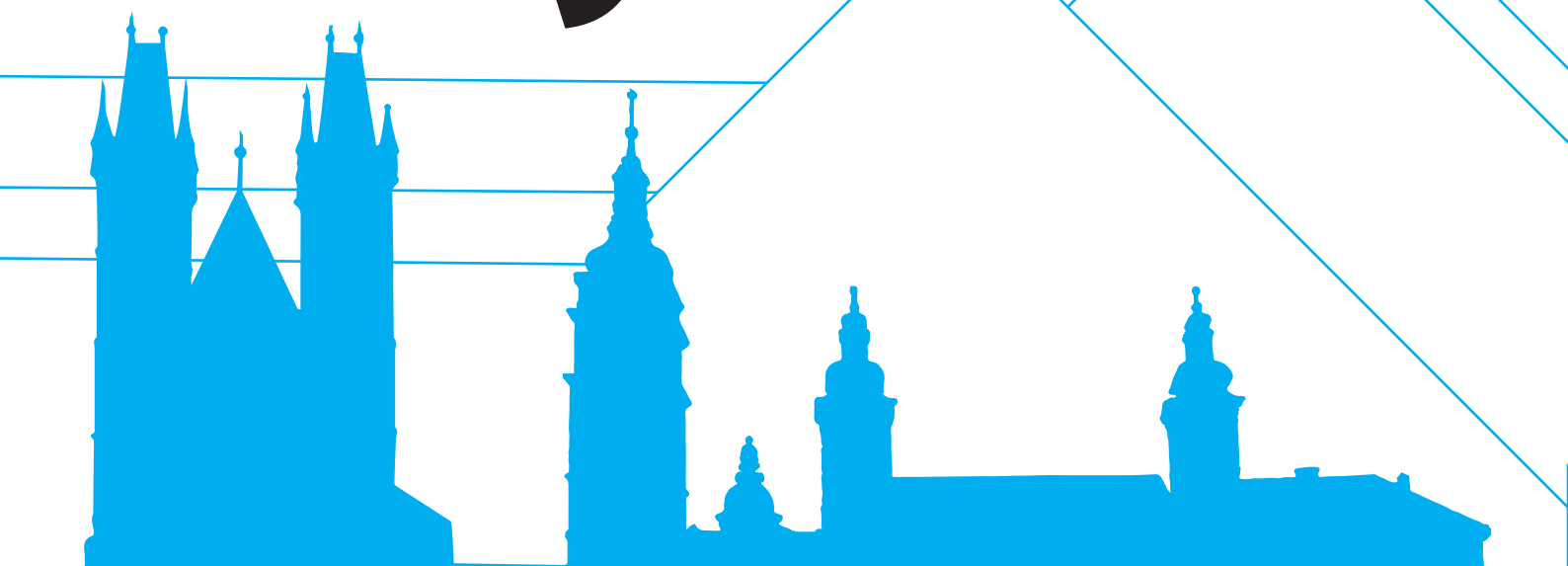




University of Hradec Králové
Faculty of Informatics and Management

Hradec Economic Days



Vol. 16

Proceedings of the international scientific
conference Hradec Economic Days 2026

April 9–10, 2026
Hradec Králové, Czech Republic



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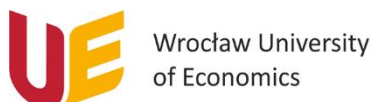
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Vol. 16(1)

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Conference organizers:



Conference partners and co-funding institutions:

OP JAK grant Budoucnost vzdělávání: Strategické řízení a rozvoj priorit Univerzity Hradec Králové, no. CZ.02.02.XX/00/23_022/0009008



Spolufinancováno
Evropskou unií



Hradec Králové region grant
no. 26RGI02-0066



Editors: Martin KRÁL, Petra MAREŠOVÁ, Krzysztof FIRLEJ, Ivan SOUKAL
Publisher: University of Hradec Králové

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Articles can be cited as **a conference contribution in edited proceedings:**

Lastname, A. (2026). Title of conference article. In M. KRÁL, P. Maresova, K. Firlej, & I. Soukal (Eds.), *Hradec Economic Days, volume 1, 2026* (pp. page #–page #). University of Hradec Králové. <https://doi.org/10.36689/u hk/hed/2026-01-####>

or as **a conference contribution in periodical proceedings or journal:**

Lastname, A. (2026). Title of conference article. *Hradec Economic Days*, 16(1), page #–page #.
<https://doi.org/10.36689/u hk/hed/2026-01-####>

ISSN 2464-6067 (Online)

ISBN 978-80-7435-966-8

DOI: 10.36689/u hk/hed/2026-01-000

Preface

Ladies and gentlemen, dear colleagues,

the Hradec Economic Days (HED) conference has been traditionally and continuously held since 2003. Our 24th HED takes place April 9–10 in Hradec Králové. The University of Hradec Králové organized the conference in cooperation with the Wrocław University of Economics, the Cracow University of Economics.

The aim of the HED 2026 conference is to present the results of scientific research activities in the fields of economics, business economics, and management. We became a regular platform for meeting experts from such disciplines strengthening interdisciplinary relations and establishing personal contacts important for the submission of joint research projects and creating space for the presentation and publication of young members of an academic community. To fulfill these goals, HED offered presentation sessions and a plenary session with foremostly keynote speakers:

- Ahmad Bin Jusoh (Universiti Teknologi Malaysia),
- Lukáš Režný (Univerzita Hradec Králové),
- Stanislav Popelka (Univerzita Palackého v Olomouci).

We partnered with the Czech National Bank to boost academia and practice interconnection. The discussion forum with the deputy governor Eva Zamrazilová deals with the recent topic of economic outlook and monetary policy amid current international uncertainty. I am proud we expanded the conference with a new session Eye-Tracking and Other Cognitive Research in Marketing which supports networking and increases the visibility of a cognitive studies laboratory at our faculty. Finally, a special session is held to discuss Survey Design for Decision-Making: From Questions to Actionable Evidence with Taiwo Temitope Lasisi and Samuel Amponsah Odei.

Proceedings from the conference HED 2026 contain 30 contributions in English. The authors of the conference papers are academicians and other professionals from the Czech Republic, Slovakia Poland, and Malaysia. I would like to warmly thank all participants of the HED conference for their contributions and favor. My final thanks belong to the HED jack-of-all-trades Ivan Soukal, chief editor Martin Král, our organization, and scientific committee for their work. I would like to thank our co-funding our partners: OP JAK grant Budoucnost vzdělávání: Strategické řízení a rozvoj priorit Univerzity Hradec Králové, no. CZ.02.02.XX/00/23_022/0009008 and Hradec Králové region grant no. 26RGI02-0066.

Hradec Kralove, April 1, 2026



Assoc. Prof. Petra Marešová
General Chairman of Hradec Economic Days
Faculty of Informatics and Management
University of Hradec Kralove

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Marriage Formation under Institutional and Regional Contexts: Evidence from Poland

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Abstract: This article examines long-term changes in marriage formation in Poland between 2010 and 2023, with particular emphasis on religious (predominantly Catholic) marriages. From an economic and management perspective, marriage is treated as a long-term household decision shaped by institutional arrangements, economic uncertainty, and cultural norms. The study combines a national-level analysis with a regional case study of Podkarpackie Voivodeship (NUTS-2), a south-eastern region characterised by relatively high levels of religiosity and traditional family norms. The empirical analysis is based on official annual statistics retrieved from the Local Data Bank of Statistics Poland (GUS). Descriptive time-series analysis and dynamic indices are used to quantify changes in the number and structure of marriages, and an exploratory exponential-trend projection is applied to illustrate possible continuation of observed tendencies, with the COVID-19 period treated as a short-term institutional shock. The results show a persistent decline in the number of marriages in Poland over the analysed period, with a pronounced drop in 2020 and only partial recovery afterwards. Religious marriages decrease in absolute terms and as a share of all marriages, although the pace of change varies across years. Similar directions are observed in Podkarpackie Voivodeship, yet changes are less dynamic than at the national level and the relative importance of religious marriage remains higher, pointing to the moderating role of region-specific institutional and cultural contexts. Overall, the findings contribute to research on demographic change by showing how household marriage decisions respond to institutional transformation and economic uncertainty within a single country marked by pronounced regional heterogeneity. The findings should be interpreted in light of the study's reliance on aggregated data and the exploratory nature of trend projections. The study is explicitly descriptive; trend projections are illustrative rather than predictive.

Keywords: household decision-making; religious marriage; institutional change; regional differentiation; economic uncertainty

JEL Classification: J12; D10; D02

1. Introduction

Marriage formation is a core demographic and economic process with direct implications for labour-market behaviour, household finances, housing decisions, and long-term welfare outcomes, particularly in contexts where households bear substantial responsibility for social risk management. In many European countries, marriage has become less universal and

increasingly postponed, reflecting changing economic conditions, institutional arrangements, and shifting cultural norms.

Poland provides an informative case because aggregate trends resemble those in Western Europe, yet the underlying mechanisms operate within the distinct institutional trajectory of Central and Eastern Europe. In addition, substantial regional heterogeneity persists, particularly in religiosity and family norms. The Podkarpackie Voivodeship, located in south-eastern Poland and characterised by persistently high levels of religiosity and traditional family norms, represents a context of strong institutional continuity. This makes it a valuable case for examining how locally embedded institutional structures interact with broader demographic and economic trends.

Despite extensive research on the Second Demographic Transition and marriage decline in Europe, far less is known about how macroeconomic uncertainty interacts with regionally embedded institutional structures to shape household marriage decisions within a single Central and Eastern European country.

The article addresses three research questions: (1) How have marriage and religious marriage trends evolved in Poland during 2010–2023? (2) How do these patterns differ between Poland and Podkarpackie Voivodeship? (3) How can the observed patterns be interpreted through the lens of household decision-making under uncertainty and institutional change?

This study contributes to the literature in three main ways. First, it bridges demographic analysis with an institutional-economic framework by conceptualising marriage formation as a long-term household risk-management decision shaped by labour-market uncertainty, macroeconomic volatility, and evolving welfare-state arrangements in Central and Eastern Europe. Second, it advances research on regional heterogeneity by introducing a within-country institutional comparison, showing how locally embedded religious and normative structures moderate the pace (though not the direction) of demographic adaptation to structural economic change. Third, it provides transparent and replicable longitudinal evidence for 2010–2023, treating the COVID-19 period as an exogenous institutional shock and offering an updated empirical baseline for future causal and micro-level analyses.

2. Theoretical Background

2.1. Marriage as an Institutional and Economic Decision

Marriage is a core social institution structuring household formation through formal and informal rules that coordinate behaviour and stabilise expectations surrounding long-term commitments (Giddens, 2007; Marody & Giza-Poleszczuk, 2004). In economics and management research, marriage is conceptualised as a forward-looking household decision involving resource allocation, labour division and risk-sharing (Becker, 1981; Cherlin, 2020). Empirical research shows that employment instability and early-career uncertainty tend to delay long-term commitments, prompting households to adopt postponement strategies under risk (Alderotti et al., 2021; Comolli, 2017).

2.2. The Second Demographic Transition and West–East differentiation

Changes in marriage behaviour are most commonly interpreted within the framework of the Second Demographic Transition (SDT). According to this perspective, advanced societies are moving away from a model in which marriage and the nuclear family constituted the dominant form of private life organisation towards more diversified life-course trajectories characterised by delayed commitments and pluralised family forms (Lesthaeghe, 2014; Lesthaeghe & Neels, 2002). The SDT framework links declining marriage rates and postponement of family formation to broader processes of value change, individual autonomy, and redefined life priorities.

A central mechanism underlying the SDT is individualisation, understood as the growing dominance of individual preferences and self-realisation over traditional social norms. As a result, marriage increasingly competes with alternative life strategies, such as extended education, career development, and economic stabilisation, which are often prioritised before formal family formation (Giddens, 2007). From an economic perspective, this implies a reordering of life-course decisions, in which labour market integration and financial security precede long-term household commitments.

Importantly, the pace and manifestation of the SDT vary across regions. While many demographic outcomes observed in Central and Eastern Europe resemble those in Western Europe, the underlying mechanisms may differ due to distinct institutional trajectories following the post-socialist transformation (Lesthaeghe, 2014; Szukalski, 2020). This suggests that convergence in observed marriage trends does not necessarily imply convergence in the socio-economic processes that generate them.

2.3. Religion as an Institution and Regional Heterogeneity in Marriage Behaviour

In this study, religion is conceptualised as a social institution rather than as a system of individual beliefs. From an institutional perspective, religion consists of formal and informal rules, normative expectations, and organisational structures that shape behaviour by coordinating socially accepted life-course patterns and stabilising collective expectations (Norris & Inglehart, 2011; Voas & Chaves, 2016). In this sense, religious institutions may reduce uncertainty associated with long-term commitments and contribute to the persistence of specific marriage norms, particularly in regions where their institutional embeddedness remains relatively strong.

The Podkarpackie Voivodeship represents a regional context characterised by a comparatively high institutional presence of religion, reflected in a higher proportion of religious marriages than the national average (GUS, 2023; CBOS, 2022). A regional perspective therefore allows for examining how locally embedded institutional arrangements interact with broader demographic trends. While the general direction of change in marriage behaviour remains consistent with nationwide patterns, regional differences suggest varying capacities of institutions to moderate the timing and form of household decisions.

Religious institutions can influence marriage patterns not only by shaping normative frameworks but also by providing social coordination mechanisms that support formal union formation. However, their stabilising role is not immune to broader institutional changes.

Periods of heightened uncertainty, including economic shocks and administrative constraints, may temporarily weaken institutional coordination and delay marriage formation, even in regions characterised by strong institutional continuity. The COVID-19 period illustrates how exogenous shocks can disrupt established patterns of marriage behaviour without necessarily implying a structural decline in the institutional role of religion.

While previous studies have examined marriage decline in Europe, less attention has been paid to how regional institutional contexts within a single country moderate household responses to economic and institutional uncertainty.

3. Research Methodology

The analysis is based on annual aggregate demographic data obtained from Statistics Poland (GUS), Local Data Bank, covering the period 2010–2023. The study uses data on the total number of marriages and the number of religious (Catholic) marriages at both the national level and the regional level of the Podkarpackie Voivodeship (NUTS-2). All variables were extracted from publicly available statistical reports and databases, ensuring full transparency and replicability of the analysis. The study relies exclusively on secondary, aggregate data and does not involve individual-level information.

In Polish vital statistics, religious marriages refer to church-registered unions; in practice this category is predominantly Catholic. Accordingly, we use “religious marriages” as the operational label throughout.

Descriptive time-series analysis was applied to identify long-term trends and short-term fluctuations in marriage formation. To assess year-to-year changes, dynamic indices with a variable base and fixed base were calculated. Variable-base indices were used to capture annual fluctuations, while fixed-base indices allowed for the assessment of cumulative changes over the analysed period. This approach facilitates the identification of periods characterised by increased volatility and heightened sensitivity to external disruptions.

In order to explore long-term tendencies, linear and exponential trend models were estimated for the analysed time series. These trend models were used solely for exploratory purposes to illustrate the direction and persistence of observed changes. The resulting projections do not account for potential future institutional, economic, or policy-related shocks and should therefore not be interpreted as predictive forecasts. Model fit was assessed using R^2 and RMSE statistics (Table A1), supplemented by graphical inspection.

Due to the aggregated nature of the dataset, the analysis does not allow for the identification of individual-level motivations or causal mechanisms underlying marriage decisions. Nevertheless, the applied methodology is appropriate for documenting structural trends and regional differentiation in marriage formation over time. The analysis is descriptive and does not estimate causal effects. Given the structural disruption in 2020, projections should be interpreted cautiously.

