an effectively functioning organization – a proposition partially applicable to the Gulf. A paradox arises: actors share cultural and historical foundations, with economic development and prospects ideally suited for deep integration. Despite this ideal foundation, autonomous considerations receive greater attention, enjoying higher priority.

The EU's principal decision-making bodies establish a legal order binding on member states. Key institutions include the Council, Parliament, Commission, and Court. Beyond heads of state/government and ministerial coordination levels exist elected legislative representation and executive organs. Complementary entities encompass a central bank, audit institution, and sectoral policy committees. In contrast, the Gulf has attained far lower institutionalization. Primary decision-making occurs via the Supreme Council, followed by the Ministerial Council and Secretariat. Additional committees oversee specific domains. Absent are a court, parliament, and central bank; decisions typically require unanimous voting. The latter implies veto rights for each member, rendering decisions feasible only with full consensus. In practice, this hampers decision-making and signals not a true union model but rather a coalition of sovereign states (Malkawi, 2019).

As the comparison presented in Table 5 demonstrates, the European Union has followed a longer and more highly institutionalized path of integration, particularly with regard to supranational decision-making. This comparison also highlights the most fundamental difference between the two integration processes. While the European Union has deepened internal integration through common legislation, regulatory implementation mechanisms, and legal harmonization, the GCC has remained predominantly characterized by the primacy of member state sovereignty. Consequently, the European Union can be regarded not only as a basis for comparison but also as a reference model. The success of the European integration project has largely been underpinned by a sustained willingness to reach political compromises, whereas such a commitment has been more limited and inconsistent among the Gulf monarchies. Therefore, the GCC should be understood not merely as a framework for regional cooperation but as a partially realized integration project that has achieved only limited success.

According to Balassa's stages of economic integration, there is a gap of several levels between the European Union and the Gulf. The EU has partially reached the highest stage of economic

integration, while the next step would be political integration. Although efforts have been made in this direction, the substantial differences in views among the member states mean that such a development does not appear feasible at present.

6. Conclusions

In its current state, the Gulf cannot fulfill the role originally envisioned for it, with the most severe cause being the absence of consensus among member states. Parties recurrently view each other as rivals rather than allies, consistently resulting in collisions. The prominent role of independent interest assertion impedes relinquishing national autonomy for regional integration benefits. Political differences prove insurmountable barriers within the organization's life; the Gulf constitutes an exceedingly fragile integration, retarding its deepening. Minor advances exist, yet these are of lesser significance – governmentally autonomous decisions exerting negligible impact on deepening integration. A recurring element is individual countries' fear of any party's excessive empowerment, overriding support for economic integration. Trade and customs interests, diversification needs, and institutional strengthening represent common goals; however, political and security policy considerations supersede them. Countries perceive that deeper integration – such as monetary union – with its robust, shared institutional frameworks would curtail independent decision-making capacities. Earlier opinions outright proclaimed the integration's total failure, though this holds only partially. The positive and negative factors affecting the integration of the GCC are summarized in Table 6. According to Ulrichsen (2018), the organization's true weakness manifests during threats and disputes, as primary decision-making bodies assume marginalized roles.

Factor	Impact
Common threat perception	Positive
Economic diversification	Positive
Infrastructure projects	Positive
Sovereignty concerns	Negative
Member-state rivalry	Negative
Institutional weakness	Negative
U.S.–Iran war	Uncertain

Table 6: Key Factors Shaping GCC Integration. Source: Author's own work.

Unresolved interest conflicts among the six Gulf member states preclude deepening, rendering decision-making efficacy questionable. Within this rivalry, the Emirates and Saudi Arabia's weight is preeminent; unity with other countries remains elusive in certain integration aspects. Significant advances occurred in industrial regulations and minor symbolic matters. Nevertheless, the organization proves incapable of effectively intervening as a mediator during internal and external disputes, thus failing one of its fundamental tasks. Persistent tensions among members suggest that, in coming years, progress toward regional unity will remain confined to smaller, less critical issues. The organization's history permits the assumption that, absent genuine resolution of acute inter-member tensions, higher-degree integration remains unattainable. The future of regional cooperation remains uncertain in light of ongoing regional tensions, while the U.S.–Iran war may bring about significant changes in the trajectory and depth of regional integration.

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Erika Zsuzsanna Madarász[19]

Sustainable Urban Logistics Planning in the V4 countries – A comparative analysis

While the number of studies on sustainable urban mobility—and logistics in particular—is growing, a comparative analysis of logistics planning in the V4 countries reveals a research gap. This study examines the attitudes toward sustainable logistics planning in the countries of the Visegrad Group. One of the key areas of urban development is urban logistics, which causes numerous negative environmental impacts. The innovations of the 21st century that are bringing about radical change — including the use of autonomous vehicles and technologies — contribute to its sustainable transformation. A comparative content analysis of relevant national and local planning documents revealed that the logistics planning practices of the V4 countries follow a similar trajectory. Although the integration of self-driving technologies into freight transport appears only sporadically in strategic documents, emission reduction and the promotion of intermodal solutions can be identified as a unified, consistent objective.
Keywords: urban logistics, logistics planning, self-driving, autonomous
JEL-Code: O18, R42

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Introduction

The planning of logistics processes is a key area of sustainable urban development (Kiba-Janiak, 2017; Witkowski & Kiba-Janiak, 2014). However, urban development planning documents typically focus on passenger transport (Behrends et al., 2008; Letnik et al., 2018), and local governments—lacking colleagues with the necessary know-how and logistical expertise—participate little or not at all in shaping urban freight transport processes (Lindholm, 2010). The European Union has formulated directives to support efficient, safe, and sustainable road transport and has set a target of reducing transport-related emissions by 90 percent by 2050. In the Czech Republic, Slovakia, and Poland, the contribution of road transport to air emissions increased between 2014 and 2023, while Hungary saw a slight decrease (EUROSTAT, 2026).

Modern urban freight transport systems must simultaneously adapt to the demand pressures arising from global urbanization and to shifting consumer preferences in the wake of the pandemic, while minimizing the negative externalities resulting from their operations, e.g. traffic congestion and traffic safety risks. Sustainable urban logistics models are needed to reduce current negative externalities (Taniguchi, 2014; Russo & Comi, 2012; Kiba-Janiak, 2017). Meanwhile, during the transition to autonomous vehicles, it is crucial to prepare for innovation and engage in strategic planning (Ayyildiz & Erdogan, 2024), yet international research today consistently finds that there is currently a huge gap between the theory and practical application of introducing autonomous technologies into urban logistics (Mills et al., 2021; Mohsen, 2024; Balázs-Kalász & Rostás, 2026).

There is a research gap regarding the comparison of urban logistics planning in the countries of the Visegrad Four Group, although, their similarities—such as their shared historical past and their similar cultural, economic, and social structures—provide a good basis for comparing them. In the V4 countries, the contribution of the transportation and warehousing sector to GDP has typically been higher than the EU average since the 2010s, ranging between 5% and 7% (KSH, 2022). In the V4 countries (and on average across the EU as well), approximately three-quarters

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of inland freight transport takes place by road. Over the past decade, the share of road freight transport has risen steadily in the Visegrad Group countries (*Figure 1*).

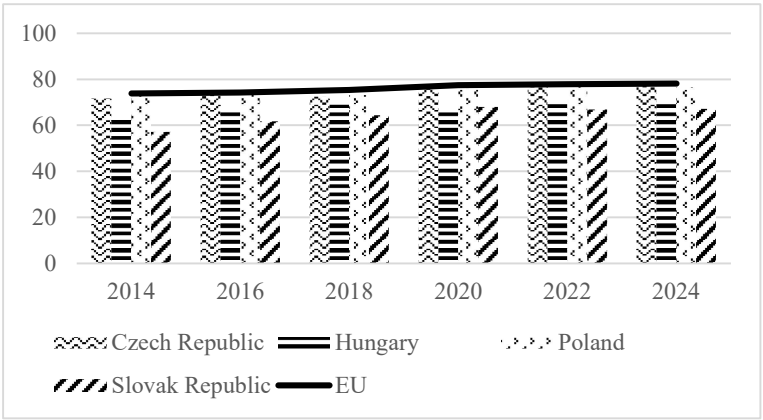

Figure 1. The share of road freight transport in total inland freight transport in the V4 countries (%)
Source: Compiled by the author based on Eurostat data