4. Results

The first stage of the analysis examines changes in the total number of marriages in Poland (Figure 1). The national-level perspective provides a reference point for subsequent regional analyses and allows for the identification of periods characterised by significant disruptions to observed trends.

Figure 1 presents the total number of marriages in Poland over the period 2010–2023. The results indicate a clear and persistent downward trend, interrupted by short-term fluctuations that did not result in a lasting reversal in any of the analysed years. A particularly sharp decline is observed in 2020, corresponding to the period of exceptional institutional and administrative constraints. In subsequent years, only a partial rebound can be observed, which does not offset the scale of the earlier decline.

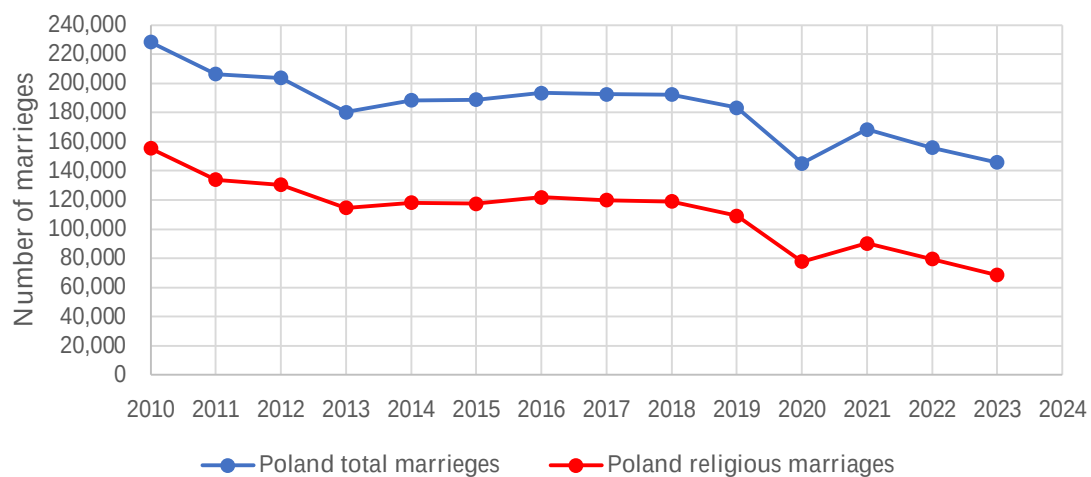


Figure 1. Number of marriages (count), Poland, total and religious, 2010–2023

The next stage of the analysis focuses on changes in the number of marriages in the Podkarpackie Voivodeship, which – due to its specific cultural and institutional context – constitutes an informative regional case when compared to nationwide demographic trends (Figure 2).

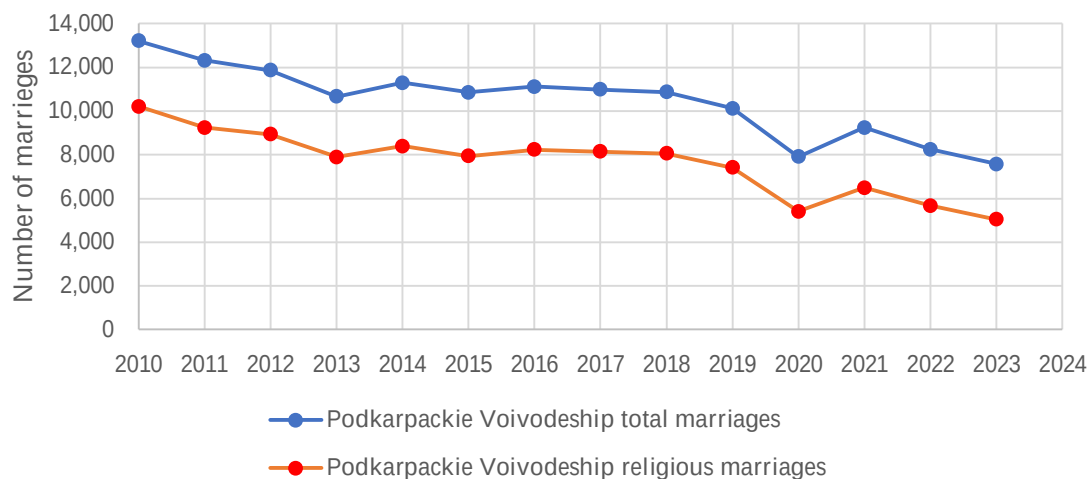


Figure 2. Number of marriages (count) in Podkarpackie Voivodeship, total and religious, 2010–2023

Despite the distinct social characteristics of the region, the observed changes follow the same general direction as those identified at the national level. The number of marriages in the Podkarpackie Voivodeship also exhibits a downward trend, although the pace of decline appears slightly less pronounced than in Poland as a whole.

To assess the pace and variability of changes across consecutive years, year-to-year dynamic indices with a variable base were calculated (Table 1).

Table 1. Year-to-year dynamic indices ($t/t-1 \times 100$) of the number of marriages (count) in Poland and Podkarpackie Voivodeship, total and religious, 2010–2023.

Year	Poland marriages in general	Podkarpackie Voivodeship marriages in general	Poland religious marriages	Podkarpackie Voivodeship religious marriages
2010	-	-	-	-
2011	90.42	93.26	86.20	90.48
2012	98.73	96.23	97.27	96.73
2013	88.49	89.86	87.88	88.30
2014	104.49	105.91	103.17	106.40
2015	100.18	96.15	99.35	94.58
2016	102.45	102.41	103.77	103.68
2017	99.55	98.87	98.43	98.86
2018	99.93	98.96	99.25	98.94
2019	95.29	93.09	91.72	91.94
2020	79.10	78.16	71.22	73.08
2021	116.05	116.91	116.11	119.82
2022	92.57	89.11	87.93	87.40
2023	93.63	91.94	86.17	88.85

Note: 2010 is not defined for a variable-base index.

The results indicate increased volatility in the number of marriages during periods of heightened uncertainty, suggesting the sensitivity of marriage decisions to external disruptions. At the same time, similarities in the direction and magnitude of changes observed at the national and regional levels suggest the presence of shared structural conditions influencing household behaviour across spatial scales.

The analysis is complemented by fixed-base indices (Table 2), which allow for the assessment of cumulative changes over the longer term.

Subsequent analysis focuses on the structure of religious marriages, with particular emphasis on Catholic marriages, which have historically played a significant role in the Polish family model. For transparency, we also decompose religious marriages into their dominant denomination and show annual counts for Catholic and all religious marriages.

Table 2. Fixed-base indices (2010 = 100) of the number of marriages (count) in Poland and Podkarpackie Voivodeship, total and religious, 2010–2023

Year	Poland marriages in general	Podkarpackie Voivodeship marriages in general	Poland religious marriages	Podkarpackie Voivodeship religious marriages
2010	100.00	100.00	100.00	100.00
2011	90.58	93.26	86.20	90.48
2012	87.63	89.75	83.85	87.53
2013	77.40	80.66	73.69	77.29
2014	82.30	85.42	76.02	82.23
2015	77.88	82.13	75.53	77.78
2016	80.63	84.11	78.38	80.63
2017	79.78	83.16	77.15	79.71
2018	78.93	82.30	76.57	78.87
2019	72.59	76.61	70.23	72.52
2020	53.01	59.88	50.02	53.00
2021	53.58	70.01	58.08	63.50
2022	55.53	62.39	51.07	55.50
2023	49.30	57.36	44.00	49.31

Figure 3 compares the annual counts of Catholic marriages and total religious marriages in Poland, 2010–2023.

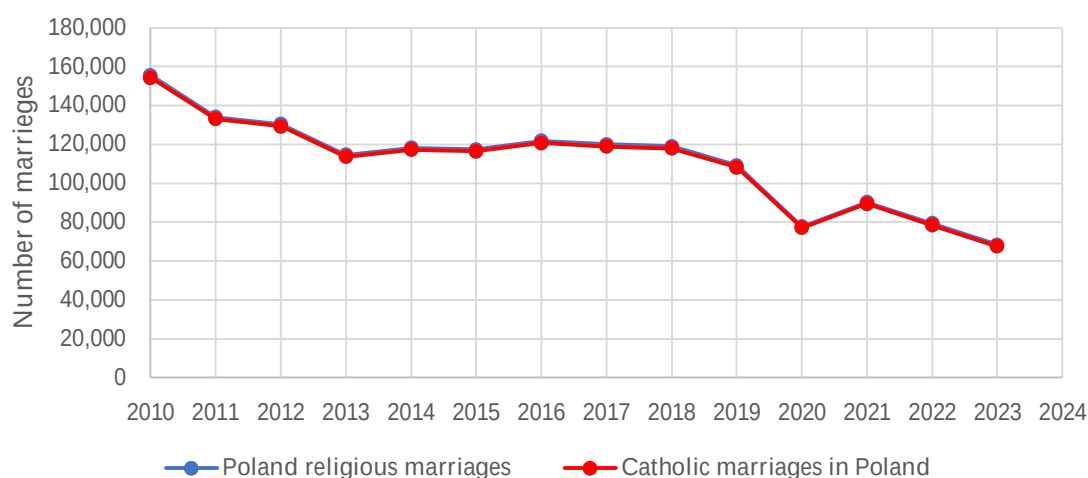


Figure 3. Catholic and religious marriages (count) in Poland, 2010–2023

The results indicate the continued dominance of Catholic marriages within the structure of religious unions. However, similarly to overall marriage trends, a gradual decline in their absolute number is observed. The gradual nature of these changes suggests institutional adaptation rather than abrupt structural shifts in marriage behaviour.

Regional analysis (Figure 4) demonstrates that the share of Catholic marriages in the Podkarpackie Voivodeship remains relatively high compared to the national average. Nevertheless, a downward trend is also evident in this region. These findings indicate that even in areas characterised by strong institutional continuity, adaptive processes consistent with broader national patterns are observable.

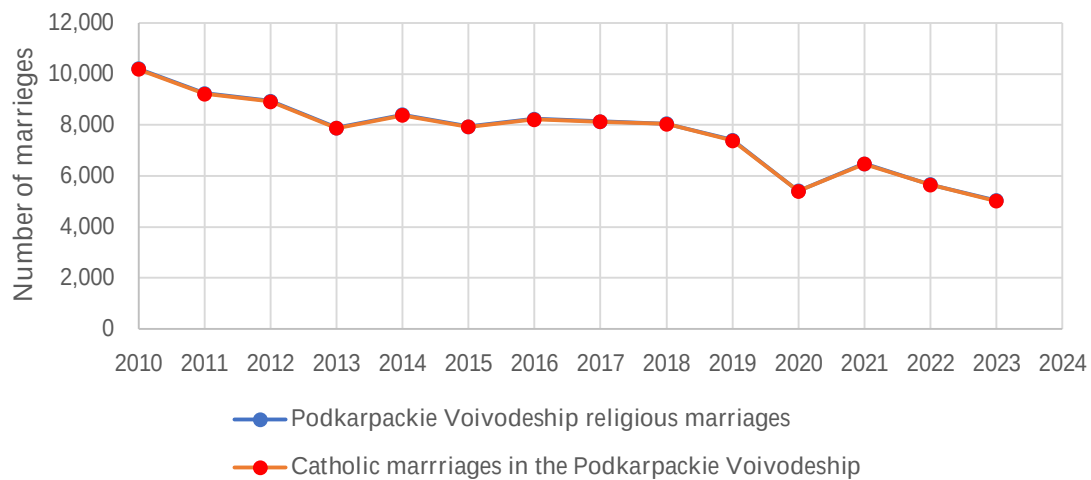


Figure 4. Catholic and religious marriages (count) in Podkarpackie Voivodeship, 2010–2023.

The final stage of the empirical analysis involves estimating future changes in the number of marriages in order to extend the interpretation of results with an exploratory dimension. Extrapolations are illustrative across the 2020 structural break; model fit statistics are reported in Table 3.

Table 3. Exponential trend model fit (2010–2023)

Series	R ²	RMSE	N
Poland – total marriages	0.75	12,210.24	14
Poland – religious marriages	0.83	10,439.61	14
Podkarpackie – total marriages	0.85	677.50	14
Podkarpackie – religious marriages	0.85	606.82	14

Models estimated on 2010–2023; projections are illustrative across the 2020 disruption.

Model fit is moderate at the national level but stronger for regional series, reflecting the structural disruption observed in 2020. The exponential specification provides satisfactory fit for regional series ($R^2 > 0.85$), while fit at the national level is moderate due to the structural disruption in 2020.

Table 4 presents exponential trend projections for 2024–2026.

Table 4. Exponential trend projection of marriages (2024–2026)

YEAR	Exponential trend projection			
	Poland – total (count)	Poland – religious (count)	Podkarpackie – total (count)	Podkarpackie – religious (count)
2024	149,093	74,443	7,859	5,331
2025	145,136	70,799	7,579	5,094
2026	141,283	67,332	7,309	4,867

Note: Based on exponential trend models estimated for 2010–2023. The 2020 disruption limits structural stability; projections are illustrative only.

The projections suggest a continuation of the downward trend in subsequent years, with a possible gradual deceleration in the rate of decline. It should be emphasised that these projections are illustrative in nature and should not be interpreted as predictive forecasts, as they do not account for potential future institutional, economic, or policy-related changes.

The projected trajectories do not indicate a short-term reversal of the observed downward trend.

5. Discussion

The analysis confirms a long-term decline in marriage formation in Poland, observable both at the national level and in the Podkarpackie Voivodeship. This decline should not be interpreted as a short-term fluctuation but rather as a manifestation of structural changes in household decision-making. Marriage formation may be understood as a strategic household decision made under conditions of uncertainty, where households weigh long-term commitments against economic stability and institutional predictability. This interpretation is consistent with research showing that heightened economic uncertainty and unstable early-career trajectories tend to delay long-term family commitments, as households adopt postponement strategies under risk (Alderotti et al., 2021; Comolli, 2017). In the Polish context, the decline observed after 2010 coincided with periods of labour-market volatility affecting younger cohorts, tightening housing affordability conditions, and, in the early 2020s, a sharp inflationary episode that reduced household purchasing power (Hick et al., 2025; Amores et al., 2025). While the present study does not estimate causal effects, the temporal alignment between macroeconomic instability and intensified fluctuations in marriage formation supports an uncertainty-based interpretation of household behaviour.

While the overall direction of change remains consistent across spatial levels, the regional analysis reveals clear differences in the pace of adjustment. The Podkarpackie Voivodeship, characterised by a relatively strong institutional presence of religion and persistent family norms, exhibits a slower decline in marriage formation compared to the national average. This finding supports the interpretation that local institutional arrangements may moderate but not reverse broader demographic trends. Rather than preventing change, strong institutions appear to shape the timing and form of household adaptation. This moderating effect can be interpreted within an institutional framework. Where religious and normative structures remain strongly embedded, they may stabilise expectations surrounding marriage and reduce behavioural volatility, thereby slowing the speed of demographic adjustment. At the same time, the persistence of a downward trajectory indicates that local institutional continuity delays, rather than reverses, broader structural change (Śleszyński et al., 2023; Rejowska, 2021).

The structure of religious marriages further illustrates this mechanism. Despite the continued dominance of Catholic marriages within the category of religious unions, their absolute number has been gradually decreasing. This pattern suggests an evolutionary adjustment of institutional practices rather than abrupt structural disruption. Religious institutions continue to function as coordination mechanisms that stabilise expectations and

provide normative frameworks for marriage formation, even as households increasingly postpone formal commitments.