Literature review

Strategic planning documents for the urban logistics sector cover the flow of goods, services, and related information, and define objectives and associated tasks (Kiba-Janiak, 2019). Municipalities with long-term, strategic urban logistics plans participate more actively in shaping logistics processes than those without such plans (Bjørgen et al., 2022; Kiba-Janiak, 2017). At the supranational level, the EU initially placed emphasis on regions, but from the mid-90's the focus shifted to urban development (URBAN programs 1994–2006, Aalborg Charter 1994, URBACT program 2003, EUKN program 2004). The 2007 Leipzig Charter on Sustainable European Cities encompasses the key aspects of the integrated economic, social, and environmental development of cities and their surrounding areas. The document was updated in 2020 (New Leipzig Charter, EC, 2020), reaffirming the importance of the sustainable development of cities and functional urban areas and the resilience of cities (Barta, 2009). In line with its climate protection goals, the EU has established a legal and regulatory framework that also applies to the sustainable development of urban logistics. In the key strategic planning documents related to this (White Paper, 2011; 2030 Agenda, 2015), the common objectives are the use of renewable energy sources and new technologies, as well as making cities more livable. Subsequently, the EU introduced the framework for Sustainable Urban Mobility Plans (SUMP) (COM, 2013) and Sustainable Urban Logistics Plans (SULP) (EC, 2019) for Functional Urban Areas and mandated the preparation of a SUMP for every major EU city with a population of over 100,000 located along a TEN-T route. It also recommends that Member States designate a national SUMP contact point and establish a national SUMP program (EC, 2024). The SUMP and SULP concepts constitute a unified methodology aimed at supporting European cities in sustainable urban development. But despite the developed and adopted SUMP documents, cities are on different paths during the sustainable transition, and the implementation of the plan's provisions also varies by city. There is no universal model for future urban logistics that can be applied to every city; instead, different scenarios characterize each city and functional urban area (Toy et al., 2025).

The SULP methodology aligns with the SUMP methodology. The European Union's programs promoting SULP adaptation: ENCLOSE (2012–2014), NOVELOG (2015–2018), and SULPITER (2016–2019) were established to understand urban logistics problems and challenges and to facilitate effective, coordinated logistics planning. The SULPITER program supports

decision-makers in shaping a sustainable regulatory framework for logistics processes, improving efficiency and reducing costs, and sharing best practices.

One key means of achieving sustainable economic, social, and environmental goals is the development of innovative transportation systems (Moradi et al., 2025). One of the radical innovations of the fourth industrial revolution, also known as Industry 4.0, is autonomous vehicle technology, which is "so specialized and new that it cannot be compared to any other known urban innovation" (Lukovics et al., 2025, 6). The benefits of deploying self-driving vehicles in passenger and freight transport include *transportation benefits* (e.g. less congestion, reduced traffic, shorter transit times), *economic benefits* (lower costs for transport companies, increased efficiency), and *enhanced safety and environmental protection* (Milakis et al., 2017; Bucsky, 2018; Bagloee et al., 2016; Fagnant & Kockelmann, 2015; de Leo & Miragliotta, 2026). In their research, Yuan et al. (2026) modeled the route planning challenges of last-mile deliveries and concluded that the combined use of cargo bikes and autonomous robots reduces delivery costs by 32–46%, depending on the robots' speed. At the same time, the international literature identifies numerous challenges associated with the adoption of autonomous vehicles, and some studies even predict an increase in costs and delivery route lengths (Auld et al., 2017). One of the autonomous driving technologies in the road freight transport are the "platoons". The trucks connected in a "platoon" means that, only the lead truck has a driver; the rest are self-driving (Bhoopalam et al., 2018). Further solutions for autonomous urban road freight transport are the sidewalk robots or the full autonomous trucks (Rodrigue, 2024).

Methodology

The reviewed urban logistics planning literature forms the basis for the secondary research underlying the present study, which is a qualitative comparative document analysis of mobility and logistics planning documents at various levels in the Visegrad Group countries: Poland, the Czech Republic, Slovakia, and Hungary. The qualitative document analysis based on keywords is suitable for uncovering deeper connections and even identifying new directions during the analysis; however, its subjective nature may skew the results (Géring, 2014). The aim of comparative document analysis is to identify what urban logistics content appears in the national-level mobility plan documents of the V4 countries under study and in the SUMP plan documents of the V4 capitals. The list of keywords was determined deductively, based on a prior analysis of the international literature (Babbie, 2001). Keywords are linguistic elements that provide information about the content of a text (Berend et al., 2013). The following 10 keywords and their word stems were used for analysis: logistics; urban; city; freight transport; transport; cargo transport; road; smart city; autonomous; self-driving.

V4 countries' shared historical past and similar cultural, economic, and social structures provide a smooth foundation for comparing the urban logistics aspects of their national-level planning documents and for conducting a comparative analysis of the SUMP and SULP documents of the V4 capitals. Of the capitals of the V4 countries, Budapest is the only one to have a Sustainable Urban Logistics Plan. Consequently, in the absence of such a plan, the SUMP documents for Warsaw, Prague, and Bratislava, and the SULP document for Budapest, were examined. Key factors determining the state of urban logistics planning are the involvement of the decision-making in shaping urban freight transport processes and the nature of sector-specific measures, such as the existence, method, and frequency of data collection, or the presence of urban freight transport in strategic documents (Lindholm, 2010; Letnik et al., 2018; Cowie & Fisken, 2023).

Sustainable Urban Logistics Planning in the Visegrád Group Countries

An Analysis of National-Level Planning Documents included urban logistics content in the V4 Countries

The analyzed documents establish strategic pathways for future logistics, offering crucial directives for optimizing freight movement in V4 countries.

The Transport Policy of the Czech Republic (2021) encompasses several sustainable transport strategies. These include, among others, the Public Transport Strategy and the Freight Transport Strategy. The document includes a separate action plan for the introduction of autonomous driving technologies. The country is striving to take advantage of the opportunity for infrastructure developments to also incorporate the smart systems necessary for connecting transport networks. Autonomous driving technologies are characterized as a global trend. The Strategy for the Development of Intelligent Transport Systems (2020) focuses on the development of logistics hubs and infrastructure and encourages intermodal solutions. It notes that Intelligent Transport Systems are already available to logistics market stakeholders and that the state can influence them primarily through research and development, standardization, and legislation, while refraining from intervening in the operational management of freight transport. The use of alternative propulsion systems also receives special attention.

Hungary's Transport Development Concept (2024) sets out mobility objectives and related measures. It does not include a specific plan for freight transport, but it does contribute indirectly to the development of the logistics sector. The review of the National Transport Infrastructure Development Strategy (2014) began in December 2025, with the involvement of relevant stakeholders. The plan emphasizes the importance of infrastructure development, particularly in connection with the TEN-T network, and notes that data collection in the field of mobility is also crucial, as it provides a foundation for strategic planning. The Hungarian National Logistics Concept (2030–2035)[20] was completed by the end of 2025, which would make Hungary the logistics distribution hub of the Central and Eastern European region (the relevant planning documents of the Czech Republic and Slovakia also aim for the same). In line with EU directives, the new Hungarian national-level logistics planning document places great emphasis on the use of shared modes of transport and alternative energy, as well as the development of intermodal networks.

In Poland—as in the other V4 countries and the EU as a whole—great emphasis is placed on promoting intermodality and electromobility, as evidenced by logistics planning documents. Infrastructure developments are primarily linked to TEN-T corridors. The National Urban Policy (2022) supports sustainable urban mobility at the national level and assists Polish cities in adapting their SUMPs.

In its Strategic Mobility Development Plan (2016), Slovakia set out development paths for sustainable passenger and freight transport and improvements in the efficiency of road and rail transport by 2030 *(Table 1*).