The sharp decline observed during the COVID-19 period illustrates how sensitive marriage decisions are to sudden institutional disruptions. Administrative restrictions, heightened uncertainty, and disruptions to social coordination temporarily weakened the capacity of institutions — both civil and religious—to facilitate marriage formation. Beyond formal restrictions, the pandemic intensified perceived income risk and planning uncertainty, particularly among younger individuals at transitional stages of labour-market entry. Under such conditions, postponement of marriage may be understood as a rational sequencing strategy in the face of increased volatility, consistent with evidence on union formation under uncertainty (Guetto et al., 2021).

However, the partial rebound observed after the pandemic suggests that such shocks may delay rather than permanently suppress marriage decisions. A similar pattern of sharp decline in 2020 followed by partial recovery has been documented in several European countries, suggesting that the pandemic operated through common institutional and behavioural channels (Cantalini et al., 2024; Recaño, 2024). The distinctive contribution of the present study lies in demonstrating how these macro-level tendencies unfold within a single country marked by pronounced regional institutional heterogeneity.

The overall direction of change remains consistent with the Second Demographic Transition, particularly the postponement and declining prevalence of formal unions (Lesthaeghe, 2014), suggesting differentiated temporal adaptation within a common structural direction of demographic change. However, the regional differentiation suggests that the speed of adaptation is shaped by institutional embeddedness rather than solely by value change. The present findings do not allow for disentangling economic and cultural mechanisms, but rather indicate their potential interaction at the macro level. From an economics-of-the-family perspective, the sensitivity of marriage timing to macroeconomic volatility reflects its forward-looking, resource-dependent nature (Comolli, 2017; Alderotti et al., 2021).

From a public policy and regional governance perspective, these findings emphasise the importance of accounting for institutional heterogeneity across regions when designing demographic and family-related policies. Uniform policy instruments may yield differentiated outcomes depending on local institutional capacity and social embeddedness. Consequently, regional governance structures and institutional coordination mechanisms should be considered key elements in managing demographic change.

Finally, while the exploratory projections indicate a continuation of the downward trend in marriage formation, they should not be interpreted as forecasts. Future trajectories will depend on the interaction between economic conditions, institutional adaptation, and policy interventions. This highlights the need for further research integrating micro-level data on household decision-making with regional institutional analyses.

6. Conclusions

This study shows that marriage formation in Poland has experienced substantial structural change since 2010, with a persistent decline and a marked, temporary disruption during the COVID-19 period.

Compared to the national level, changes in Podkarpackie Voivodeship are less dynamic and the relative importance of religious marriage remains higher, pointing to the moderating role of regional institutional and cultural contexts.

Overall, the study contributes to research on demographic change by linking aggregate marriage patterns with household decision-making under conditions of economic uncertainty and ongoing institutional transformation in Central and Eastern Europe.

7. Limitations and Future Research

This study has several limitations that should be considered when interpreting the results. First, the analysis relies on aggregated administrative data, which does not allow for the identification of individual-level motivations or causal mechanisms underlying marriage decisions. The findings therefore document structural patterns and temporal dynamics rather than behavioural determinants.

The study focuses exclusively on formal marriages; trends in cohabitation may follow different dynamics and require separate analysis.

Second, the empirical scope is intentionally limited to selected demographic indicators and does not explicitly incorporate economic variables such as income, employment stability, housing conditions, or family policy instruments. While these factors are likely to influence marriage formation, the descriptive approach adopted here aims to capture institutional and contextual regularities rather than estimate multivariate causal effects.

Finally, the trend projections presented in the Results section are exploratory and should not be interpreted as forecasts, as they do not account for potential future institutional, economic, or policy-related shocks. Future research should integrate micro-level demographic data with labour-market and housing information in order to examine the mechanisms underlying household decision-making. Comparative analyses across regions with differing institutional contexts would further enhance understanding of how local structures moderate broader demographic trends.

Structural-break specifications could further refine the interpretation of post-2020 dynamics.

Conflict of interest: none

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The Behavioral and Economic Landscape of Cognitive Health: An Integrated Framework for Prevention and Policy

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Abstract: Cognitive health is a crucial dimension of human capital, shaping productivity, labor market participation, and long-term societal welfare. As populations age, cognitive decline and dementia create growing public-health and macroeconomic pressures that existing, largely reactive care models struggle to address. This paper develops an interdisciplinary framework integrating behavioral and health economics to analyze how individual behavior, diagnostic systems, and institutional incentives jointly determine cognitive health outcomes. Drawing on empirical literature and recent trial evidence, including the AGELESS multidomain intervention for cognitive frailty and lifetime economic modeling of the FINGER prevention program, the study examines behavioral determinants of underinvestment in cognitive health, the economic consequences of delayed diagnosis, and the cost-effectiveness of multidomain prevention. Particular attention is paid to modifiable lifestyle and cardiovascular risks, behavioral biases, and the role of digital tools in supporting prevention. The findings indicate that structured multidomain interventions can be cost-effective across settings and that effective cognitive health policy requires coordinated strategies for prevention, early detection, and incentive alignment.

Keywords: cognitive health; behavioral economics; dementia prevention; diagnostic safety; health capital; digital health;

JEL Classification: I12; D91; H51

1. Introduction: The Economic Case for Cognitive Health Investment

Cognitive health constitutes a foundational component of human capital, influencing productivity, labor force participation, decision-making quality, and overall societal welfare. As demographic transitions shift advanced economies toward aging population structures, cognitive decline and dementia are increasingly recognized as major global public health challenges with substantial economic and societal costs (WHO, 2021). Traditional approaches to cognitive disorders have been predominantly biomedical, emphasizing neuropathology, pharmacological interventions, and clinical management. While indispensable, this perspective alone is insufficient to explain persistent underinvestment in prevention, delayed diagnosis, and systemic inefficiencies in care delivery. This perspective is grounded in the human capital tradition (Becker, 1983) and its extension to health capital (Grossman, 1972),

which conceptualize health as a stock that can be accumulated, maintained, and depreciated over time.

Three structural realities motivate a broader analytical lens:

First, a substantial share of dementia risk is attributable to modifiable behavioral factors, including physical inactivity, poor diet, sleep disturbance, social isolation, and unmanaged cardiovascular risk. Recent trial evidence confirms the modifiability of cognitive trajectories through lifestyle intervention.

Second, health systems systematically underperform in early identification of mild cognitive impairment (MCI), resulting in delayed intervention and escalating long-term costs. Evidence from the OECD working paper *The Economics of Diagnostic Safety* demonstrates that diagnostic errors across healthcare systems represent a significant economic burden, accounting for a measurable share of total healthcare expenditure and GDP in advanced economies (Slawomirski et al., 2025). These inefficiencies are particularly consequential in progressive conditions such as cognitive decline, where timing critically determines cost trajectories.

Third, emerging evidence from large-scale trials demonstrates the economic viability of prevention. The Finnish Geriatric Intervention Study to Prevent Cognitive Impairment and Disability (FINGER) program, evaluated over a lifetime horizon, shows potential cost savings of 16,928 SEK (approximately 1,600 USD) per person along with 0.043 quality-adjusted life year (QALY) gains, supporting extended dominance for multidomain prevention programs (Ngandu et al., 2023). The 2025 AGELESS trial in Malaysia further confirms that multidomain interventions can be cost-effective in low-middle income countries (LMICs), demonstrating improvements in cognitive and physical function among older adults with cognitive frailty at costs feasible for resource-constrained settings (Ponvel et al., 2025).

These findings challenge the prevailing reactive model of dementia care and invite reconsideration of prevention as an economically rational investment rather than a discretionary expense.

This paper advances the central argument that cognitive health must be understood as the product of interacting behavioral choices, economic incentives, and diagnostic system performance. Behavioral biases influence individual health investments; institutional incentives shape provider behavior; and structural inefficiencies distort resource allocation. These mechanisms jointly determine population-level cognitive outcomes and fiscal sustainability.

The objectives of this paper are threefold:

1. To analyze the behavioral and economic mechanisms that jointly determine cognitive health outcomes, with emphasis on modifiable risk factors, prevention gaps, and diagnostic inefficiencies.
2. To evaluate the cost-effectiveness of multidomain prevention programs (FINGER, AGELESS) and digital health tools, and to assess their implications for health system design and public policy.

2. Methodology

This study adopts a narrative, theory-driven review design to develop an integrated behavioral-economic framework for cognitive health. We combined targeted literature searches with purposive selection of landmark trials, economic evaluations, and policy reports rather than conducting a formal systematic review.

Literature searches were performed in PubMed, Scopus, and Google Scholar for articles published primarily in English from approximately 2000 onwards, using combinations of keywords such as “*cognitive health*”, “*dementia prevention*”, “*multidomain intervention*”, “*FINGER trial*”, “*cognitive frailty*”, “*AGELESS trial*”, “*behavioral economics*”, “*diagnostic safety*”, “*cost-effectiveness*”, and “*digital health*”. In addition, we screened reference lists of key articles and consulted grey literature from international organizations, including OECD and the World-Wide FINGERS Network, to capture recent economic and policy analyses.

Evidence selection was guided by conceptual relevance rather than exhaustive coverage. We prioritized: epidemiological studies quantifying modifiable risk factors for dementia; multidomain randomized controlled trials targeting lifestyle and vascular risk (e.g. FINGER, AGELESS); economic evaluations and long-term modeling studies of prevention programs; and (iv) reports on diagnostic safety and digital health-supported interventions. Data from included sources were synthesized narratively and structured around a priori themes derived from health-capital theory and behavioral economics: modifiable risk and life-course accumulation, behavioral barriers to prevention, diagnostic efficiency, multidomain interventions, digital tools as behavioral supports, and socio-economic gradients. Quantitative results such as QALYs, costs, and adherence rates were summarized in tables to facilitate interpretation by policymakers and health-economics audiences.

Because the aim was to build an integrative framework and policy overview, we did not perform formal risk-of-bias assessment or meta-analysis; limitations of this narrative approach are considered in the discussion.

2.1. Modifiable Risk Factors in Cognitive Decline

A growing body of epidemiological research indicates that a substantial share of dementia risk is attributable to modifiable behavioral and environmental factors. (Livingston et al., 2020)

Table 1. Modifiable risk factors in cognitive decline

Aspect	Description
Core idea	Dementia risk is substantially influenced by modifiable behavioral and environmental factors, not just chronological aging.
Key modifiable risk factors	Physical inactivity; hypertension and cardiovascular disease; diabetes and metabolic syndrome; obesity; social isolation; smoking; insufficient cognitive stimulation.
Biological pathways	Vascular damage; neuroinflammation; metabolic dysregulation; reduced neuroplasticity.
Life course accumulation	Early life education, midlife cardiovascular health, and later life behaviors jointly shape long run cognitive trajectories.
Economic/“capital” perspective	Cognitive capacity behaves like a stock of capital subject to depreciation and investment, consistent with the earlier framework.

Policy Implication

From a policy perspective, the presence of modifiable risk factors fundamentally changes the economic interpretation of cognitive decline. If cognitive impairment were purely genetically determined or biologically unavoidable, prevention policy would have limited scope. Instead, the existence of behavioral determinants implies that substantial portions of the future disease burden may be preventable through targeted behavioral interventions and systemic incentives.

2.2. Evidence from Multidomain Intervention Trials

The theoretical argument for multidomain intervention targeting multiple risk pathways simultaneously receives strong empirical support from recent large-scale trials. Earlier multidomain intervention studies, such as the MAPT trial (Vellas et al., 2014), provided initial evidence that combining cognitive, nutritional, and lifestyle components may influence cognitive trajectories, although results were more heterogeneous than in later trials.

The FINGER Trial

The Finnish Geriatric Intervention Study to Prevent Cognitive Impairment and Disability (FINGER) was a landmark randomized controlled trial demonstrating that a multidomain lifestyle intervention (diet, exercise, cognitive training, vascular risk monitoring) can improve or maintain cognitive functioning in at-risk older adults (Ngandu et al., 2023). Subsequent economic modeling confirmed long-term cost-effectiveness, with lifetime savings and QALY gains.

The AGELESS Trial (2025)

The AGELESS trial, conducted in Malaysia, recruited 106 older adults (age ≥ 60 years) with cognitive frailty defined as the simultaneous presence of physical frailty (≥ 1 Fried criteria) and mild cognitive impairment (CDR = 0.5) (Ponvel et al., 2025). Participants were randomized to either a 24-month multidomain intervention or a control group receiving an educational module.

Intervention components included:

Table 2. AGELESS Trial – intervention components and primary outcomes

Element	Key finding
Physical Activity	Structured exercise programs and activity counseling
Cognitive Training	Memory and reasoning exercises
Nutrition counseling	Dietary guidance aligned with healthy aging principles
Psychological counseling	Support for mood and motivation
Cardiovascular care	Monitoring and management of vascular risk factors
Primary outcomes and timepoints	Cognitive performance, physical function, vascular health markers, and dietary behavior at 0/12/24 months

Primary outcomes assessed at baseline, 12 months, and 24 months included cognitive performance (modified Neuropsychological Tests Battery), physical function (gait speed, balance, strength), vascular health markers, and dietary behavior.

Key findings:

Table 3. AGELESS Trial – key outcome findings

Outcome category	Key finding
Cognitive improvements	Significant gains across multiple cognitive domains at 12 and 24 months
Physical function	Improved mobility, strength, and functional capacity
Vascular outcomes	Better blood pressure control and improved metabolic parameters
Dietary behavior	Increased adherence to healthy eating patterns
Cost-effectiveness	Cost-effective versus usual care, with favorable incremental cost-effectiveness ratios (ICERs)
Adherence	Overall adherence 52.8% at 12 months; 52.8%–90.6% across individual intervention modules

Significance for LMICs

The AGELESS trial is particularly significant because it demonstrates feasibility and cost-effectiveness in a low-middle income country setting. This addresses a critical gap in the evidence base, as most prior dementia prevention trials were conducted in high-income countries. The trial confirms that multidomain interventions can be adapted and implemented in resource-constrained settings where the prevention potential may be even greater due to higher prevalence of lifestyle-related risk factors.

The World-Wide FINGERS Network

Both the original FINGER trial and the AGELESS trial are part of the World-Wide FINGERS Network, an international consortium harmonizing data and methodologies across multiple prevention trials globally (Kivipelto et al., 2020). This network approach enables cross-national comparisons and accelerates translation of evidence into policy.

2.3. Behavioral Channels Linking Lifestyle and Cognitive Outcomes

The behavioral determinants of cognitive health operate through several interconnected pathways that influence both neurological resilience and systemic physiological functioning.

Table 4. Behavioral channels linking lifestyle factors to cognitive outcomes

Factor	Mechanism / effect on cognition	Evidence/example mentioned
Physical activity	Improves cerebral blood flow, supports hippocampal neurogenesis, and reduces vascular risk; sedentary lifestyle and metabolic syndrome accelerate decline	Structured programs effective in AGELESS trial
Nutrition	Unhealthy diets (processed foods, saturated fats, sugars) promote inflammation and vascular damage; healthy patterns slow cognitive aging	Nutritional counseling improved diet in AGELESS trial
Sleep quality	Chronic disruption impairs memory consolidation, increases amyloid accumulation, and reduces metabolic clearance, accelerating neurodegeneration	–
Social engagement & cognitive stimulation	Isolation and low intellectual activity speed decline; active engagement builds cognitive reserve, supporting resilience despite pathology	–
Synergistic effects of behaviors	Risk behaviors cluster and jointly amplify risk; single behavior interventions have smaller effects than multidomain programs	Multidomain approach validated by FINGER and AGELESS trials

2.4 Behavioral Economic Mechanisms Behind Prevention Gaps

Table 5. Behavioral economic mechanisms behind prevention gaps

Mechanism	Core idea	Effect on preventive behavior	Implications for intervention design
Present bias	Short term effort is overweighted relative to long term, uncertain benefits	People choose immediate comfort over exercise, diet change, or sleep hygiene	Use commitment devices, short term rewards, and near term milestones to make benefits feel more immediate
Bounded rationality	Limited capacity and health literacy to process complex, probabilistic information about cognitive decline	Reliance on heuristics and social norms instead of evidence based choices	Simplify choices, provide clear defaults, and use plain language guidance to lower cognitive load
Optimism bias	Belief that negative outcomes (e.g., dementia) are less likely for oneself than for others	Underestimation of personal risk reduces motivation to change behavior	Provide personalized, salient risk feedback and concrete scenarios that make individual vulnerability more visible
Habit formation	Diet, activity, and sleep patterns become entrenched routines that are hard to change	Even motivated individuals struggle to sustain new, healthier behaviors	Support stable routines, cues, and environments that make the desired behavior the easy, automatic choice
Behavioral prevention gap	People value healthy lifestyles in principle but systematically fail to implement them consistently	Persistent gap between intentions and real-world preventive action	Combine commitment devices, decision simplification, salient feedback, and habit building structures within interventions

Despite growing public awareness of healthy lifestyle recommendations, adherence to preventive behaviors remains limited across many populations. Behavioral economics provides insight into this persistent gap between knowledge and action.

The AGELESS trial's multidomain approach directly addresses these behavioral barriers through regular group sessions, individual counseling, and structured activity schedules (Ponvel et al., 2025).

2.5. Digital Health Technologies as Behavioral Support Tools

Given the behavioral barriers described above, interventions that rely exclusively on information dissemination are unlikely to achieve substantial changes in population behavior. More effective strategies often incorporate behavioral design elements that facilitate adherence and habit formation.

Digital health technologies have emerged as promising tools in this context. Smartphone applications, wearable devices, and remote monitoring systems allow continuous tracking of lifestyle behaviors relevant to cognitive health, including physical activity, sleep patterns, and cognitive engagement.

This emerging evidence base is supported by recent economic evaluations showing that digital lifestyle interventions targeting individuals with mild cognitive impairment can delay dementia onset and remain cost-effective over long-term horizons (Fereshtehnejad et al., 2025).

Table 6. Digital health tools as behavioral support mechanisms

	Description
Behavioral nudges	Timely prompts that encourage immediate actions aligned with long term cognitive health goals
Personalized feedback	Tailored messages based on an individual's progress, risk profile, and adherence
Goal setting mechanisms	Structured, specific targets that reduce ambiguity and help translate intentions into concrete actions
Social support	Digital or hybrid peer connections providing motivation, accountability, and shared experience
Economic modeling evidence	Frontiers in Public Health model shows digital lifestyle programs for MCI may delay dementia and be cost effective over long horizons
Role in health economic frameworks	Demonstrates how behavioral interventions can be parameterized (uptake, adherence, risk reduction) in cost effectiveness and budget impact models
Integration with multidomain programs	My AGELESS and similar telerehabilitation trials test remote delivery of multidomain interventions, aiming to preserve effectiveness while lowering delivery costs and improving access

2.6 Socioeconomic Gradients in Cognitive Health Behavior

Behavioral determinants of cognitive health are not distributed evenly across populations. Socioeconomic conditions strongly influence both exposure to risk factors and capacity to engage in protective behaviors.

Individuals with lower educational attainment and income levels often face structural barriers that limit preventive behavior. These barriers may include:

- Educational attainment plays a particularly important role because it contributes to cognitive reserve while also influencing health literacy and long-term decision-making capacity. Higher levels of education are associated with greater engagement in cognitively stimulating activities and stronger adoption of preventive health behaviors.
- Empirical evidence also suggests that culturally specific factors and acculturation-related characteristics may shape cognitive health trajectories and access to prevention, particularly in heterogeneous populations (Lamar et al., 2023).
- Income inequality can also amplify risk exposure through environmental factors such as housing instability, urban pollution, and chronic psychosocial stress. These factors interact with behavioral patterns, creating compounding disadvantages that accelerate cognitive decline in vulnerable populations.

Policy Implications

From an economic perspective, these gradients highlight the importance of considering distributional effects when designing cognitive health policy. Preventive interventions that rely solely on individual initiative may disproportionately benefit already advantaged populations, thereby widening health inequalities.

Effective policy must therefore incorporate structural supports such as accessible community programs, subsidized interventions, and integrated healthcare delivery to ensure that prevention benefits reach populations at highest risk.

3. Results

Cognitive health policy must move beyond isolated clinical actions toward an integrated system strategy that aligns early detection, multidomain prevention, and behavioral support with long-term economic goals. The evidence from trials such as FINGER and AGELESS, together with broader epidemiological data on modifiable risk factors, shows that timely identification.

Taken together, the evidence reviewed here supports three system-level recommendations. First, routine cognitive screening for adults aged 60 and above, embedded in primary care check-ups, can bring individuals into preventive care earlier and at lower long-term cost. Second, multidomain programs combining physical activity, nutritional guidance, cognitive training, and vascular risk management – as demonstrated by the FINGER (Ngandu et al., 2023) and AGELESS (Ponvel et al., 2025) trials – should receive structured public reimbursement, since lifetime modeling indicates net cost savings alongside QALY gains. Third, digitally delivered behavioral support tools can extend the reach of such programs at lower marginal cost, though they require formal health-technology assessment before integration into reimbursement frameworks. Equity must be embedded in all three pillars: targeted subsidies and community-based delivery are necessary to prevent prevention benefits from accruing disproportionately to already-advantaged groups (Livingston et al., 2020).

4. Discussion

This study develops an integrated behavioral-economic framework for cognitive health by synthesizing evidence from landmark prevention trials, health-capital theory, and behavioral science. The central finding is that cognitive health outcomes are systematically shaped by modifiable behavioral factors, institutional incentive structures, and the quality of diagnostic pathways – none of which operates in isolation.

The behavioral-economic perspective contributes meaningfully to existing prevention literature by extending the health capital framework (Grossman, 1972) to cognitive outcomes and making explicit the mechanisms through which individual underinvestment in cognitive health arises. Present bias, optimism bias, and bounded rationality – mechanisms extensively documented in the behavioral economics literature (Kahneman, 2011; Thaler & Sunstein, 2008) – explain why knowledge of dementia risk does not automatically translate into preventive action. This behavioral gap is precisely what the structured group sessions and commitment mechanisms in AGELESS and FINGER are designed to close (Ponvel et al., 2025; Ngandu et al., 2023).

A key contribution of the paper is linking diagnostic system performance to the economics of cognitive health. OECD analysis of diagnostic safety establishes that delayed or missed diagnoses impose measurable costs on health systems (Slawomirski et al., 2025). In a progressive condition such as cognitive decline, diagnostic delay shortens the window for cost-effective intervention. The policy implication is that improving diagnostic accuracy is not merely a clinical quality concern but an investment with quantifiable returns in avoided care costs.

Several limitations warrant acknowledgment. The narrative review design, while appropriate for building an integrative framework, does not permit formal meta-analytic estimates of effect sizes or costs. The AGELESS trial, though informative, involved a relatively small sample ($n = 106$) in a single LMIC setting, limiting the generalizability of its cost-effectiveness estimates. Similarly, the FINGER lifetime model relies on Swedish health-system cost parameters that may not translate directly to other contexts. Future research should apply the proposed framework to multicountry longitudinal data and test the causal mechanisms identified here using quasi-experimental designs or large-scale RCTs with embedded economic evaluations.

5. Conclusions

Cognitive health represents a critical form of human capital with profound implications for individual well-being, labor market participation, and broader economic performance. It is shaped by the interaction of modifiable risk factors, behavioral biases that lead to systematic underinvestment, and diagnostic inefficiencies that delay effective intervention. Evidence from multidomain trials such as FINGER and AGELESS shows that structured programs targeting physical activity, nutrition, cognitive training, and vascular risk can prevent or slow decline in a cost-effective way, with lifetime models indicating both QALY gains and net cost savings when scaled at the population level. These findings, together with estimates that a substantial share of dementia cases is attributable to modifiable risks, strengthen the economic case for moving from reactive treatment toward proactive, long-horizon prevention and early detection. Effective policy therefore requires coordinated system-level reform: routine screening and improved diagnostic accuracy to bring interventions earlier in the disease course, funded multidomain prevention programs, behavioral support delivered through digital and community-based tools, and equitable access for high-risk and disadvantaged groups. At the macro level, such investments generate positive externalities by preserving productivity, reducing informal caregiving burdens, and lowering long-term health and social care expenditure benefits that individuals do not fully internalize in their private decisions, and that justify active public intervention. In this light, cognitive health should be treated not just as a clinical outcome, but as part of a society's economic infrastructure, warranting sustained, evidence-based investment and rapid translation of existing trial results into policy and practice.

Acknowledgements: The research/work was supported by the internal project "SPEV – Economic challenges and opportunities associated with investment mechanisms in the digital economy, 2026, University of Hradec Králové, Faculty of Informatics and Management, Czech Republic.

Conflict of interest: none

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A Citizen-Centered Multidimensional Evaluation of Electronic Public Services: Framework Development and Measurement Specification

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Abstract: The evaluation of electronic public services remains conceptually fragmented, as existing approaches often focus either on service quality attributes or on technology adoption mechanisms without fully integrating citizens' expectations and post-use evaluations. This paper addresses this gap by proposing a multidimensional evaluation framework for electronic public services that combines expectancy–disconfirmation logic with established technology acceptance theories. Drawing on the Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology (UTAUT), the framework positions adoption-related beliefs as antecedents shaping citizens' expectations and interpretations of service performance. The paper follows a conceptual and measurement-oriented approach. It systematically reviews major model families used in citizen-centered evaluation of electronic public services and synthesizes their key constructs into a coherent evaluation logic. This logic is subsequently translated into structured measurement specification (construct architecture, item blocks, and response formats) for future empirical application. The paper contributes by clarifying construct roles and separability in e-government evaluation and by providing a coherent operational template that supports diagnostic interpretation of whether negative evaluations primarily reflect weak perceived performance, unmet expectations, or their mismatch.

Keywords: citizen satisfaction; expectancy–disconfirmation; survey design; service quality measurement; adoption beliefs; trust in digital government; post-adoption evaluation; public sector digitalization

JEL Classification: D73; H11; L86; O33

1. Introduction

Digital transformation of public service delivery remains a strategic priority for governments worldwide, reflected in ongoing policy initiatives and comparative benchmarks of e-government development. In the European Union, the eGovernment Benchmark shows both progress and persistent disparities in digital service maturity across member states, underscoring the need for robust evaluation mechanisms that capture how citizens interact with and perceive digital public services across levels of public administration (European Commission, 2023). Contemporary digital government strategies

further emphasize that effective e-services are not merely technological artefacts but also require organizational change, citizen-centered design, and measurable outcomes in efficiency, transparency, and accessibility. Yet governments continue to face challenges in delivering satisfactory citizen experiences. In particular, mismatches often persist between e-government offerings and citizens' needs and preferences, frequently linked to limited user involvement and insufficient understanding of citizen expectations (Sharma et al., 2018; Patergiannaki & Pollalis, 2023).

Recent research highlights the multidimensional nature of e-government evaluation, integrating service quality, perceived value, trust, and satisfaction into broader explanatory models. Evidence suggests that service design features (e.g., usability and interactive support) shape technology-related perceptions that influence perceived service quality and continuance intentions (Chan et al., 2025), while other work links satisfaction with trust and ongoing engagement, pointing to the importance of considering both behavioral endpoints and post-use evaluative constructs (Kala et al., 2024). Despite these advances, prior research often follows either a techno-centric perspective focused on adoption models (e.g., UTAUT) or a service-centric perspective centered on generic service attributes. While useful, these approaches can blur the distinction between expectations, experienced performance, and outcomes, and may offer limited diagnostic guidance for public-sector service improvement. A public value perspective further motivates evaluation frameworks that focus on citizens' collective expectations and assessments of value created through government activity (Moore, 1995; MacLean & Titah, 2022).

This paper develops a multidimensional evaluation framework for electronic public services anchored in expectancy–disconfirmation logic and connected to a parsimonious adoption layer. The integrated logic is translated into an operationalizable measurement specification for future empirical application, and the paper concludes with implications, limitations, and directions for validation.

2. Theoretical Background

2.1. *Expectancy-Disconfirmation Model*

The EDM explains citizen satisfaction as the outcome of comparing prior expectations with experienced performance (Oliver, 1980). The core constructs are expectations, perceived performance, disconfirmation (expectation-performance gap), and satisfaction. Disconfirmation is positive when performance exceeds expectations and negative when performance falls short, which is why satisfaction is commonly treated as a central outcome in public service evaluation (Van Ryzin, 2006). EDM is diagnostically useful because it separates what citizens expected from what they perceived. However, results can be sensitive to how disconfirmation is measured (computed difference vs direct “met expectations” item), complicating interpretation in cross-sectional surveys (Van Ryzin, 2006). EDM also does not explicitly model broader antecedents of expectations (e.g. trust), which can matter in public-sector contexts (Morgeson, 2013). Accordingly, survey designs benefit from paired

expectation-performance items complemented by at least one direct met-expectation measure.

2.2. Technology Adoption beliefs (TAM and UTAUT)

Technology adoption theories provide a structured way to explain how citizens form evaluations of digital services and how these evaluations translate into intentions and continued use. Technology acceptance model (TAM) focuses on two parsimonious belief constructs (perceived usefulness and perceived ease of use) as key drivers of attitudes and behavioral intention (Davis, 1989). Its strength is simplicity and strong performance in survey research, with flexibility for extensions (Belanche et al., 2012). For eGovernment evaluation, however, TAM can be limited by its largely individual-level, pre-use orientation and weaker coverage of contextual constraints typical for public services.

Unified theory of acceptance and use of technology (UTAUT) broadens this lens by combining belief-based and contextual mechanisms: performance expectancy, effort expectancy, social influence and facilitating conditions predict behavioral intention and use (Venkatesh et al., 2003). This broader scope is valuable in public-sector settings where digital skills, enabling resources, and social norms may vary across citizen groups. At the same time, full UTAUT specifications can become measurement-heavy and context-sensitive, especially when moderators are included, requiring careful adaptation and adequate sample sizes (Venkatesh et al., 2003; Hujran et al., 2023). In evaluation-oriented survey designs, moderators are therefore often treated as controls capturing heterogeneity in citizens' capabilities and usage conditions.

2.3. Service Quality-Based Approaches

Service quality models specify what citizens evaluate during service interaction and provide validated measurement dimensions that are actionable for service improvement. E-S-QUAL captures routine online service quality through efficiency, fulfilment, system availability, and privacy, while E-RecS-QUAL addresses non-routine recovery experiences, responsiveness, compensation and contact (Parasuraman et al., 2005). In eGovernment context, extended instruments such as EGSQUAL incorporate attributes that are especially salient in public digital services, for example information quality, interactivity, assistance or interface features (Aljukhadar et al., 2022).

The main limitation of service quality models is that they are primarily descriptive. They identify perceived strengths and weaknesses but explain less clearly how perceptions translate into satisfaction and continued use without complementary cognitive and adoption mechanisms. For this reason, service quality measures are most informative when integrated with other models, such as EDM, TAM or UTAUT that link perceived performance to post-use outcomes (Verdegem & Verleye, 2009; Alruwaie et al., 2020).