[20] The full document is not yet available online. Source: Logistics Coordination Forum – Presentation of the National Logistics Concept 2030

Table 1. National-level planning documents in the V4 countries that partially address urban mobility and urban logistics

	Document name	Document type	Urban mobility components of the document
Czech Republic	Transport Policy of the Czech Republic 2021-2027 (with an outlook until 2050)	mobility plan document with some logistical content	sustainable passenger and freight transport; urban freight transport is less organized than passenger transport; urban freight transport is more polluting than passenger transport; the proportion of kilometers traveled with empty vehicles or carrying small loads is high in freight transport; Intelligent Transport Systems; preparing for autonomous technologies
	Action Plan for the Deployment of Intelligent Transport Systems (ITS) in the Czech Republic until 2020 (with the Prospect of 2050)	mobility plan document with some logistical content	transit country; development of logistics hubs; efficiency improvement; infrastructure development; promotion of intermodality; Intelligent Transport Systems
Hungary	Transport Development Concept 2023-2035	mobility plan document with some logistical content	developing a sustainable, efficient, and modern transportation system
	National Transport Infrastructure Development Strategy 2014-2019 (its review started in 2025	mobility plan document with some logistical content	supporting and integrating passenger and freight transport segments and modes that are more socially beneficial; improving the quality and efficiency of transport services; improving transport infrastructure
	National Development 2030 – National Development and Spatial Planning Concept 2014-2020	comprehensive development plan	comprehensive, long-term development objectives in line with the EU's development objectives
	National Logistics Concept 2030-2035	logistics plan document	rail, intermodal, and digital developments; Hungary as a Central European logistics hub; reducing greenhouse gas emissions; promoting renewable energy
Poland	Strategy for Sustainable Transport Development 2019-2030	mobility plan document with some logistical content	the need for a sustainable transportation system in Polish cities, the modernization of public transportation; promoting electromobility
	National Urban Policy 2022-2030	mobility plan document with some logistical content	focuses on the development of cities and FUA; mitigating negative externalities; encouraging the development of SUMP documents
Slovak Republic	Strategic Transport Development Plan of the Slovak Republic (Phase II.) 2016-2030	mobility plan document with some logistical content	improving the efficiency of road and rail transport; sustainable passenger and freight transport

Source: own compilation based on EC (2023) and document analysis

A comparison of the V4 countries' national-level planning documents on mobility, with a focus on logistics, has shown that the four countries currently are on a similar path in the field of

logistics planning. While each planning document includes urban logistics objectives, the focus remains on passenger transport. Yet, as the Czech Transport Policy document also points out: urban freight transport places an even greater burden on the environment than passenger transport, and while many measures have been taken in the latter area to reduce pollutant emissions, freight transport has been sidelined in this regard. The secondary research also revealed that Hungary, the Czech Republic, and Slovakia all envision their countries playing the role of a Central European logistics hub. The implementation of autonomous vehicles typically does not appear in the planning documents of the V4 countries examined.

A Comparative Analysis of the SUMP and SULP Planning Documents of the V4 Capitals

According to a study by Böhler, Huaylla and Felton, (2021), 68% of European cities—85 out of 125 municipalities surveyed—are aware of the European guidelines on sustainable urban logistics plans; awareness is higher among medium-sized and large cities. However, only 29% of the cities participating in the study collect data on urban logistics. At the same time, despite the unified EU framework, the quality of SUMP documents varies from city to city. Some cities have integrated the document into urban planning in a comprehensive, city-specific manner, while others have filled it with general content (Süle et al., 2026). An analysis of the V4 countries shows that, except of Slovakia, approximately 4–5% of cities in each country have adopted SUMP documents as part of an environmentally conscious mobility strategy.

In the Slovak Republic, only two cities have adopted a SUMP document: Bratislava and Košice. In the Czech Republic, every city with a population of over 40,000 has a SUMP document; in Hungary, 27 cities have one (*Figure 2*), and in Poland, 45 cities have one (EU, SUMP Database, 2025).

Figure 2. Hungarian cities with a SUMP document and the road routes of the TEN-T network in Hungary
Source: own compilation of the author

It should be noted, however, that since 2015, the existence of a SUMP document has been a prerequisite for accessing grants from the Cohesion Fund. Logistics planning is generally overshadowed within urban planning, and local governments typically have less experience in planning urban logistics processes than in planning passenger transport (Behrends et al., 2008; Dablanc, 2007; Paddeu, 2017; Kerwall et al., 2026). Consistent with this, in Hungary and Poland, only one city each (Budapest and Poznań) has a Sustainable Urban Logistics Plan, while in

Slovakia and the Czech Republic, no city has yet developed a SULP document (*Table 2*). At the same time, Hungarian cities with populations exceeding 100,000 typically have a low level of sustainable logistics planning (Madarász & Smahó, 2025).

Table 2. Number of cities in the V4 countries that have adopted SUMP and SULP documents

	Number of cities with a SUMP or a simplified SUMP	Percentage of cities with a SUMP or a simplified SUMP	Number of cities with a SULP document
Czech Republic	27	4,29%	0
Hungary	27	7,76%	1
Poland	45	4,98%	1
Slovak Republic	2	1,45%	0

Source: Compiled by the author based on the EU SUMP database (2025)

The SUMP document for the Polish capital (Warsaw SUMP, 2023) includes a section on urban logistics that is closely linked to the Polish sections of the TEN-T network. The plan emphasizes the importance of urban logistics planning for efficient, functional, and safe freight transport. Overall, it can be said that the regulation of new technologies related to freight transport is less prominent in Polish law, even though the technological revolution is a significant factor in the transformation of road freight transport. In Poland, one city has a Sustainable Urban Logistics Plan (Poznań SULP, 2019). The document addresses the logistical applications of self-driving vehicles and the need for related specialized infrastructure preparations, while also emphasizing that this technology is currently still in the testing phase in Europe. In preparation for autonomous urban freight transport, the document contains forward-looking plans. An electronically accessible loading bay management system for self-driving vehicles will make inner-city logistics more efficient and give city center spaces new functions. The online platform outlined in the plan improves the balance between supply and demand in urban logistics, allowing industry players to exchange information about needed shipments or their available capacity, thereby helping to optimize urban freight transport. The interactive map proposed in the plan document also effectively reduces emissions and costs by providing carriers with real-time traffic information to support route planning. The SULP document discusses in detail new autonomous logistics solutions, such as autonomous robots and small autonomous urban vehicles. The logistics document highlights the advantages of mini-hubs when combined with autonomous vehicles. The mini-hubs or micro-hubs are logistics facilities inside the urban area for consolidating the goods and allowing a shift mode to environmentally friendly transport modes, e.g. e-van or cargo bikes (Urban Freight Lab, 2020). Their financial advantage lies in reduced costs, as retailers need to maintain smaller inventories in expensive downtown rental spaces, since the proximity of the transfer centers allows them to receive ordered goods very flexibly and quickly during the last mile, and for a minimal fee, they can also arrange for order fulfillment or return logistics. The social benefit of this type of supply chain transformation is a better quality of urban life.

Prague's Sustainable Urban Mobility Plan (Praha SUMP, 2019) proposes, in the long term, the creation of a freight transport specialist position within local planning to make cooperation among stakeholders more effective and enable the municipality to fulfill its coordinating role more successfully. In line with EU objectives, the Czech urban mobility plan also encourages stakeholders in the sector to adopt intermodal and integrated logistics solutions; however, the issue of the logistics application of self-driving vehicles is not addressed.

Bratislava's Sustainable Urban Mobility Plan (SUMP) was established in 2020 for the entire Bratislava region (Bratislava SUMP, 2020). This plan does not focus on freight transport (nor is that its purpose), nor does it mention preparations for autonomous urban logistics, but it does

highlight the need for smart transport solutions and the importance of information and communication technologies.

The logistics plan for the Hungarian capital (Budapest SULP, 2018) also mentions the creation of a so-called Living Lab, where urban logistics systems and new technologies can be tested in real time. "In Living Labs, physical and financial spaces for experimentation are facilitated to introduce and test new governance approaches, technologies, or practices through interventions and experiments with the aim of purposefully re-shaping social and material realities towards sustainability solutions" (Yilmaz et al., 2026, 1). The logistics plan also includes important IT innovations, such as virtual consolidation centers (VCCs), a loading bay reservation system, smart poles, and real-time traffic information systems. VCCs are for IT-based consolidating the goods without physical presence of them, while a loading bay reservation system supports the stakeholders, above alle carriers prebooking slots for loading and unloading and avoiding long waiting times. Smart poles and real-time traffic information systems enable the real-time data sharing and therefore enhance the effectivity of urban transport. Like Poznań's sustainable logistics plan, Budapest's logistics plan also includes smart loading zones, which are available during designated time slots, even for small self-driving electric vehicles. Shared parking and loading zones are also intended to improve land use in the city center.

Based on the content of their SUMP and SULP documents, a similar attitude characterizes the municipal governments of the Visegrad Group capitals regarding urban logistics planning. The application of self-driving technologies in freight transport appears only sporadically; however, reducing emissions and promoting intermodality and e-solutions can be identified as common goals in all urban mobility planning documents. *Table 3* shows the main similarities and differences found regarding the logistics planning of the V4 counties.