2.4. Trust-based Approaches

In digital public administration, citizen evaluations also depend on trust in the institutions and technological infrastructure behind digital services. Trust helps reduce

uncertainty and perceived risk, strengthening links between perceived quality and behavioral intentions (Carter & Bélanger, 2005; Welch, 2004). The literature often distinguishes trust in government/institutions, trust in technology and interpersonal trust (Bélanger & Carter, 2008; Welch, 2004; Hujran et al., 2023). However, trust is context dependent and can be recursively related to satisfaction. This recursion complicates mediation claims in cross-sectional surveys and motivates treating trust primarily as a contextual control (or, at most, a cautiously interpreted moderator) when the focus is on service evaluation and questionnaire-based modelling (Bélanger & Carter, 2008; Welch, 2004; Morgeson, 2013).

3. Methodology

This paper demonstrates how technology adoption theories (TAM and UTAUT) can be used to evaluate electronic public services by developing a multidimensional evaluation framework anchored in expectancy–disconfirmation logic and operationalizing its constructs into a measurement specification (item pool, scale structure, and response formats). The study is conceptual and measurement-oriented; it does not administer a survey, conduct a pilot, or report original empirical data. The methodology therefore documents the procedure used to (i) identify relevant constructs, (ii) integrate them into a coherent evaluative logic, and (iii) translate them into an operational template suitable for future empirical application.

3.1. Evidence Base and Literature Selection Strategy

The evidence base consists of established model families widely used in research on technology adoption and citizen evaluation of digital public services: TAM, UTAUT, expectancy–disconfirmation approaches, service quality–based approaches, and trust-based approaches. Sources were prioritized when they (i) represent theoretically established constructs with frequent use in the relevant literature and (ii) provide scales or measurement practices that can be implemented concisely in a questionnaire format.

3.2. Construct Inclusion Criteria and Reduction Rules

Candidate constructs were screened using two criteria: (i) theoretical establishment and frequent use in technology adoption and eGovernment evaluation research and (ii) feasibility of concise measurement using survey scales. A reduction step was applied to maintain parsimony and avoid redundancy. Where constructs substantially overlapped across model families, they were mapped onto shared proxy dimensions to preserve explanatory coverage while keeping the operationalization feasible for future empirical studies.

3.3. Framework Synthesis Procedure

Framework synthesis proceeded in three steps: (1) Construct inventory: Constructs extracted from the selected model families were listed and provisionally grouped by their role in the evaluation process (evaluative constructs, belief-based antecedents, service-encounter attributes, and contextual factors). (2) Conceptual structuring: The groups were arranged to reflect the temporal logic of service evaluation. Service-encounter attributes were

organized into candidate, interpretable dimensions intended for subsequent empirical validation, ensuring the framework remains actionable for service improvement. (3) Minimal relationship specification: A minimal set of relationships was specified to support expectancy–disconfirmation evaluation while integrating adoption beliefs as upstream determinants, without expanding the framework into a measurement-heavy specification.

3.4. Measurement Operationalization

The framework was operationalized through construct-to-item alignment, resulting in an operational template (item pool and block structure). All attitudinal items are specified as 7-point scales. The measurement template is organized into blocks covering: (a) service context and usage conditions, (b) expectations, (c) perceived performance, (d) belief-based constructs from adoption theories, (e) self-efficacy and capability constraints, (f) a service quality item pool, (g) outcomes (with overall satisfaction as the primary dependent variable), and (h) controls, including contextual factors. To mitigate known sensitivity in expectancy–disconfirmation measurement, expectations and perceived performance are specified as matched attribute-level items enabling index construction and gap scores, complemented by at least one direct “met expectations” item.

3.5. Planned Validation in Future Empirical Application

Because the operationalization is not administered in this paper, dimensionality, reliability, and model relationships are not empirically tested here. The intended next step is empirical validation, including assessment of dimensionality and reliability (e.g., factor-analysis procedures) and robustness checks for alternative disconfirmation operationalization’s (gap-based versus direct measures).

4. Results

The primary result of this study is the development of a coherent, multidimensional evaluation framework that integrates expectancy–disconfirmation logic with technology adoption theories and service quality perspectives. The framework clarifies the roles of expectations, perceived performance, and disconfirmation as core evaluative mechanisms, while positioning adoption-related beliefs as antecedents shaping how citizens interpret their service experience (Figure 1). By explicitly separating these components, the framework addresses a common limitation of prior e-government evaluation studies, which often conflate perceptions, beliefs, and outcomes into single latent constructs (Sharma et al., 2018).

A second contribution is the translation of the framework into an operationalizable measurement specification. The proposed instrument aligns adoption beliefs (benefits beliefs grounded in TAM/UTAUT) with expectation formation, while service quality attributes define the content of perceived performance. This structure enables evaluators to distinguish whether dissatisfaction arises primarily from unmet expectations, weak perceived performance, or their mismatch, which is central to public service satisfaction research (Van Ryzin, 2006; Morgeson, 2013). Trust is included as a contextual control to account for

institutional and technological legitimacy effects without conflating them with perceived service quality (Carter & Bélanger, 2005; Welch, 2004).

4.1. Evaluation Backbone: Expectancy, Performance, Disconfirmation, Satisfaction

At its core, the framework (Figure 1) adopts expectancy–disconfirmation logic and distinguishes four analytically separable constructs: expectations (E), perceived performance (P), disconfirmation (D), and overall satisfaction (S). Consistent with established applications in public service evaluation, expectations and perceived performance jointly determine disconfirmation, and disconfirmation is a central predictor of satisfaction (Van Ryzin, 2006).

A key measurement implication is that perceived performance should not be captured only as a single global impression. Instead, perceived performance is operationalized as attribute-level appraisals reflecting concrete facets of the service experience (for example usability, reliability, security, and information quality), which supports diagnostic interpretation and aligns with citizen survey practices linking facet ratings to overall satisfaction (Van Ryzin, 2006).

To address sensitivity in the measurement of disconfirmation, the framework adopts a dual operationalization. First, disconfirmation can be computed as a subtractive gap score based on matched expectation and performance measures. Second, disconfirmation is captured by at least one direct perceived confirmation/disconfirmation item (for example met or exceeded expectations). This dual approach supports interpretability when difference scores are noisy in cross-sectional survey designs (Van Ryzin, 2006).

4.2. Adoption and Behavioral Outcomes

The framework incorporates technology acceptance theory as a linking layer between post-use evaluation and behavioral outcomes (Figure 1). Consistent with UTAUT, behavioral intention is retained as the primary behavioral endpoint, and use behavior is included where feasible (Venkatesh et al., 2003).

To maintain parsimony and avoid redundancy with attribute-level evaluation, the adoption layer retains perceived benefits (usefulness/performance expectancy) as a higher-level value belief, while ease of use/effort is captured diagnostically within the matched attribute-level expectations and performance measures rather than as a separate adoption construct. Benefit beliefs are positioned as antecedents that can shape expectation formation and support interpretation of how evaluative judgements translate into behavioral intention (Venkatesh et al., 2003).

In post-use settings, behavioral endpoints may be operationalized as behavioral intention and related signals (e.g., intention to reuse or recommend), which you can see in Figure 1. Empirical evidence from online public service contexts links confirmation of expectations to intention and positive word of mouth, supporting inclusion of post-evaluation behavioral intentions in the model (Belanche et al., 2012).

4.3. Attribute-based Performance Measurement

Service quality models are incorporated as a measurement layer defining the substantive content of perceived performance and matched expectations. Accordingly, service quality attributes are treated as the operational content of E and P rather than as a competing explanatory model (Figure 1). This operationalization is consistent with E-S-QUAL, where efficiency, fulfilment, system availability, and privacy capture normal-use service quality, and complementary recovery dimensions capture non-routine problem handling (Parasuraman et al., 2005).

For governmental contexts, specialized instruments provide tailored attribute pools. In particular, EGSQUAL offers government-website-specific dimensions and validated item pools suited for evaluating public sector digital services (Aljukhadar et al., 2022).

4.4. Capability Constraints: Self-efficacy

Beyond core TAM/UTAUT belief constructs, the framework includes self-efficacy as a capability constraint relevant in heterogeneous citizen populations. Self-efficacy is operationalized as confidence in completing e-service procedures and handling difficulties independently, and it is treated as distinct from service quality attributes because it captures user capability rather than service characteristics. This approach is consistent with eGovernment evaluation studies that measure self-efficacy explicitly through survey items capturing confidence and independent task completion (Alruwaie et al., 2020).

4.5. Trust as a Control Construct

Finally, trust is included as a contextual factor relevant to eGovernment adoption and evaluation. Prior work distinguishes trust in government and trust in the Internet/technology channel as relevant beliefs associated with citizens' willingness to transact online with government (Carter & Bélanger, 2005; Welch, 2004).

However, because trust and satisfaction can be mutually reinforcing in cross-sectional self-report designs, the framework positions trust primarily as a contextual control rather than a central mediator. This choice is consistent with arguments that broader institutional predispositions can shape citizens' expectations entering the service encounter and complicate causal interpretation if treated as an endogenous mediator (Morgeson, 2013).

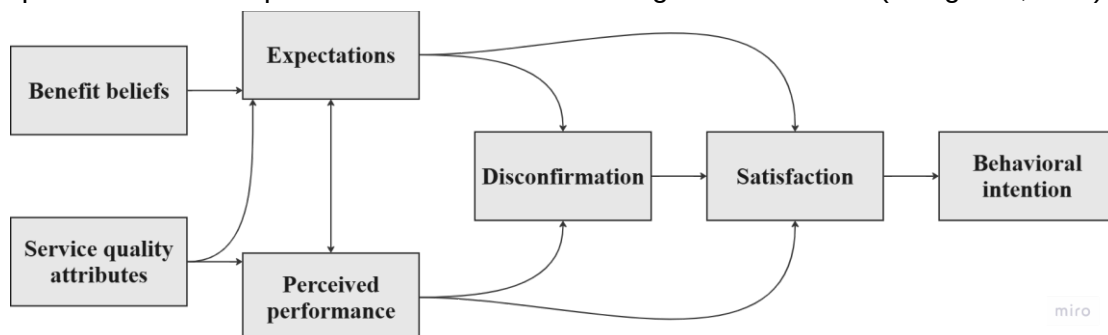


Figure 1. Evaluation framework linking expectations, performance, and behavioral intention

Note: The figure should be read from left to right; Control and contextual variables are not depicted in the figure but are specified in the measurement operationalization.

4.6. Measurement Operationalization

Tables 1 and 2 summaries the measurement operationalization of the proposed framework.

Table 1. EDM backbone: constructs and operationalization

Construct	Role in framework	Operationalization
Expectations (E)	Pre-use expectations about service attributes (baseline for later comparison).	Attribute-level expectations phrased in future/anticipated terms (matched to P items). Example format: "I expected that the service would be ... (easy to use / reliable / secure)." (7-point scale)
Perceived performance (P)	Post-use appraisal of the same service attributes experienced in the encounter.	Matched attribute items phrased as perceived performance. Example: "The service was ... (easy to use / reliable / secure)." (7-point scale)
Disconfirmation (D)	The (mis)match between E and P; central mechanism linking experience to satisfaction.	Two complementary approaches: (1) computed gap: $(D_i = P_i - E_i)$ + aggregated indices; (2) direct confirmation item (global): "Overall, the service met my expectations" (7-point scale)
Satisfaction (S)	Overall post-use evaluation (primary dependent variable in the framework).	Global satisfaction item(s). Example comparative wording used in EDM work: "How satisfied or dissatisfied are you with ...?" (7- point scale)

Table 2. Adoption/value layer, behavioral endpoints, capability and context

Construct	Role in framework	Operationalization
Behavioral intention (BI)	Post-evaluation behavioral endpoint	2–3 items on intention (future-oriented). UTAUT uses a 3-item intention scale. Intention to use/reuse the service or recommend to others. (7-point scale)
Benefit beliefs	Perceived value/goal attainment	2–3 global value items (7-point scale), e.g., "Using this e-service helps me complete the task effectively / saves time / improves efficiency." Not computed as a gap score and not an attribute facet.
Self-efficacy (SE)	Citizen capability/confidence to complete the service successfully (constraint layer linked to effort and support).	2-3 confidence items: Examples: "I could use eGov services if I wanted to"; "I could use eGov services if there was no one around to tell me what to do" (7-point scale)
Attribute pool for E and P (core)	Content of matched E and P	Use validated domains and select concise items per domain: Efficiency (e.g., ease of finding what is needed), System availability, Privacy, Fulfillment (7-point scale)
Attribute pool for E and P (eGov-specific)	Context tailoring for E/P	Example items shown in instrument: "The government's website provides accurate information"; "The government's website provides personalized information"; "The government's website has an appealing design." (7-point scale)
Service context and user characteristics	Heterogeneity and boundary conditions (voluntariness, experience, skills), used mainly as controls/moderators.	Service type, channel, frequency, prior experience (7-point scale; voluntariness (7-point scale). Add demographics and digital skills items as controls.

All attitudinal indicators use 7-point scales. Expectations (E) and perceived performance (P) are measured with matched attribute-level items (including usability/effort as service

attributes), enabling disconfirmation to be captured both as a computed gap score ($P - E$) and via a direct confirmation/disconfirmation item to improve interpretability in cross-sectional designs (Van Ryzin, 2006). To preserve the meaning of matched $E-P$ comparisons, the instrument is intended to evaluate one specified electronic public service (ideally one recent service encounter) per questionnaire. Possible extensions with additional control variables and behavioral endpoints are provided in Appendix (Full Table 2).

5. Discussion

This paper contributes to e-government evaluation research by integrating adoption-oriented and evaluation-oriented traditions within a single, connected evaluative logic. Technology acceptance models such as TAM and UTAUT provide robust explanations of behavioral intention and use, yet they do not explicitly represent the post-use mechanism central to public service performance assessment, namely the separation of expectations, experienced performance, and their comparison through disconfirmation (Venkatesh et al., 2003; MacLean & Titah, 2022). Embedding behavioral endpoints and parsimonious value beliefs within an expectancy–disconfirmation structure therefore offers a clearer account of how citizens arrive at satisfaction judgements and how these judgements relate to post-adoption intentions (Verdegem & Verleye, 2009; Alruwaie et al., 2020).

A key theoretical implication is improved construct separability in a domain where beliefs, perceptions, and outcomes are often collapsed into broad latent variables. In public-sector contexts, expectations are shaped not only by prior experience but also by institutional predispositions and legitimacy perceptions, which can bias subsequent evaluation (Morgeson, 2013). Treating perceived benefits (usefulness/performance expectancy) as a higher-level value belief and retaining behavioral intention as an endpoint, while operationalizing ease of use/effort primarily as attribute-level content of expectations and perceived performance, strengthens conceptual clarity and reduces redundancy in measurement. Positioning trust as a contextual control rather than a central mediator further limits endogeneity concerns and supports interpretation in cross-sectional designs (Carter & Bélanger, 2005; Welch, 2004; Morgeson, 2013).

Methodologically, the framework implies a measurement strategy prioritizing interpretability and diagnostic value. Matched expectation–performance items enable attribute-level diagnosis, allowing evaluators to locate dissatisfaction in concrete service facets rather than relying on global impressions (Van Ryzin, 2006). The dual operationalization of disconfirmation (computed gap scores complemented by a direct confirmation/disconfirmation item) addresses known sensitivity in EDM measurement and provides a practical robustness check in cross-sectional surveys (Van Ryzin, 2006). Positioning service quality scales as the attribute-level content of expectations and performance facilitates the use of validated item pools while keeping the evaluative mechanism explicit (Parasuraman et al., 2005; Aljukhadar et al., 2022). Including self-efficacy as a capability constraint further improves diagnostic interpretation by distinguishing service deficiencies from user capability barriers (Alruwaie et al., 2020).

For empirical analysis, future applications can estimate the framework using regression-based models or structural equation modelling, with confirmatory factor analysis to validate dimensionality and reliability of the measurement structure. Where feasible, linking survey responses to usage logs and employing two-wave (pre-/post-use) designs would strengthen behavioral measurement and reduce ambiguity in expectation and disconfirmation measurement (Venkatesh et al., 2003; Van Ryzin, 2006). In practice, the framework supports targeted interventions: weak perceived performance suggests redesign of usability, reliability, information quality, or support; expectation-driven dissatisfaction points to improved communication and guidance; and trust deficits indicate a need for assurance and legitimacy-building measures beyond the interface (Moore, 1995; MacLean & Titah, 2022).

5.1. Study Limitation

The study is conceptual and does not provide empirical estimates. Many applications will rely on cross-sectional self-report data, where expectations may be measured retrospectively and relationships may be affected by common-method bias. Disconfirmation is also sensitive to operationalization: gap scores ($P - E$) can be noisy and mechanically related to their components; therefore, robustness checks comparing gap-based and direct confirmation measures are recommended (Van Ryzin, 2006). Finally, the framework prioritizes parsimony for survey feasibility and does not model dynamic feedback processes (e.g., satisfaction shaping future expectations or trust), which would require longitudinal validation across services and contexts.

6. Conclusions

This paper proposes a multidimensional framework for evaluating electronic public services that integrates expectancy–disconfirmation logic with a parsimonious adoption layer and attribute-based service quality measurement. By combining EDM's core mechanism (expectations, perceived performance, disconfirmation, satisfaction) with benefit beliefs and behavioral endpoints from TAM/UTAUT, and by treating service quality domains as the attribute-level content of expectations and performance (including usability/effort as service characteristics), the framework clarifies how citizens form evaluations and how these evaluations translate into satisfaction and post-use intentions. The framework is translated into operationalizable measurement specification using matched attribute-level E/P items, dual disconfirmation operationalization (gap scores and a direct confirmation item), and contextual controls such as trust.

The study has several limitations. The framework is conceptual and has not yet been empirically validated, and many applications will rely on cross-sectional self-reports where expectations may be elicited retrospectively and disconfirmation is sensitive to operationalization. The proposed relationships are intentionally parsimonious to support measurement feasibility and may not capture dynamic feedback processes that require longitudinal designs.

Future research should validate the measurement structure psychometrically, assess reliability and discriminant validity, and test the implied relationships across different

service types, administrative levels, and citizen groups. Where feasible, two-wave pre-/post-use designs and linkage to usage logs would strengthen behavioral measurement and reduce ambiguity in expectation and disconfirmation measurement. Despite these constraints, the framework provides a theoretically grounded and adaptable foundation for citizen-centered evaluation and supports more precise diagnosis of whether negative evaluations arise from weak perceived performance, unmet expectations, or their mismatch.

Conflict of interest: none

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Appendix

Appendix A: Full table 2

Table 2. Adoption/value layer, behavioral endpoints, capability and context with possible extensions

Construct	Role in framework	Operationalization
Behavioral intention (BI)	Post-evaluation behavioral endpoint	2–3 items on intention (future-oriented). UTAUT uses a 3-item intention scale. Intention to use/reuse the service or recommend to others. (7-point scale)
Use Behavior (UB)	Actual usage (frequency/duration), i.e., the behavioral end of UTAUT.	Prefer objective logs when feasible; UTAUT reports usage measured as duration via system logs. If not feasible: self-reported frequency/recency (last use, number of uses in period).
Benefit beliefs	Captures goal attainment / overall value of using the e-service (does it help the citizen accomplish the task). shape expectation formation (people who believe the service is valuable may enter with higher expectations).	2–3 global value items (7-point scale), e.g., “Using this e-service helps me complete the task effectively / saves time / improves efficiency.” Not computed as a gap score and not an attribute facet;
Self-efficacy (SE)	Citizen capability/confidence to complete the service successfully (constraint layer linked to effort and support).	2-3 confidence items: Examples: “I could use eGov services if I wanted to”; “I could use eGov services if there was no one around to tell me what to do”
Core e-service quality (E-S-QUAL domains)	Attribute content of P (and matched E): what exactly citizens evaluate during normal use.	Use validated domains and select concise items per domain: Efficiency (e.g., ease of finding what is needed), System availability, Privacy, Fulfillment
eGovernment-specific quality (EGSQUAL)	Public-sector specific attributes often missing from generic e-service quality (information, assistance, security, aesthetics).	Example items shown in instrument: “The government’s website provides accurate information”; “The government’s website provides personalized information”; “The government’s website has an appealing design.”
Service context and user characteristics	Heterogeneity and boundary conditions (voluntariness, experience, skills), used mainly as controls/moderators.	Service type, channel, frequency, prior experience; voluntariness can be measured on a 7-point nonvoluntary-voluntary scale (in UTAUT design). Add demographics and digital skills items as controls.
Controls	Captures heterogeneity in digital capability and context: improves interpretability and allows group comparisons.	Age, gender, education, prior experience with public services, voluntariness, mandatories.
Trust in government (institutional trust)	Context factor shaping expectations and evaluations; treated as control due to reciprocal links with satisfaction.	Example item: “I trust the government agency behind the e-government service.”

Trust in technology/Internet	Confidence in the channel/infrastructure; affects risk perception and willingness to transact.	Example item: "I trust the Internet as a medium for electronic commerce." (Adapt for eGov context: "as a medium for transacting with government").
Social influence (SI)	Normative pressure or expectations from important others (optional extension).	Example items: "People who influence my behavior think that I should use the system"; "People who are important to me think that I should use the system."
Facilitating conditions (FC)	Perceived availability of support/resources/knowledge enabling use (optional extension).	Example items: "I have the resources necessary to use the system"; "I have the knowledge necessary to use the system"; "A specific person (or group) is available for assistance with system difficulties."

The Effects of Brexit and Geopolitical Determinants on the Dynamics and Structure of Polish and Czech Agri-Food Trade with the United Kingdom in 2015–2024

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Abstract: The primary objective of this study is to evaluate the impact of geopolitical shifts, specifically Brexit and global supply chain disruptions, on the dynamics and structure of agri-food trade between Poland, the Czech Republic, and the United Kingdom from 2015 to 2024. The research utilizes secondary data from the Trade Map (ITC) database. The analysis is based on Compound Annual Growth Rate (CAGR), dynamics indices, and Market Share metrics across selected product groups according to the Harmonized System (HS 01–24). The findings reveal a profound asymmetry in the adaptive strategies of the studied economies. Poland successfully leveraged Brexit as a catalyst for expansion, recording spectacular growth in the cereals sector (nearly a 17-fold increase in value) and meat products (market share in the UK rising to 14.8%). In contrast, the Czech model evolved toward niche specialization, showing regression in low-margin categories such as milling products and vegetables. The study confirms the occurrence of a "substitution effect," where Polish producers effectively filled supply gaps left by Western European suppliers. The results suggest high resilience of the Polish food system to non-tariff barriers, alongside a simultaneous marginalization of British imports within CEE markets.

Keywords: Brexit; agri-food trade; international competitiveness; CAGR; supply chains; non-tariff barriers.

JEL Classification: F14; F15; F51

1. Introduction

The process of the United Kingdom's withdrawal from the structures of the European Union, commonly referred to as Brexit, constitutes one of the most significant events in Europe's recent economic history.

The literature on Brexit focuses on analysing its effects on economic integration and the costs associated with the disintegration of the internal market. Institutional and analytical studies indicate that the United Kingdom's withdrawal from the Single Market entailed a shift from a model of "deep integration" to the regime established under the Trade and

Cooperation Agreement (TCA), which- despite maintaining zero tariff rates- generates significant regulatory and administrative costs (European Parliament, 2023).

Ex ante studies based on computable general equilibrium (CGE) models predicted a decline in trade intensity as a result of rising non- tariff barriers and the weakening of Single Market effects. Empirical analyses have confirmed that, after 2021, trade between the United Kingdom and the EU declined markedly, with stronger decreases observed in highly regulated sectors, including agri- food products (Du et al., 2024; European Parliament, 2023).

In the context of individual Member States, the effects are shown to vary depending on the structure of exports and the degree of dependence on the UK market. For Poland, prior to 2021, the United Kingdom was one of the key export markets for agri-food products (European Commission, 2024; Ministerstwo Rozwoju i Technologii, 2020), for the Czech Republic this importance was more moderate, though still significant in selected segments of the processing industry.

The agri-food sector is regarded in the literature as particularly sensitive to regulatory changes due to the applicable sanitary and phytosanitary (SPS) standards, certification requirements, and the short shelf life of products. (Ambroziak, 2022). The introduction of mandatory customs declarations, veterinary certificates, and border controls following the entry into force of the TCA increased transaction costs and extended delivery times.

Empirical studies indicate that even in the formal absence of tariffs, non-tariff barriers act as quasi-tariffs, reducing trade volumes. Du et al. (2024) show that the effect of the TCA was asymmetric, affecting UK exporters more strongly, while some EU exporters demonstrated a relatively greater capacity for adaptation.

European Commission reports confirm that, despite disruptions, the United Kingdom remains one of the EU's most important partners in trade in agri-food products, and the EU's trade surplus in this area remains at a high level (European Commission, 2024). This indicates a partial compensation for losses through the reorganisation of supply chains and the substitution of export destinations.

In the domestic literature, prior to the Brexit referendum, the need to revise the export strategies of the Polish agri- food sector was emphasised (Kosior & Ambroziak, 2018). Post-Brexit analyses (Ambroziak, 2022, 2024) indicate that Polish agri-food exports to the United Kingdom recorded a relatively limited decline in 2021 (approximately 4%), which points to the high adaptability of firms and a strong competitive position in selected segments- particularly in processed meat products.

With regard to the Czech Republic, the literature is less extensive; however, studies on agriculture in Central and Eastern Europe (Andrei et al., 2020) emphasise the relationship between changes in the trade regime and the sector's ability to maintain competitive advantages. It is indicated that smaller economies with a more diversified export structure may display greater resilience to unilateral demand shocks, while at the same time exhibiting a more limited capacity for expansion.

From a theoretical perspective, this adaptation aligns with the concept of “trade resilience”, understood as the ability of a trade system to absorb shocks and reconfigure export destinations while maintaining the relative stability of value added.

The COVID-19 pandemic constituted an independent global shock affecting food trade through logistical disruptions, restrictions on labour mobility, and a collapse in demand in the HoReCa sector. Korir et al. (2021) indicate that, in the short term, the pandemic led to significant fluctuations in prices and trade volumes for fresh and meat products.

The literature emphasises that the agri-food sector demonstrated greater resilience than many industrial branches, however, the effects of the pandemic varied depending on the degree of product processing and the export orientation of firms. In the context of Brexit, the pandemic further increased regulatory and logistical uncertainty in the first year of the TCA's operation.

Russia's aggression against Ukraine in 2022 triggered a sharp increase in the prices of energy, fertilisers, and agricultural commodities, which directly affected the costs of agricultural production and food processing in the EU. European Commission reports (European Commission, 2024) point to sharp increases in fertiliser prices in 2022 and growing inflationary pressure in the food sector.

At the same time, the liberalisation of trade in agricultural products with Ukraine reshaped the structure of imports in the Central European region, increasing price competition and affecting the margins of domestic producers (Ambroziak, 2022). The literature indicates that the accumulation of regulatory shocks (Brexit) and cost shocks (war, energy) leads to a lasting reconfiguration of value chains in the European food system.

Although there is a substantial body of literature on the general effects of Brexit and the impact of the pandemic and the war on food trade, the number of studies combining these phenomena in a comparative perspective of Poland and the Czech Republic, and focusing on the product structure of trade over the long- term horizon of 2015- 2024, remains limited.

The main objective of this study is to assess the impact of geopolitical changes- particularly Brexit and disruptions in global supply chains- on the dynamics and structure of agri-food trade between Poland and the Czech Republic and the United Kingdom. The study seeks to identify differences in the adaptive strategies of the two economies with regard to key groups of agri-food products. The following research questions are posed in the paper:

- RQ1: How did the United Kingdom's withdrawal from the EU Single Market affect the dynamics of agri-food exports and imports in Poland and the Czech Republic?
- RQ2: Which commodity groups (according to the HS classification) demonstrated the greatest resilience to non-tariff barriers, and which experienced a decline?
- RQ3: Did Polish and Czech producers effectively exploit supply gaps in the UK market through a substitution effect?

2. Methodology

To assess the impact of geopolitical changes on trade in the agri-food sector, this study uses secondary data obtained from the Trade Map database (International Trade Centre). The selected time span covers the years 2015- 2024, which allowed for a precise analysis of trends in two key sub-periods: the pre- Brexit period (2015- 2020)- covering the phase of stabilisation

and post-referendum uncertainty- and the post- Brexit period (2021- 2024), characterised by operation outside the EU Single Market.

The study's time frame also allows for the inclusion of the impact of exogenous factors, such as the COVID-19 pandemic and disruptions in global supply chains caused by the war in Ukraine.

The scope of the analysis covers trade in goods classified in Sections I–IV of the Harmonized System (HS 01–24). In order to ensure high reliability of the results and to reflect the specific production structures of Poland and the Czech Republic, a purposive selection of nine HS chapters was made. The analysis focuses on sectors of substantial importance to domestic production capacity, grouping them into three functional categories:

- Animal products: Live animals (HS 01), Meat and edible offal (HS 02), and Dairy products, eggs, and honey (HS 04);
- Plant products (raw materials): Vegetables (HS 07), Fruit and nuts (HS 08), Cereals (HS 10), and Oil seeds and industrial crops (HS 12);
- Processed products: Products of the milling industry, malt and starch (HS 11), and Sugar and confectionery (HS 17).

The application of the above selection criteria made it possible to exclude commodity groups of an exotic nature or those based on re-export, thereby ensuring that the identified changes reflect genuine shifts in the competitiveness of national food systems.

To verify the research questions, the following methods were applied:

1. Analysis of dynamics and trends- fixed-base indices (2015= 100) and the compound annual growth rate (CAGR) were used to assess the stability of growth in the analysed sub-periods. The CAGR indicator (Ambroziak et al., 2025) was calculated according to the following formula (1):

$$yCAGR = \left(\frac{v_{tn}}{v_{t_0}} \right)^{\frac{1}{n}} - 1 \quad (1)$$

Where v_{tn} denotes the value of exports/ imports in the final year, and v_{t_0} represents the value of exports/ imports in the initial year of the analysed sub-period, and n is the number of years in the analysed sub-period.

2. The Market Share indicator makes it possible to assess a country's relative competitive position in a partner's market, while limiting the influence of overall fluctuations in that market's import volume (Kowalska et al., 2021) (2):

$$MS_i = \frac{X_{i \rightarrow UK}}{M_{World \rightarrow UK}} \times 100\% \quad (2)$$

Where $X_{i \rightarrow UK}$ denotes the value of exports of goods from chapter i from the analysed country (Poland/ Czech Republic) to the United Kingdom, and $M_{World \rightarrow UK}$ represents the value of the United Kingdom's total imports from the world.

The analysis is based on nominal values expressed in EUR. It should be noted that, due to high food price inflation in the period 2021- 2024, increases in value terms may not fully correspond to increases in physical volume (quantities traded). For this reason, the results are interpreted primarily through changes in market shares and structural relationships, which are more resilient to inflationary effects than raw nominal data.

3. Results

3.1. Dynamics of Poland's and the Czech Republic's Trade in Selected Agri-Food Products with the United Kingdom

The data presented (Table 1) cover a decade of trade transformation, taking into account the impact of Brexit and the COVID-19 pandemic. To provide a reliable account of these changes, the analysis was based on five turning points:

- 2015 (Base year)- the starting point of the analysis, representing stable intra-EU trade;
- 2019 ("Old order" peak)- the last full year before the pandemic and the beginning of the Brexit transition period;
- 2020 (Transitional and crisis year)- a period marked by supply chain disruptions and regulatory uncertainty;
- 2021 (EU exit)- the end of the Brexit transition period;
- 2024 (Current situation)- the most recent data reflecting the new balance following the full implementation of trade rules applicable to a third country.