Table 3. Main similarities and differences of logistics planning among the V4 countries

Similarities	**Differences**
- following the EU-framework	- level of the adoption of SUMPs
- enhancing the sustainability goals	- proportion of adopted SUMPs
- aiming reduction of emission	- level of document embedding
- use of IT-based solutions	
- targeting the use of e-vehicles or cargo-bikes	
- autonomous vehicles are just mentioned	

Source: own compilation of the author

Summary

A comparative analysis of national-level mobility and logistics planning documents within the Visegrad Group (V4) indicates a high degree of convergence in strategic planning paths. While integrated urban logistics objectives are present in the analyzed documentation, empirical findings suggest that passenger mobility remains the predominant focus, often sidelining the substantial environmental externalities associated with urban freight transport. The Czech Transport Policy exemplifies a recognition that urban freight logistics generate a higher relative burden on the environment than passenger mobility; however, targeted emission-reduction measures for freight remain underrepresented compared to passenger transport efforts. Secondary analysis highlights a shared strategic ambition among Hungary, the Czech Republic, and Slovakia to establish themselves as regional logistics hubs in Central Europe. Furthermore, the strategic adoption of autonomous vehicles (AVs) and self-driving technologies in freight transport is currently sporadic,

appearing infrequently in the formal planning documents of the V4 nations examined. Finally, evaluation of Sustainable Urban Mobility Plans (SUMP) and Sustainable Urban Logistics Plans (SULP) demonstrates that municipal governments in V4 capitals align with their national counterparts, exhibiting similar attitudes toward urban logistics. Notwithstanding the focus on passenger travel, the optimization of freight emissions, the promotion of intermodality and the use of electric vehicles as well as the enhancing of low-emission urban zones and introduction of smart loading bays are identified as common objectives across the urban mobility strategies of the Visegrad Group cities. A common characteristic in the logistics planning of the V4 countries is also the adaptation of the related EU-framework, although it is diversified by countries.

Regardless of the decision-making level or stakeholder involved, it is in everyone's common interest that the transition to sustainable (and autonomous) urban logistics take place in a way that maximizes the benefits and minimizes the drawbacks as much as possible. This requires a value-adding preparatory work supported by this research. A new approach is needed in urban logistics planning; local governments no longer play merely a regulatory role but are proactive participants in the ecosystem, and cities are involved in transforming urban logistics processes in line with sustainability and professional considerations. Preparing to embrace innovations reduces the risks associated with them and increases the chances of capitalizing on their potential, including in the field of urban logistics. Local governments would be well advised to proactively prepare for the implementation of new technologies in the urban logistics sector as well.

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***Dóra Szendi*[21]**

Smart city performance of the EU15 capitals, a comparative study

The urban population is growing steadily today, and smart cities are playing an increasingly important role across all continents. More international organizations and institutions are supporting the development of smart cities, and an increasing number of recommendations are being made for measuring their effectiveness. This study examines the capitals of the EU15 region in terms of their smart performance and ranks them accordingly. The assessment is conducted using a comprehensive smart city index, in line with the recommendations and pillars outlined in the international literature. The index evaluates the cities' performance across six components and identifies differences among them. The results suggest that there are disparities in urban indicators even within the region; like the European average, northern-southern and western-eastern differences can be observed. The Northern and Western cities perform consistently well across multiple components, while Southern cities lag due to economic and governance challenges.
Keywords: smart city, EU15 capitals, measurement, performance.
JEL code: R11

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Introduction

Urbanization is a critical challenge of nowadays. Urban population is increasing continuously in the world (in 2024, 58% of total population was living in cities by the Worldbank data) and expected to grow further. According to a 2025 UN report, more than 12,000 cities worldwide have populations of at least 50,000 (including 33 megacities with more than 10 million inhabitants) and the total number of urban citizens will be growing to the two third of the global population until 2050 (UN, 2025). In 2025, Tokyo was the most populated city with more than 37 million inhabitants, however until 2035 it is expected to change, as Delhi can overlap it with more than 43 million. This rapid urbanization has set several challenges for the cities (increased pollution, overcrowding, heat islands or traffic jams) which require novel solutions from the cities. Smart cities can be among the possible answers which use high-developed technological solutions with active citizen-participation models to tackle these problems. Since their emergence, more people have been trying to rank these smart cities researching which ones are the most successful and resilient for the external shocks (like the short and long term effects of COVID19 pandemics analysed by Szendi & Sárosi-Blága, 2022). Among research institutes, the IMD publishes an annual report on city rankings, and the Cities in Motion Index is another from such comparisons. In Europe, regarding the assessments, cities in the northern and western part of the continent perform exceptionally well; in my study, I focused on the capital cities of the classical EU-15 (who have joined the EU until 1995, except UK). My goal was to establish a smart city ranking for these cities and to determine whether there are differences among them within this geographical region, and to what extent the traditional EU15 is homogeneous in terms of smart cities. The novelty of this analysis lies in the fact that, by continuing to apply the methodology used in the previous studies (Szendi, 2019; Szendi et al. 2020), we can conduct a cross-sectional comparison of the EU15 capital cities, thereby gaining insight into the development of smart city initiatives. Furthermore, the analysis of these capitals may yield novel findings by revealing the internal development dynamics within a region that can be considered economically homogeneous in terms of the capitals' smart performance, and highlight which capitals were the most successful during the years that included the COVID-19 pandemic.

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Theoretical background

Smart city is a concept of the 21st century emphasizing the need for ICT adoption and the life quality improvement of the cities. Several researchers and institutions have analysed them and tried to find a complex approach, however, regarding smart cities or their performance measurement there is no uniformly accepted definition or concept. The smart city concept has gone through several changes over the years (Anari & Jakobi, 2025). The first definitions were created in the 1990s and initially focused on incorporating digital technologies into urban infrastructure to enhance efficiency and functionality (Wendt-Lucas et al., 2025). After that many hard and soft elements were built into the model (like citizen participation, sustainability, environment, resilience) and the definition became more multidimensional. Based on Macke et al. (2018) a smart city is an area which integrates ICT and human capital to improve the quality of life of inhabitants and foster economic growth. A quite complex definition was carried out by Vázquez et al. (2018) who stated that a smart city "highlights the potential of cities to improve citizen welfare, emphasizing the need for local governments and public–private partnerships to redesign services in a collaborative, sustainable, and innovative manner in order to optimize opportunities for socioeconomic development and enhance the quality of life". So, this latter encompasses many different aspects of smart city development.

In my definition, a smart city is an area that applies innovative strategies and solutions to improve the quality of life of their inhabitants, while making effective use of their creativity and knowledge base (Szendi, 2019). Besides quality of life (which is not only a single component of many models, but also the long-term objective of SC development), I have stressed the active participation of the citizens.

From the first comparing analysis of smart cities, the measurement has developed, and more components and indicators were added to it. One of the most comprehensive analyses was made by Giffinger et al. (2007) for the European medium-sized cities with six smart components (economy, people, governance, mobility, environment, life quality) creating a strong basis of SC evaluation. In their rank based on 74 indicators, Luxemburg was the smartest one before Aarhus and Turku, so the Scandinavian cities and Western Europe were quite well performing areas. In their overall performance the so-called hard dimensions of Economy and People were the highest evaluated ones. The next figure summarizes the main components and dimensions of different smart city models.

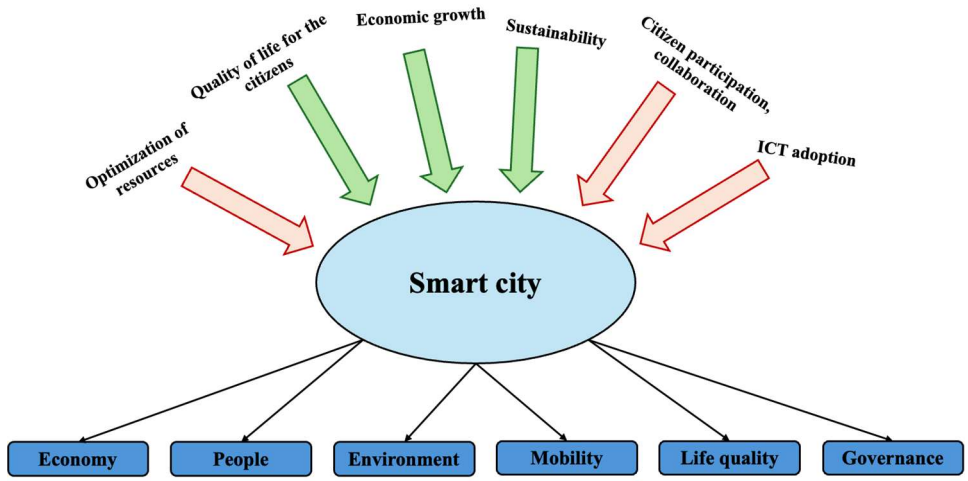

Figure 1. Dimensions and components of smart cities
Source: own compilation
Note: orange arrows are the way of smart city methods, while the green arrows are indicating the main objectives of smart cities