Table 1. Trade balance of Poland and Czechia with the United Kingdom in key product groups, together with the dynamics of changes (thousand EUR, %)

HS code	Commodity group	Country	2015	2019	2020	2021	2024	Growth (2015–2024)
01	Live animals	PL	-6,652	-2,954	-8,214	-6,373	-15,450	-132.3%
		CZ	329	130	478	551	254	-22.80%
02	Meat	PL	340,799	471,389	474,252	545,585	888,906	160.80%
		CZ	-1,930	-5,702	-4,805	-1,251	-3,662	-89.7%
04	Dairy products	PL	77,495	85,773	56,806	103,067	164,667	112.50%
		CZ	-2,950	-2,271	-156	-3,952	-5,938	-101.3%
07	Vegetables	PL	114,856	163,769	162,082	179,950	211,909	14.50%
		CZ	-4,187	-5,502	-1,447	-303	-309	+92.6%
08	Fruit	PL	52,307	56,207	45,200	74,809	98,389	88.10%
		CZ	-1,806	-605	-845	-242	-348	+80.7%
10	Cereals	PL	9,389	1,697	8,678	56,135	157,864	1,581.4%
		CZ	-69	-46	493	-11	339	n.a.*
11	Products of the milling industry	PL	5,859	8,246	10,554	10,460	8,281	41.30%
		CZ	13,425	240	-1,595	-1,245	-1,047	-107.8%
12	Oil seeds	PL	1,582	4,104	3,527	7,974	8,012	406.40%
		CZ	1,708	990	902	902	3,227	88.90%
17	Sugar and confectionery	PL	28,584	23,762	25,387	31,599	91,005	218.40%
		CZ	44,111	38,717	42,285	44,819	84,475	91.50%

Note: In the case of cereals for Czechia, the percentage change is not interpretable due to the transition from a negative value (deficit in 2015) to a positive value (surplus in 2024).

The comparative analysis reveals a fundamental difference in the structure of the two countries' trade with the United Kingdom. Poland consistently generates a substantial trade surplus, particularly in highly processed sectors such as meat (HS 02) and dairy products (HS 04). At the same time, Czechia records a deficit in most of these categories, indicating that it is a net importer of food products from the UK market.

The most pronounced increase was recorded in the cereals sector (HS 10). Poland expanded its positive trade balance from just under EUR 9.4 million in 2015 to nearly EUR 158 million in 2024. This represents an almost seventeenfold increase, suggesting an effective filling of supply gaps in the UK market following Brexit. Although the percentage growth in the meat category (HS 02) (+160.8%) is lower than in cereals (HS 10), in absolute terms it constitutes the most significant success of Polish exports. The increase in the surplus by more than half a billion euros annually indicates that the Polish meat- processing industry has become a key pillar of the United Kingdom's food security. Against the backdrop of the success of processed products, the live animals category (HS 01) appears problematic. Poland deepened its deficit in this group by 132.3%, indicating that imports of breeding material from the United Kingdom substantially exceed exports to that market. This is the only category in which dependence on UK supplies has clearly increased.

The trade profile of Czechia with the United Kingdom is considerably more modest and rests on different foundations than that of Poland. In contrast to Poland, Czechia records a trade deficit in key staple product categories such as meat (HS 02), dairy products (HS 04), and fruit and vegetables (HS 07, 08), indicating that it functions primarily as an importer of these goods from the UK (or via the UK) rather than as a significant supplier. Although the balance for vegetables and fruit remains negative, Czechia has recorded a substantial improvement, with deficit reductions of +92.6% and +80.7%, respectively, suggesting an optimisation of supply chains. Sugar and confectionery (HS 17) remains the only category in which Czechia maintains a high and stable surplus (EUR 84.5 million in 2024), nearly doubling its 2015 result.

3.2. Dynamics of Poland's and Czechia's Trade with the United Kingdom

The use of fixed- base indices (2015= 100) makes it possible to precisely distinguish three phases shaping the contemporary architecture of trade exchange: pre-referendum stabilisation, the period of uncertainty (2019- 2020), and operation outside the EU Single Market (after 2021). The data presented in Tables 2 and 3 reveal profound asymmetries in the responses of individual commodity groups to the new geopolitical conditions.

Poland demonstrated a remarkable adaptive capacity, effectively transforming its trade model in response to non-tariff barriers. An evolution can be observed from the traditional dominance of animal products towards the export of strategic raw materials and highly processed plant-based products (Table 2).

The most striking feature of the analysis is the cereals sector (HS 10), which recorded explosive growth. The dynamics index reached 1671.7% in 2024, indicating an almost seventeenfold increase in export value relative to the base year. The breakthrough surge after

2021 suggests that, in the face of destabilisation in eastern markets, Poland became a key alternative supplier for the United Kingdom.

Table 2. Export and import dynamics for Poland–United Kingdom trade (2015 = 100, %)

HS Code	Commodity group	2015	2019	2020	2021	2024
Exports						
01	Live animals	100	0.0	0.0	2,518.8	10,843.8
02	Meat	100	128.1	128.9	126.7	206.7
04	Dairy products	100	124.6	128.1	133.1	211.7
07	Vegetables	100	152.2	140.8	151.6	179.0
08	Fruit	100	106.9	92.6	117.0	154.3
10	Cereals	100	101.9	133.5	603.5	1,671.7
11	Products of the milling industry	100	116.4	122.6	112.9	137.4
12	Oil seeds	100	236.4	278.3	334.5	393.9
17	Sugar and confectionery	100	108.5	109.9	125.8	306.0
Imports						
01	Live animals	100	44.3	123.2	101.6	257.7
02	Meats	100	92.7	93.1	10.5	18.5
04	Dairy products	100	231.9	552.2	133.8	205.2
07	Vegetables	100	363.8	132.7	39.9	59.1
08	Fruit	100	104.7	118.3	9.3	15.0
10	Cereals	100	14,153.6	7,016.1	1,548.2	41.1
11	Products of the milling industry	100	96.1	74.7	58.2	134.2
12	Oil seeds	100	205.9	351.7	109.7	244.6
17	Sugar and confectionery	100	236.3	216.0	202.3	243.4

A similar, though specific, pattern is observed in the live animals category (HS 01). Following a period of virtually no trade (2016- 2020), the index reached 10843.8% in 2024. Such an extreme value results from a low- base effect, nevertheless, the scale of the return of Polish producers is unprecedented. At the same time, the pillars of trade- meat (HS 02) and dairy products (HS 04)- recorded steady growth, doubling their values by 2024 (to 206.7% and 211.7%, respectively), which indicates strong loyalty among UK consumers.

In import relations with the United Kingdom, the opposite phenomenon can be observed- namely, a progressive erosion in the importance of UK goods. Dramatic declines in the meat (HS 02) and fruit (HS 08) sectors, where the indices fell to 18.5% and 15.0%, respectively, point to an almost complete disappearance of these flows in statistical terms.

Czechia's trade with the United Kingdom in the analysed period is characterised by considerably greater instability than Poland's, showing strong fluctuations and clear signs of market displacement in key categories (Table 3).

In the export domain, the most pronounced decline was recorded in the milling industry (HS 11). The dynamics index fell to only 4.3% in 2024, indicating the near- complete elimination of Czech flour from the UK market. Czechia is also the only country among those analysed that recorded a real decline in vegetable exports (HS 07) in 2024 relative to the base year (2024= 89.6%), pointing to a loss of competitiveness following the introduction of full border controls.

On the other hand, a positive performance was observed in the dairy sector (HS 04), where Czechia maintained higher dynamics than Poland for most of the period, ending 2024 with an index of 219.5%. In the area of imports, Czechia consistently increased its purchases of sugar (HS 17), reaching an index of 290.4%, which contrasts with the trends observed in Poland and suggests a different structure of industrial demand.

Table 3. Dynamics of Czechia's exports to and imports from the United Kingdom (2015 = 100, %)

HS Code	Commodity group	2015	2019	2020	2021	2024
Exports						
01	Live animals	100	25.4	96.9	160.6	107.8
02	Meat	100	62.2	81.1	312.2	227.0
04	Dairy products	100	235.7	298.1	236.2	219.5
07	Vegetables	100	90.3	139.6	92.5	89.6
08	Fruit	100	1,823.1	2,288.5	2,307.7	669.2
10	Cereals	100	158.7	400.5	107.1	364.1
11	Products of the milling industry	100	12.3	3.6	1.5	4.3
12	Oil seeds	100	111.7	101.8	87.7	193.7
17	Sugar and confectionery	100	115.3	99.7	104.7	196.3
Imports						
01	Live animals	100	0.5	10.8	148.4	161.8
02	Meat	100	286.8	242.8	74.0	191.1
04	Dairy products	100	141.1	123.6	175.3	208.7
07	Vegetables	100	130.1	37.8	9.9	9.9
08	Fruit	100	58.9	78.6	46.0	28.5
10	Cereals	100	133.6	96.4	82.2	130.8
11	Products of the milling industry	100	181.9	252.8	175.6	200.1
12	Oil seeds	100	540.7	493.5	366.4	231.8
17	Sugar and confectionery	100	116.2	174.9	166.4	290.4

The comparative analysis indicates that Poland more effectively exploited supply gaps in the UK market, particularly in the agricultural raw materials sector (cereals). Czechia, by contrast, faces a pronounced decline in traditional sectors (milling, vegetables), which may stem from higher logistical costs and a smaller scale of production compared with the Polish agri-food sector.

3.3. CAGR Dynamics in Poland's and Czechia's Agricultural Trade with the United Kingdom

Dividing the analysis, into sub-periods- the pre-Brexit period (2015–2020) and the post-Brexit period (2020–2024), makes it possible to precisely capture the point at which the vectors of trade dynamics changed. The use of the CAGR indicator mitigates short- term fluctuations, revealing the long- term adaptive trends of both economies.

The analysis of the compound annual growth rate (CAGR) across two time intervals – the pre-Brexit period (2015–2020) and the period following the full implementation of the new trade rules (2020–2024) – points to a pronounced asymmetry in trade relations. While Polish exports demonstrated strong resilience and growth, imports from the United Kingdom experienced a sharp decline in many categories (Table 4).

The most remarkable change was recorded in the cereals sector (HS 10). The compound annual growth rate in the post-Brexit period (2020–2024) reached 88.12%, representing an increase of more than 82 percentage points compared with the pre-Brexit period. This suggests that Polish cereal producers effectively filled supply gaps in the UK market, becoming a key alternative supplier in the new geopolitical environment.

Table 4. Compound annual growth rate (CAGR, %) of Poland's trade with the United Kingdom

HS Code	Commodity group	Export 2015-2020	Export 2020-2024	Difference (p.p.)	Import 2015-2020	Import 2020-2024	Difference (p.p.)
01	Live animals	n.a.*	n.a.*	–	4.26	20.27	16.01
02	Meat	5.21	12.54	7.33	-1.41	-33.23	-31.82
04	Dairy products	5.08	13.38	8.30	40.74	-21.92	-62.66
07	Vegetables	7.08	6.20	-0.88	5.82	-18.32	-24.14
08	Fruit	-1.52	13.62	15.14	3.41	-40.37	-43.78
10	Cereals	5.95	88.12	82.17	134.00	-72.34	-206.34
11	Products of the milling industry	4.15	2.90	-1.25	-5.67	15.77	21.44
12	Oil seeds	22.72	9.07	-13.65	28.60	-8.68	-37.28
17	Sugar and confectionery	1.91	29.17	27.26	16.65	3.03	-13.62

Note: As the value in 2020 was zero, the standard CAGR cannot be computed for this interval.

In the groups constituting the traditional pillars of exports- meat (HS 02) and dairy products (HS 04)- more than a twofold acceleration in growth was observed. The CAGR for meat increased from 5.21% to 12.54%, and for dairy products from 5.08% to 13.38%. Such strong acceleration indicates the durable embedding of Polish products in UK supply chains and the high resilience of these sectors to complex veterinary procedures. The fruit sector (HS 08), meanwhile, underwent a transformation from a declining trend (-1.52%) to dynamic growth at 13.62%. A significant acceleration was also recorded in the export of sugar and confectionery (HS 17), where the CAGR rose from 1.91% to 29.17%.

In import relations from the United Kingdom to Poland after 2020, a phenomenon of a sharp collapse in growth dynamics can be observed across most categories. The strongest decline affected the cereals (HS 10), fruit (HS 08), meat (HS 02), and dairy products (HS 04) sectors, where the CAGR fell to -72.34%, -40.37%, -33.23%, and -21.92%, respectively.

This points to the near- complete displacement of UK agricultural raw materials by suppliers from the EU Single Market or eastern sources (Ukraine). The only exceptions are products of the milling industry (HS 11), which, after a period of decline before 2020, rebounded to a CAGR of 15.77%, and sugar (HS 17), which maintained positive, albeit significantly weakened, growth (a decrease from 16.65% to 3.03%). In the live animals category (HS 01), a sharp increase in imports was recorded in the most recent period (20.27%); however, due to zero base values in some years of the 2015–2020 interval, a full mathematical comparison of the export CAGR cannot be determined using the standard method.

The CAGR analysis demonstrates that Brexit affected Poland's trade selectively. For exports, it became a catalyst for growth, particularly in the cereals category and in highly processed products. For imports, by contrast, post-Brexit barriers proved critical, leading to a profound marginalisation of UK agri-food products in the Polish market.

The analysis of Czech–UK trade in the examined period indicates substantially greater volatility and deeper structural reorientations than in the case of Poland. With a smaller scale of mass production, Czechia shows a tendency towards abrupt shifts in the dynamics of individual product categories following Brexit (Table 5).

Table 5. Compound annual growth rate (CAGR, %) of Czechia's trade with the United Kingdom

HS Code	Commodity group	Export 2015-2020	Export 2020-2024	Difference (p.p.)	Import 2015-2020	Import 2020-2024	Difference (p.p.)
01	Live animals	-0.63	2.69	3.32	-35.98	96.96	132.94
02	Meat	-4.11	29.36	33.46	19.41	-5.80	-25.21
04	Dairy products	24.41	-7.36	-31.77	4.32	13.99	9.67
07	Vegetables	6.89	-10.50	-17.39	-17.67	-28.42	-10.74
08	Fruit	87.03	-26.46	-113.49	-4.70	-22.41	-17.70
10	Cereals	31.99	-2.35	-34.34	-0.72	7.92	8.64
11	Products of the milling industry	-48.67	5.02	53.69	20.38	-5.67	-26.05
12	Oil seeds	0.36	17.44	17.08	37.61	-17.21	-54.82
17	Sugar and confectionery	-0.06	18.46	18.52	11.83	13.52	1.69

The most striking change in Czechia's exports is the “revival” of the meat sector (HS 02). Before 2020, this category was in decline (CAGR –4.11%); however, after Brexit it experienced a sharp increase to 29.36%. The positive difference of as much as 33.46 percentage points suggests that Czech producers effectively filled market niches vacated by other EU suppliers.

A similar upward trend was observed in the sugar and confectionery category (HS 17). The stabilisation of growth at 18.46% (compared with almost zero growth before 2020) indicates a lasting strengthening of the Czech sugar industry's position in the UK market. An interesting development is also the slowdown of declines in products of the milling industry (HS 11): after a substantial contraction in 2015–2020 (–48.67%), the sector returned to growth at 5.02% (an improvement of nearly 54 percentage points). In the case of oil seeds (HS 12), growth dynamics increased from 0.36% to 17.44%.