From the above we can summarize the most definitions common points regarding methods and objectives. Most definitions are emphasizing the improvement in the quality of life besides economic growth and sustainability. It can be achieved by the optimisation of resources through ICT adoption and the effective collaboration of public and private authorities.
Nowadays, the analysis of smart cities in the EU relies on multidimensional indices, citizen perception data, and multicriteria evaluation frameworks. The performance measurement and ranking of smart cities mainly relies on the six-component model of Giffinger et al. (2007) which integrates besides technological indicators also the citizen participation, some governmental issues and soft elements of being smart. In the concept of Marjanovic et al. (2026) it includes infrastructure and technology with human and social capital.
A multi criteria approach is represented in the study of Shmelev and Shmeleva (2024) who have checked 1300 cities and regions in Europe based on a set of 17 smart and sustainable performance indicators using the ISO quality standard for the indicators. The results show that Stockholm, Paris and London are among the best cities, while the European cities differ most in environmental and governance dimensions. Another article (made by Huovila et al., 2019) has only classified the factors determining smart city development and built an applicable framework for smart city assessment. All the indicators can be grouped based on the authors in input, output, process, outcome or impact types along the different dimensions of smartness. Both hard and soft types of indicators are classified which is unique trend in such analyses. One of the most diverse clusters is governance and citizen engagement (together with education and ICT components) which has all the types of indices. This can be a good starting point for future analyses.
Besides multidimensional approaches, more models and methods are carried out based on citizen participation or questionnaire surveys, which try to measure the performance of smart cities by only soft dimensions. Marjanovic et al. (2026) have started from the six-dimension approach mentioned above, however, have used only the data coming from the Urban Audit Perception Survey. A sum of 29 indicators was assessed and ranked for 40 European cities in 2023. The results have revealed that the Northern and Western European cities, such as Zürich, Copenhagen, and Vienna, lead the ranking with the highest index values, while the Southern European cities, including Madrid, Lisbon, and Athens, have shown moderate performance. The development of the Eastern and Balkan cities like Cluj-Napoca, Prague, and Ljubljana is rapid, however the one-year analysis does not allow long term evaluation of the data. Among Eastern European cities, Cluj-Napoca performs outstanding (Marjanovic et al., 2026). The same basis was applied by Stankovic et al. (2026) for urban efficiency measured by six components (mobility, liveability, environment, economy, governance and people). The results have raised attention on the fact that only 4 out of the 80 analysed cities have achieved urban efficiency. However, there are significant differences across countries, and the cities in Southern Europe tend to exhibit lower levels of urban efficiency compared to their counterparts in other regions.
Georgiadis et al. (2021) have also checked the smart city performance including the citizens' perceptions based on six pillars for the Greek cities with a questionnaire survey of 545 inhabitants. After the introducing question about smart city definition, the respondents were asked about some components how they correlate with smart cities (modern management, ICT, sustainable development, energy efficiency, citizen involvement, urban mobility). Most of the participants emphasized the efficient use of energy and sustainable development as the most important factors for smart city concept, while also a strong issue is technological development.
The IMD is evaluating the smart cities since 2019 along technological and structural factors, where in 2026 Zurich was the smartest among 148 cities. Based on the IMD, the next classification can be created among the best performing (top5) European capitals assessed by the total number of cities.

Table 1. Position of the top performing EU15 capitals based on the IMD smart city index (2019, 2023, 2026)

Rank	IMD 2019	Rank	IMD 2023	Rank	IMD 2026
5	Copenhagen	4	Copenhagen	5	Copenhagen
8	Helsinki	8	Helsinki	11	Helsinki
11	Amsterdam	10	Stockholm	14	Stockholm
17	Vienna	15	Amsterdam	17	Amsterdam
21	Madrid	28	Vienna	28	Vienna

Source: own compilation based on IMD data

Based on the IMD ranking, the best performing EU15 capitals are in the Northern part of the EU, Copenhagen and Helsinki, and after 2023 also Stockholm are among the top 10 or 15 cities, while Vienna and Amsterdam have also stable positions.

Starting from the indicators of IMD, Ivaldi et al. (2026) have analysed the smart city notion based on the following dimensions using the IMD index values: digital readiness, infrastructure and mobility, environmental quality, community and economic resiliency, proximity and liveability, and circular economy and resource management. They computed a type of maturity level of cities and made four clusters among them. In their assessment the given clusters had specific character with a good performance of one or two dimensions, but not generally overperforming cities in all dimensions. This also raised attention to the need of complex performance approach of cities. In this model, the best performing cities were from Europe Helsinki, Copenhagen and Oslo (Scandinavian capitals), while the average performance cluster included most of the Western European smart cities, while the worst cluster e.g. Athens and Rome. Also this analysis has reflected the classical economic development clusters in smart city development inside Europe.

Loucanova et al. (2026) have started from the quintuple helix approach (elaborated by Carayannis and Rakhmatullin, where to the classical triple helix it was further added the civil society and the natural environment as fourth and fifth element), including natural capital, social capital (evaluated by the civil society), economy, governance and education for smart city measurement. From the results (having both quantitative and qualitative data), they have created three clusters of cities among the EU capitals with different character. The first was explained by high index scores, besides the Scandinavian capitals also the Baltic capitals and Vienna are members of the cluster. The medium performing cluster contains Western European capitals, while the lowest index scores were associated with the Southern and Eastern capitals, so the geographic division of Europe is quite clear by this model.

Smart-city research in Europe shows that cities perform very differently depending on the indicators used: multidimensional assessments highlight strong results for Stockholm, Paris, and London, while citizen-perception surveys rank Zürich, Copenhagen, and Vienna highest. Across studies, environmental quality, governance, and citizen engagement emerge as the most uneven dimensions, and clustering approaches consistently reveal a clear geographic divide, with Scandinavian and Western European capitals outperforming Southern and Eastern ones.

Methodology

In my study, I rank Western European capitals in terms of smart cities for 2022 and compare the results with our previous findings (Szendi et al., 2020). Several studies have been conducted on European capitals that have assessed smart city performance based on multiple pillars; as a synthesis of these and primarily building on the model by Giffinger et al. (2007), I analysed the indicators of Western European capitals based on six components. In this study, “Western Europe” refers to the 15 EU member states that joined the European Community by the end of 1995 (except for London, which left the European Union following Brexit and is therefore not included in the analysis). Thus, a total of 14 capital cities were included in the analysis. The figure below illustrates the countries analysed and the methodology of the study. The main data sources were

the Eurostat database, the Urban Audit and Urban Audit Perception Survey databases, and the Metro region database. A sum of 26 indicators was applied among the 6 components of the analysis.

Economy	Mobility
GDP per capita (euro)	Public transport in the city, for example bus, tram or metro: very satisfied
GVA per capita (euro)	Share of journeys to work by public transport (rail, metro, bus, tram) -%
Patent nr per 10000 capita	Number of registered cars per 1000 population
Unemployment rate	**Environment**
People	Ozone O3 concentration days average compared to EU target (120)
Employment rate (%)	Particulate matter PM10 concentration average compared to EU target (50)
Share of students in higher education in the total population (per 1000 persons)	Municipal waste generated (domestic and commercial), total - 1000 t
Young-age dependency ratio (population aged 0-19 to population 20-64 years)	Green spaces such as public parcs or gardens: very satisfied
In this city it is easy to find a good job: strongly agree	**Living**
Governance	Cultural facilities such as concert halls, theatres, museums and libraries in the city: very satisfied
When you contact administrative services of this city, they help you efficiently: strongly agree	Public spaces in this city such as markets, squares, pedestrian areas: very satisfied
Generally speaking, most people in this city can be trusted: strongly agree	The financial situation of your household: very satisfied
The public administration of the city can be trusted: strongly agree	Most important in my city: health services
Individuals using the internet for interacting with public authorities	In this city, it is easy to find good housing at a reasonable price: strongly agree
	Total nights spent in tourist accommodation establishments per resident population
	Overcrowding rate by degree of urbanisation - total population

Figure 2. Applied indicators and geographical scope of the analysis
Source: own compilation

The methodology organizes indicators into six thematic categories: Economy, People, Governance, Mobility, Environment, and Living conditions, like the model of Giffinger et al. (2007). Each category includes specific measurable variables. Many variables are perception-based on the Eurostat's Urban Audit Perception Survey (e.g., "very satisfied," "strongly agree"), so the applied methodology relies not only on objective statistics but also on survey data reflecting residents' experiences. There are both hard indicators (e.g., patents, unemployment rate) and subjective perceptions in the measurement of urban smartness.
To compare data measured on different scales and in different units, it was necessary to transform the values. One method for this is the so-called z-transformation, which converts each indicator value into a standardized value with a mean of zero and a standard deviation of one. The value of an indicator can be computed with the following equation.

$$X = \frac{X_i - \bar{X}}{standard\ deviation}$$

where X means the standardized value; X_i is the indicator's value in city i; $\bar{X}$ is the average of the indicator among the examined capitals; the $standard\ deviation$ is the standard deviation of the indicator among the examined EU15 capitals.

In certain cases, it was necessary to adjust the data during the interpretation of components and the creation of the composite index, where the scaling of the given indicators differed. In these cases, I calculated using the inverse value of the indicator (the included indicators: unemployment rate, ozone concentration, particulate matter concentration, municipal waste, and overcrowding rate). The value of a given component (sub-category or pillar) is the sum of the standardized values of the selected indicators, while the smart index can be calculated as the arithmetic mean of the pillars' values (as it is also by Giffinger et al. 2007).
Of course, the composite index approach also has limitations, as there are no generally accepted recommendations regarding either the components used or the scope of data to be considered, and

the literature does not treat them uniformly. There may also be differences regarding whether weighting is applied during the construction of the indices, and if so, what shifts in emphasis occur among the individual components; furthermore, the ability to make repeatable spatial comparisons of the data over time and across the geographic units under study is not guaranteed for long time series. Consequently, the analysis is naturally limited in both space and time; however, since all available data originate from the Eurostat database, it can be considered methodologically consistent, meaning that the methodological regulations of individual countries do not influence the distribution of the index.

Results

After collecting the data and summarizing the index scores, I have created the rank of the EU15 capitals based on their smartness level. The table presents a comparison of European capitals based on the aggregated smart city index for two years (2015 and 2022), allowing for both ranking changes and performance trends to be observed. From the results we can see that among the top three we can see quite stable position; however, the leadership has changed. In 2015, Luxembourg ranked 1st (15.89), followed by Copenhagen (14.90) and Stockholm (14.75). By 2022, Copenhagen moved into 1st place (16.54), while Luxembourg dropped slightly to 2nd (15.40), and Stockholm remained stable in the 3rd place (13.31).

Table 2. Ranking of the Western European capitals based on the smart city index (2015, 2022)

rank	capital	Index sum 2015	rank	capital	Index sum 2022
1	Luxembourg	15.89	**1**	Kobenhavn	16.54
2	Kobenhavn	14.90	**2**	Luxembourg	15.40
3	Stockholm	14.75	**3**	Stockholm	13.31
4	Helsinki	8.86	**4**	Dublin	12.28
5	Dublin	6.38	**5**	Amsterdam	8.81
6	Amsterdam	5.15	**6**	Helsinki	8.01
7	Wien	3.84	**7**	Wien	1.76
8	Paris	0.82	**8**	Paris	-3.89
9	Bruxelles	-3.36	**9**	Bruxelles	-4.42
10	Madrid	-7.35	**10**	Berlin	-7.18
11	Berlin	-8.87	**11**	Madrid	-8.06
12	Lisboa	-11.00	**12**	Lisboa	-12.60
13	Athina	-18.27	**13**	Athina	-18.31
14	Roma	-21.74	**14**	Roma	-21.66

Source: own compilation

There are some capitals who have showed significant improvement, like Dublin or Amsterdam, while Helsinki has made a slight drop in rank, but maintained a high score. So, the north-western European capitals have shown the best performance among the smart indices. Vienna's position remained stable in 7th place, but its score dropped sharply, which is like the value change of Paris. The worst performing capitals are in Southern Europe, with Madrid, Lisbon, Athens, and Rome. The table shows a quite stable but increasingly polarized urban hierarchy.
The results and changes are represented on the below figure, which reflects the values of the smart index. As we have seen above by the ranking, there are three strong performing smart capitals, Copenhagen, Luxembourg, and Stockholm stand out as the highest positive values in both years.

Compared the two years in Copenhagen there was a slight increase in the index value, while Luxembourg and Stockholm have shown a small decline.
In Dublin and Amsterdam, it was a significant improvement in the smart index, however their values were not balanced in the given sub-indices. Athens and Rome have the lowest figures in both years, with persistent low smart city performance. Both for the top-ranked regions and for those at the bottom of the list, there is a strong correlation with other analyses in the literature based on composite indices (e.g. Lapinskaité et al. 2022; Tundys & Wisniewski, 2024; Loucanova et al. 2026). In most cases, the results show a dominance of Northern Europe (Helsinki, Stockholm, and Copenhagen), while at the bottom of the list—even when using multidimensional indices—two capitals from the Mediterranean region, Athens and Rome, typically appear.

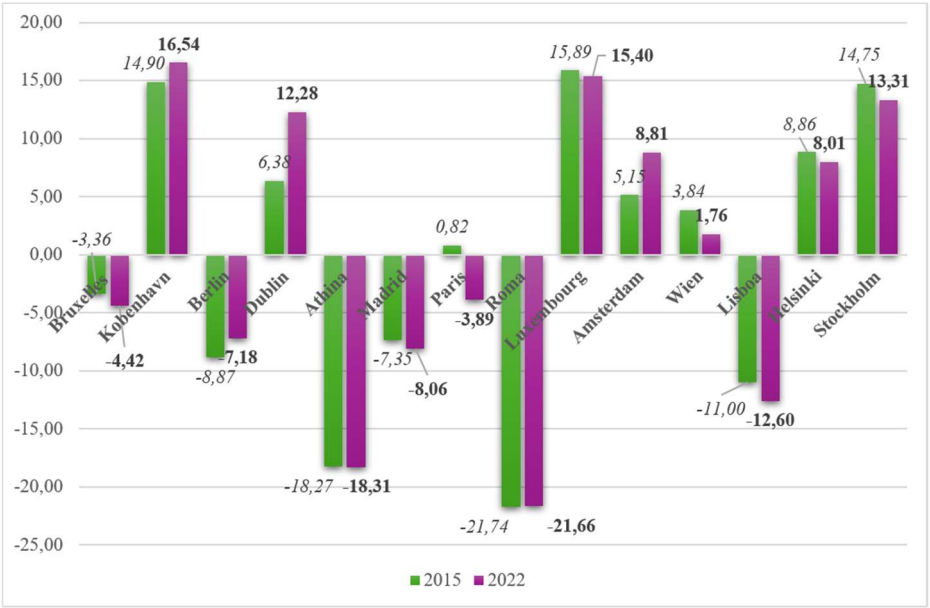

Figure 3. Smart index values of the Western European (EU15) capitals (2015, 2022)
Source: own compilation

So, the chart reveals persistent regional disparities: Northern and some Western European EU15 cities tend to maintain strong positive values, while Southern cities remain negative. While some cities improved between 2015 and 2022 (e.g., Dublin, Amsterdam), others experienced stagnation or decline. Overall, the differences between cities remain pronounced, with no clear convergence over time. Compared to our previous analysis results (Szendi et al., 2020), Copenhagen and Stockholm were among the smartest capitals in 2015 for the whole European continent, and for the EU a clear northern-southern divide was recognizable. The results are quasi-similar, so the EU15 almost reflect the trends of the EU.
Besides the complex index, it is also worth to check the performance of the given components in the cities. That is why I have created the below radar charts to have a comparative approach for the factors influencing the smartness of the city. The first compares the EU15 capitals across the six smart city components for 2015. The values range from –8 to +8, allowing a comparable view of strengths and weaknesses. Economy and Governance show the widest variation across cities. Some cities (e.g., Luxembourg, Copenhagen) score very high, while others (e.g., Athens, Rome) are strongly negative. Mobility and Living are more moderate, with most cities clustered around small positive values. Environment varies but tends to be moderately positive in Northern cities and weaker in Southern ones.

Copenhagen and Luxembourg stand out with consistently high scores, especially in Governance and Economy (values around +6 to +8). These cities appear well-balanced across most components. Stockholm and Helsinki also perform strongly, particularly in Environment, Governance, and Living, indicating a sustainability-oriented smart city model. Amsterdam shows high values in Economy and Governance, though Mobility is relatively weaker. Dublin stands out in Environment, while Berlin is more balanced but slightly weaker in Governance. Vienna and Paris show mixed profiles with moderate scores in most components. Athens and Rome display the lowest overall scores, particularly in Economy and Governance. Lisbon and Madrid also show weaknesses, especially in Governance and Economy, though their Mobility and Living scores are less negative.

In 2015, Governance is a key differentiator pillar, as there are some high-performing Northern cities, but Southern cities lag significantly. Environment tends to be stronger in cities like Stockholm, Helsinki, and Dublin, indicating environmental policy effectiveness. Mobility is relatively even across cities, suggesting that transport systems are less polarizing but not a strong competitive advantage. Living is generally positive across many cities, indicating relatively good quality of life even where economic or governance factors are weaker.

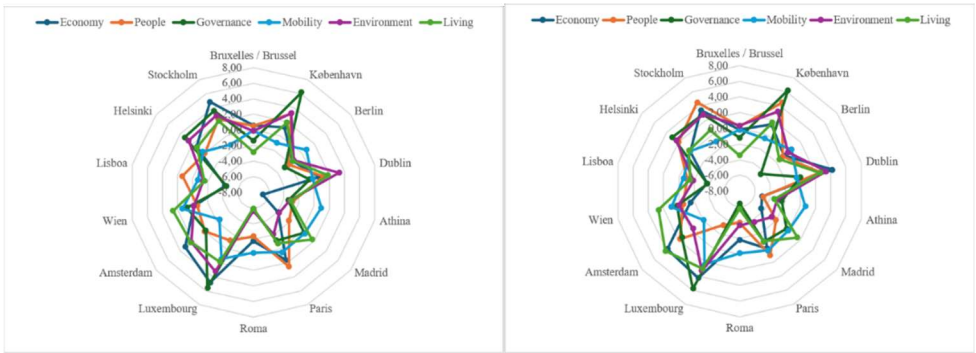

Figure 4. Smart index components of the Western European (EU15) capitals (2015 left, 2022 right)
Source: own compilation

The right figure represents the smart index component values in 2022, which also highlights top-performing areas, as Copenhagen and Luxembourg show consistently high scores across most components, especially in Governance, Economy, and Living. Stockholm and Helsinki are in contrast strong in Environment and Living, indicating sustainability-oriented development. Amsterdam, Berlin, Dublin, Vienna are generally positive across multiple components but lacking a dominance in all areas. In Athens and Rome, similarly to 2015, there are consistently negative values in Economy and Governance, while Lisbon and Madrid perform mixed but generally below-average. Also, in 2022, Governance and Economy are decisive factors, while Environmental performance is a strength of Northern cities, reinforcing the sustainability gap within Europe.

From the two radar maps, a clear North - South divide emerges, where the Northern and Western cities perform consistently well across multiple components, and Southern cities lag due to economic and governance challenges.

So, the figures demonstrate that smart city performance depends on a balanced combination of components rather than strength in a single area. Leading cities (e.g., Copenhagen, Luxembourg, Stockholm) exhibit consistency across governance, economy, and quality of life, while weaker cities are characterized by systemic deficiencies, particularly in governance and economic capacity.

Summary

In my recent analysis I have checked the smart city performance of the EU15 member states' capitals (except London) smart city performance for 2022 and have compared it with previous analysis results from 2015. The selection objective was to analyse the Western European capitals from the aspect of smart cities and track the tendencies of the indicator. Copenhagen, Luxembourg, and Stockholm consistently rank as the strongest smart-city performers, though Copenhagen overtook Luxembourg between 2015 and 2022. Northern and Western capitals show stable high scores, while Southern cities such as Athens, Rome, Lisbon, and Madrid remain persistently weak. Some cities, including Dublin and Amsterdam, improved significantly over time, although their sub-index values remain uneven. Vienna and Paris kept mid-level positions but experienced notable score declines. The overall hierarchy of European capitals appears increasingly polarized rather than converging. Radar charts for 2015 show wide gaps in Economy and Governance, with Northern cities performing strongly and Southern cities scoring negatively. Environment is a clear strength for cities like Stockholm, Helsinki, and Dublin, while Mobility and Living remain more balanced across capitals. The 2022 radar chart confirms continued dominance of Copenhagen and Luxembourg across most components. Southern capitals still struggle with systemic weaknesses in Economy and Governance, reinforcing the North–South divide. Overall, leading cities succeed through balanced strength across governance, economy, environment, and quality of life, while weaker cities show structural deficiencies across multiple dimensions.

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KÖNYVSZEMLE / BOOK REVIEWS

Judit Doszpodné Polgár[22]

Navigating the Nexus: Geography, Technology and the Cloud Societies

Saran, S. - Sarma, A. (2025): GeoTechnoGraphy: Mapping Power and Identity in the Digital Age. India Viking. ISBN: 978-0143469513

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Samir Saran's and Anirban Sarma's book aims to examine current trends and the effects of digitalization by considering geography, technology, and society. The title, *GeoTechnoGraphy,* refers to the collision of these fields; their nexus is indispensable to understanding today's world order. In an era where crisis and uncertainty have become the 'new normal', gaining a comprehensive knowledge of the interconnections between pivotal events and trends is essential; this book serves as a vital tool in building such awareness. The Introduction poses a relevant question: 'How do we reboot the present to ensure that the future doesn't repeat the errors of the past?' In *GeoTechnoGraphy* the authors seek to answer this question, through secondary sources and extensive examples.

In the Introduction*,* the authors explain the term 'cloud societies' and describe their emergence. 'Clouds' are societies that utilize the Internet and social media to express their views and opinions, while also maintaining connections with like-minded peers and interest groups. Although cloud societies are virtual communities, they remain rooted in certain geographies, and their online activities significantly affect the offline realm. Therefore, Saran and Sarma argue that geography still plays a crucial role in world affairs, even as it becomes increasingly interconnected with technology and society. These fields have undergone a fundamental change: starting from early settlements and moving through the transition from agrarian to industrial societies, followed by the Third Industrial Revolution, communities have evolved into digital societies shaped by technological and geographical factors. This era is now characterized by the widespread use of social media, the rising importance of Artificial Intelligence (AI), and the dominance of Big Tech firms. The authors examine the tech-driven epoch, its disadvantages, and opportunities for regulation.

Chapter 1 opens with two political examples: Donald Trump's 2016 electoral victory and the Egyptian protests of the early 2010s. Both cases demonstrate the power of societies and the significance of place. The authors argue that the environment is more than a physical setting; it encompasses cultural, emotional, and spiritual dimensions (Papp et al., 2022a, 2022b; Sárvári, 2021). Even in pre-modern societies, individuals were connected through similarity and natural affinity, in addition to their shared geographical area. As these communities evolved, solidarity did not vanish, but rather transformed, becoming more diffuse and organic. In this 'new era of solidarity', the organization of work and production differs from the methods prevalent during Fordism. Today, specialization and interdependence are the defining characteristics of the global economic system (Gervai et al., 2015). These interdependent social relationships require governance to manage potential conflicts. Saran and Sarma describe two landmark historical events, the Magna Carta and the Peace of Westphalia, which are considered the foundations of modern governance and sovereignty. In the eighteenth and nineteenth centuries, several nation-states emerged and consolidated, some of which later expanded their territories through colonization. In the following century, decolonization became the primary objective for colonized nations, such as India. The end of the Second World War and the establishment of the United Nations marked the end of formal colonization and the beginning of a new rules-based order. See further examples in Bethlendi and Holczinger (2026) and in Deák and Sárvári (2023).

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The expansion of social media has significantly reshaped how communities are constructed. Chapter 2 explores this recent transformation and its implications. Today, individuals are linked by shared values, interests, and cultural affinities rather than physical proximity. Saran and Sarma assert that these digital connections lack the inherent strength of face-to-face contact, although online collectives still possess considerable influence, as demonstrated by the #SaveAarey campaign. Regulation is necessary in cyberspace, yet it fundamentally diverges from the Westphalian model. Nations approach digital governance differently; for instance, China, with its social credit system and censorship, and Russia, through its state-led internet control, represent outliers (Bartha, 2024; Morris & Sárvári, 2021; Sárvári & Szeidovitz, 2018; Vaszkun et al., 2022). Most countries prioritize digital rights, with freedom of speech occupying a prominent position. The authors draw a comparison between India and the United States in this context. However, social media platforms often mediate free speech by establishing their own rules and guidelines for discourse. These content standards effectively function as a form of legislation, a phenomenon precisely captured by the phrase 'code is law.' For average users, daily life is dictated by this 'code', which can result in detrimental real-world outcomes (Sárvári, K., 2021). One such effect is the 'new tribalism,' where topics like politics, climate change, and the Black Lives Matter movement become deeply polarizing. This online fragmentation is further fueled by fake news, leading to widespread disinformation with serious societal impacts.

Chapter 3 continues to illustrate these grave societal impacts through examples such as the protests surrounding the Israel-Hamas conflict and the role of digital platforms during the Arab Spring. These cases clearly demonstrate that the flow of information has been accelerated. The authors discuss the expression of international solidarity and 'despatialization', which refers to the shrinking of space and time. These phenomena have contributed to another significant transformation within the media landscape. The digital revolution arrived with incredible speed, offering benefits through the democratization of information; however, the instantaneous sharing of experiences can also entail negative repercussions. Users often project an enhanced and idealized self-image on digital platforms, which rarely corresponds to their objective reality. In addition to these distorted individual representations, history itself is now mediated by the media. Saran and Sarma describe digital media as a 'double-edged sword' because of its dual capacity to both unite and divide. In this era, the previously introduced 'cloud societies' have emerged, defined increasingly by the content they share online. This online dominance has granted tech corporations tremendous influence over almost every aspect of modern life.

The next chapter, titled *From Censers to Censors: Is Big Tech the New Clergy?,* addresses the dominance of major technology firms. While the term 'clergy' traditionally referred to community religious leaders, today's top technologists and Silicon Valley CEOs have assumed this role. Algorithms are now even partially regarded as a new form of religion, as they exert a profound influence over life choices and command an almost spiritual devotion from users. This remains true despite their inherent biases and the proliferation of misinformation. The prejudiced nature of these technologies is illustrated through the example of Google. By dominating the market, Big Tech corporations foster user dependency, making it increasingly difficult for individuals to leave their platforms. Saran and Sarma assert that technology tends to 'play God', potentially resulting in devices that program their owners rather than remaining under human control. In this context, the mention of Artificial Intelligence (AI) is inevitable; some researchers even argue that AI is capable of establishing a new colonial world order. As technology corporations increasingly impact democratic processes, institutions, and even geopolitics, the authors conclude that governance is urgently needed (Sárvári, B., 2021).

Chapter 5 poses the question of accountability regarding transnational Big Tech firms. The difficulty of regulating these corporations stems from their dominant, and at times, monopolistic positions. Their significant market share and success are rooted in a network-based approach: as more people utilize these platforms, a greater volume of data becomes available, allowing companies to extract insights and refine their algorithms. However, data management remains a concerning issue due to the lack of transparency and the unethical manipulation of user

consent. Prominent firms, such as Google, Amazon, and Facebook, have faced scrutiny regarding unethical data practices. Consequently, governments have sought to counter the dominance of major digital entities through various frameworks. Primary examples include India's digital public infrastructure (DPI) and Europe's General Data Protection Regulation (GDPR). The authors describe the GDPR as 'the world's toughest and most comprehensive personal data protection law', noting its global impact on privacy practices. Another potential solution for overseeing tech giants is the use of 'regulatory sandboxes', which can foster the emergence of fintech start-ups, providing them with a better opportunity to innovate and compete with major firms. Furthermore, this chapter also raises the critical question of who can be held accountable for user-generated content on digital platforms.

Despite national efforts to counter the dominance of Big Tech, so-called 'digital badlands' have emerged and continue to operate in the online sphere. Chapter 6 introduces the metaphor of the Apocalypse to describe illegal activities and their profound repercussions in the digital era. These virtual places are regarded as the breeding ground for cybercrimes and cyberattacks. One grave societal consequence is the escalation of hatred through social networks. In Myanmar, the case of the Rohingya Muslims illustrates the devastating power of hate speech and the rapid circulation of genocidal propaganda. Furthermore, several studies examining the impact of Covid-19 conclude that online hostility significantly increased during the pandemic. Consequently, nations face the arduous task of balancing the encouragement of free speech with the suppression of hate speech. While their approaches vary, there is a near-universal consensus that digital service providers must engage more actively in the fight against online hatred. The authors suggest that Big Tech and social media platforms should invest more in both human and technological resources to mitigate these negative effects. Artificial Intelligence also plays a critical role in cybercrime and cyberattacks; AI can be utilized as a potent and adaptable weapon, as it constantly learns from existing defenses. Alongside the rise of AI, three other trends characterize contemporary cybercrime: 'disaster capitalization', the evolving space of cryptocurrency, and the use of 'money mules' for money laundering. 'Disaster capitalization' refers to instances where cybercriminals exploit current crises to commit illicit acts such as the surge in fraudulent e-mails observed during the Covid-19 pandemic. In the case of 'cryptojacking', criminals illegally generate cryptocurrency by hijacking their victims' computing power. Furthermore, innocent individuals are often inadvertently involved in money laundering when recruited to transfer stolen funds through 'mule accounts'. As the Fourth Industrial Revolution is the fastest-developing upheaval in history, it presents several systemic risks, including these cybercrimes. Saran and Sarma extend the apocalyptic metaphor by invoking the Four Horsemen to describe these disruptive phenomena.

The central theme of Chapter 7, captured in its title, *Terminated? AI and Our Human Future,* explores the contrast between humanity and machines. Although AI has demonstrated the ability to defeat professional players in the complex game of Go, the authors argue that such systems are unlikely to achieve consciousness. Nevertheless, their exponential growth is remarkable, a phenomenon described by the term 'AI spring'. Like all automation technologies, Artificial Intelligence impacts the global workforce and poses a threat to certain professions, leading affected workers to protest against its extensive integration into their fields. Another pressing issue is the liability of autonomous systems, particularly in the case of driverless vehicles. However, accountability is not the only challenge lawmakers face; the layered nature of these technologies presents diverse risks that must be addressed through governance. Regulatory frameworks must adapt to the rapidly evolving character of AI without hindering innovation. Saran and Sarma identify three trends that governments should consider when maintaining healthy digital ecosystems. They emphasize the need for international laws capable of being enforced upon sovereign states. Furthermore, the authors highlight the unequal distribution of technological benefits, noting that the Global North plays a dominant role in both establishing frameworks and utilizing AI-supported solutions. Ultimately, the text stresses the importance of human capacity and awareness, describing AI as 'a core driver of contemporary geopolitics'.

The final chapter synthesizes the core concepts discussed throughout the book, including cloud societies, the changing notion of place, technological advancements and harms, and the international rules-based order. The authors argue that the original principles of this order have been interrupted by fundamental shifts in the digital age. They categorize these as the 'three interruptions', affecting sovereign states, common norms and principles and international institutions. Big Tech companies, through their massive data-processing operations, often challenge the authority of traditional institutions, undermining their efforts to ensure collective security within cyberspace. These interruptions are followed by 'three disruptions': technology has significantly altered citizens' relationships with key elements - locality, mediated realities, and the political order including the prevailing myth of digital democracy. Finally, the authors propose 'three solutions' to prevent the collapse of democratic principles online: the development of robust digital laws, enhanced cooperation between governments and tech stakeholders, and, fundamentally, a re-evaluation of what constitutes human identity. The book concludes with a cautionary scenario: unless these systemic errors are addressed, the history of digital societies may prove regrettably brief.

GeoTechnoGraphy provides a rigorous examination of the fundamental transformation of societies, the emergence of advanced technology, and the growing dominance of tech conglomerates. The authors focus on the necessity of establishing and maintaining regulatory frameworks while shedding light on the inherent risks of the digital era Amidst today's crisis and turmoil, this work acts as an anchor by presenting reliable information about contemporary shifts. Saran and Sarma have compiled an extensive analysis of these phenomena, illustrated by compelling, up-to-date examples. Since nearly every aspect of modern life is influenced by these trends, the book is highly recommended for those interested in the nexus of geography, technology, and society. The text remains accessible, yet it addresses complex themes that encourage critical reflection on future implications. The authors primarily emphasize the negative facets of the digital age, yet they also outline solutions that offer positive outcomes and can enhance people's lives. Beyond detailing the disadvantages, exploring exemplary practices could have been a promising area for further research. Consequently, *GeoTechnoGraphy* serves as a valuable resource for students seeking insights into historical events, current trends, and the trajectory of our digital future.

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