It should be noted, however, that these successes came at the expense of other sectors. Czechia's fruit exports (HS 08) experienced a substantial collapse, falling from 87.03% to –26.46% (a difference of as much as –113.49 percentage points).

In the area of imports from the United Kingdom to Czechia, the live animals category (HS 01) deserves particular attention. The compound annual growth rate in this segment increased from –35.98% before 2020 to 96.96% in the post-Brexit period. Such a substantial fluctuation (a jump of 132.94 percentage points) suggests either an intensive rebuilding of livestock herds or a sudden shift in the sourcing model towards UK breeding material.

In contrast to the trends observed in Poland, after 2020 Czechia maintained positive import dynamics in the dairy (HS 04, CAGR 13.99%) and cereals (HS 10, CAGR 7.92%) categories, which may indicate a greater dependence of Czech processing industries on specific components imported from the UK. At the same time, Czechia recorded a decline in imports of meat (HS 02) and oil seeds (HS 12), where growth rates fell into negative territory, at –5.80% and –17.21%, respectively.

While Polish exports are based on steady acceleration in large-scale sectors (meat, cereals), the Czech model after 2020 displays features of corrective restructuring. Czechia successfully reversed negative trends in the export of meat (HS 02) and products of the milling industry (HS 11), while simultaneously significantly increasing imports in the livestock sector (HS 01), which may help build the foundations for the future competitiveness of the agri-food sector.

3.4. Comparative Analysis of Poland's and Czechia's Shares in UK Imports

The key indicator enabling an assessment of the actual competitive strength of agri-food products is their market share, defined as the ratio of a given country's exports to the United Kingdom's total imports from the world. The data presented in Tables 6 and 7 reveal markedly different adaptive strategies and levels of penetration of the UK market by Poland and Czechia.

For Poland, the period 2015–2024 was a time of systematic strengthening of its market position, suggesting that non-tariff barriers paradoxically became an impetus for expansion (Table 6).

Table 6. Poland's share in the United Kingdom's import market (2015–2024, %)

HS Code	Commodity group	2015	2019	2020	2021	2024	Change 2015-2024 (p.p.)
01	Live animals	0.00	0.00	0.00	0.08	0.22	+0.22
02	Meat	8.32	11.71	13.13	12.76	14.79	+6.47
04	Dairy products	2.54	3.09	3.35	3.72	4.09	+1.55
07	Vegetables	3.12	4.74	4.45	4.99	4.41	+1.30
08	Fruit	1.17	1.23	1.08	1.40	1.51	+0.33
10	Cereals	0.68	0.70	0.78	3.29	6.80	+6.12
11	Products of the milling industry	3.35	3.27	3.44	3.22	2.73	-0.61
12	Oil seeds	0.29	0.71	0.65	0.65	0.66	+0.37
17	Sugar and confectionery	2.32	2.99	3.35	3.44	5.18	+2.85

The most favourable results were recorded in the meat sector (HS 02), where a model “substitution effect” was observed. Poland's share increased from 8.32% to 14.79%, meaning that currently roughly one in every seven kilograms of meat imported into the UK originates from Poland. The correction in 2021 was only incidental in nature and was quickly offset by a strong rebound.

A similarly significant breakthrough occurred in the cereals sector (HS 10). The tenfold increase in market share- from a marginal 0.68% to 6.8%- suggests that Polish producers effectively captured market shares previously held by traditional suppliers from Western Europe (France, Germany). This success also extends to sugar and confectionery (HS 17), whose share more than doubled (to 5.18%). The growth observed in groups subject to stringent sanitary and phytosanitary (SPS) controls demonstrates the high operational efficiency of the Polish agri-business sector.

Signals of weakening emerge only from the milling sector (HS 11) and vegetables (HS 07). In the latter case, despite an increase in value, the decline in market share from 4.99%

(2021) to 4.41% (2024) indicates an exhaustion of the previous momentum- the UK import market in this category is expanding faster than supplies from Poland.

Czechia's share in the UK agricultural market is considerably more modest and shows signs of strong sectoral polarisation as well as withdrawal from low-margin markets (Table 7).

Table 7. Czech Republic's share in the UK import market (2015–2024, %)

HS Code	Commodity group	2015	2019	2020	2021	2024	Change 2015-2024 (p.p.)
01	Live animals	0.074	0.022	0.086	0.158	0.069	-0.005
02	Meat	0.001	0.001	0.001	0.005	0.003	+0.0013
04	Dairy products	0.058	0.134	0.178	0.151	0.097	+0.0389
07	Vegetables	0.003	0.003	0.005	0.003	0.002	-0.001
08	Fruit	0.000	0.008	0.011	0.011	0.003	+0.0021
10	Cereals	0.013	0.021	0.046	0.011	0.029	+0.0156
11	Products of the milling industry	3.698	0.382	0.110	0.048	0.095	-3.6024
12	Oil seeds	0.201	0.233	0.166	0.119	0.225	+0.0239
17	Sugar and confectionery	3.145	4.297	4.110	3.877	4.494	+1.3487

The most dramatic structural change was recorded in the category of products of the milling industry (HS 11). Czechia, which held a solid share of around 3.70% in 2015, has almost completely disappeared from this segment (below 0.10% in 2024). This contrasts with Poland's relatively strong position (2.73%), which may indicate the displacement of Czech exporters by Polish firms operating at a larger production scale.

The foundation of Czechia's presence remains the sugar and confectionery sector (HS 17), where Czechia controls 4.49% of the market. This is the only area in which Czechia competes meaningfully with Poland, and the combined share of both countries (over 9.5%) points to the dominance of the Central and Eastern European region in this segment. In contrast to Poland, Czechia shows negligible presence in fresh products (meat, vegetables), suggesting a concentration on neighbouring markets and a limited willingness to overcome SPS (*Sanitary and Phytosanitary measures*) barriers in the UK market.

The comparative analysis highlights differences in the strategic approaches of the two economies. While Poland achieved deep and broad penetration of the UK market (particularly in large- scale product categories), the Czech model evolved towards narrower specialisation. Brexit became an impetus for expansion for Poland, whereas for Czechia it proved to be a selective factor, forcing a withdrawal from traditional markets (such as milling) in favour of maintaining highly specialised niches.

4. Discussion

The results of the analysis point to a profound dichotomy in the responses of the food systems of Poland and Czechia to the new geopolitical conditions. After 2021, Poland moved from a phase of uncertainty to one of assertive market expansion, as confirmed by the sharp increase in the CAGR indicator for key sectors. The particularly remarkable success in the cereals sector (HS 10) suggests that Poland has become a food “safety valve” for the United Kingdom in the face of destabilisation of supply chains from the East (the war in Ukraine).

In contrast to Poland, the Czech model exhibits features of selective restructuring. While Polish exporters capitalised on economies of scale, Czechia was almost completely displaced from low-margin markets such as products of the milling industry (HS 11). This may indicate that non-tariff barriers (SPS controls and customs bureaucracy) constitute prohibitive obstacles for smaller production systems that are unable to absorb transaction costs through export scale.

It is worth noting the phenomenon of trade asymmetry. While exports from Poland and Czechia to the UK are increasing in many categories, imports from the United Kingdom are undergoing progressive marginalisation. This supports the thesis that Brexit has become a stronger impediment for UK exporters than for EU producers, who benefit from a broader raw-material base and more efficient logistical organisation within the EU.

5. Conclusions

The conducted comparative analysis of trade dynamics, compound annual growth rate (CAGR) indicators, and market shares in the UK market made it possible to formulate comprehensive answers to the research questions and to identify key trends in the agri-food sectors of Poland and Czechia in the period 2015- 2024.

With regard to the first research question (RQ1), concerning the impact of Brexit on trade dynamics, it was found that the United Kingdom's withdrawal from the EU Single Market affected the analysed economies in markedly different ways. For the Polish agri-food sector, Brexit paradoxically became a catalyst for pro- development processes. Non- tariff barriers did not halt expansion; on the contrary, in the post-Brexit period the compound annual growth rate in key sectors, such as meat processing, more than doubled (with CAGR increasing from 5.21% to 12.54%). A different tendency was observed in Czechia, where the new regulatory conditions acted as a selective barrier, leading to a profound decline in traditional export categories. At the same time, in both countries a process of marginalisation of imports from the United Kingdom was observed, indicating that bureaucratic barriers proved more burdensome for UK exporters than for suppliers from the Central and Eastern European region.

With regard to the second research question (RQ2), a clear hierarchy of resilience across commodity groups was identified. The sectors with the highest adaptive potential (so-called *growth leaders*) were cereals (HS 10), meat (HS 02), and dairy products (HS 04). In these areas, Poland demonstrated unprecedented operational efficiency, increasing its share in UK meat imports from 8.3% to nearly 15%. Products of the milling industry and vegetables were classified as sectors sensitive to regulatory changes, likely due to the high unit costs of complying with sanitary and phytosanitary (SPS) controls in the context of relatively low margins.

The analysis relating to the third research question (RQ3) confirmed the occurrence of the phenomenon referred to as a “model substitution effect.” Poland effectively captured market shares previously held by traditional suppliers from Western Europe, such as France, Germany, and the Netherlands. The most striking evidence supporting this thesis is the cereals sector, in which Poland's share in the UK market increased nearly tenfold. The

substantial growth in exports after 2021 indicates that Polish producers rapidly filled supply gaps resulting from the reorientation of the United Kingdom's sourcing channels and global disruptions triggered by the war in Ukraine.

The main conclusion of the study is that Poland has successfully transformed geopolitical threats into an impulse strengthening its comparative advantage. This success is based on a favourable price-to-quality ratio and the reliability of supply during periods of crisis. Interpretative caution is nevertheless warranted, as although nominal export values have grown dynamically, a substantial part of this increase after 2021 has been driven by global food price inflation. However, the consistent rise in market shares confirms a genuine strengthening of Poland's competitive position, independent of price effects. The Czech food system, by contrast, demonstrated lower flexibility, evolving towards a narrow niche specialisation concentrated primarily in the sugar sector.

Conflict of interest: none

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The Role of Launch Timing in Crowdfunding Performance: Evidence from HitHit

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Abstract: This study is focused on the impact of temporal factors, specifically the launch day of the week and the launch month of the year on the success of crowdfunding projects within the Czech market. Based on behavioral economics and "fresh start effect," the research explores how psychological and organizational mechanisms influence the motivation and engagement of both project founders and supporters at specific time intervals. Using a complete dataset of all launched crowdfunding campaigns from HitHit, the leading Czech crowdfunding platform, the analysis covers projects launched between November 2012 and June 2025. The study uses chi-square tests and Cramér's V, to determine whether significant correlations exist between the timing of a campaign's launch and its success rate. While the results show that these temporal factors can be statistically significant, calculated Cramér's V coefficients suggest that the actual strength of the effect is relatively low. The findings suggest that strategic timing serves as a low-cost tool for optimizing campaign performance, providing insights for project creators and platform operators.

Keywords: crowdfunding; temporal factors; campaign success; HitHit; alternative finance

JEL Classification: M13; L26

1. Introduction

Crowdfunding has become an important alternative financing mechanism for entrepreneurs and creative projects. The success of crowdfunding campaigns is commonly associated with factors such as project quality, founder reputation, and the attractiveness of offered rewards. However, beyond these traditional determinants, other factors may also influence campaign outcomes. In the digital economy, where attention represents a scarce resource, the timing of a campaign launch may play a relevant role. Temporal characteristics such as the day of the week or the month of the year may influence the visibility of a campaign and the engagement of potential backers.

Key part to this investigation is the "fresh start effect." According to Dai et al. (2014), individuals are more likely to pursue aspirational goals at the start of new temporal cycles, such as the beginning of a week, month, or year, because these "temporal landmarks" allow them to relegate past failures to a previous period and start with a clean slate. Further research by Hennecke and Converse (2017) suggests that these landmarks increase "agentic mindset," making donors potentially more decisive when encountering new opportunities at

the start of a week. In addition, Price et al. (2018) shows that these time boundaries can strongly influence consumer behavior, which in the crowdfunding context may manifest as higher conversion rates for projects launched on Mondays or in early January.

Beyond the psychological mindset of the actors, the day of the launch can also impact practical factors such as resource availability, work continuity, and the speed of the initial response (Wesemann & Antretter, 2024).

In addition to the day of the week, seasonality throughout the year plays a huge role. Studies focusing on online projects and crowdfunding campaigns suggest that project success varies by month, with spring and autumn months representing relatively favorable periods (Xu & Chen, 2018). Research by Garel and Le Pendeven (2021) further demonstrates that crowdfunding projects are highly influenced by calendar effects. Their findings show that the number of contributions is statistically and economically lower during weekends and summer holidays. Conversely, a slight increase in supporter activity is observed in January, although its economic significance remains limited.

Although crowdfunding is growing worldwide, empirical evidence on the impact of timing within specific regional markets remains fragmented. International platforms like Kickstarter have been extensively studied but the Czech market presents unique cultural and economic characteristics. This paper aims to bridge this gap by analyzing a detailed internal dataset from HitHit, the leading Czech crowdfunding platform, spanning over a decade. The analysis specifically examines whether these temporal factors and the "fresh start effect" translate into higher success rates and whether the strength of this correlation justifies timing as a strategic tool for entrepreneurs.

2. Methodology

The empirical analysis is based on a large internal dataset provided by HitHit platform. The dataset encompasses all reward-based crowdfunding projects launched from the platform's start on November 20, 2012, through June 26, 2025. To ensure the integrity of the analysis, projects that were still active at the time of data collection were excluded from the sample. This exclusion was necessary because the success of an ongoing campaign cannot be determined, and including these cases would make the dependent variable unclear and could bias the results. Because of that, the final sample consists of 5,272 completed projects with a clear outcome. Out of those were 2,737 successful and 2,535 unsuccessful.

The study focuses on the evaluation of the distribution of crowdfunding campaigns, focusing on the interaction between day of the week and the month of the year. Within this framework, it is examined whether the timing of campaign launches exhibits random characteristics, or whether systematic temporal patterns can be identified. By applying statistical hypothesis testing, the relationship between launch timing and project outcomes is investigated, while three distinct groups of the HitHit dataset are being considered. In this way, not only general behavioral tendencies of project creators are captured but also differentiated insights into successful and unsuccessful campaign dynamics are obtained.

This analytical framework assesses the relationship between campaign launch timing and crowdfunding activity through the examination of temporal patterns across three distinct performance layers. By analyzing the combined effect of the day of the week and the month of the year, it is determined whether project creators follow systematic scheduling behavior or whether the initiation of campaigns remains largely random. The approach moves from a general evaluation of total platform activity toward a more detailed comparison between successful and unsuccessful campaigns, enabling a comprehensive assessment of the influence of timing on crowdfunding dynamics. These objectives are examined through the following hypotheses:

- H_1 : The frequency of project launches is independent of the combination of the day of the week and the month of the year.
- H_2 : For successful projects, there is no statistically significant relationship between the launch day and the launch month.
- H_3 : For unsuccessful projects, the launch day and the launch month are independent factors.

The analysis is therefore based on testing the statistical independence between the day of the week and the month in which a project is launched, while successful and unsuccessful projects are considered separately. In this part of the research, the focus is placed primarily on the temporal structure of project launches and on whether these timing factors exhibit systematic relationships.

Instead of defining a strictly dependent variable, the hypotheses examine the association between two categorical variables representing the timing of the campaign launch. These variables include the day of the week and the month of the year in which the project was launched. Within the first hypothesis, the evaluation concerns whether the frequency of project launches varies across different combinations of these temporal categories. In the second and third hypotheses, the relationship between the launch day and the launch month is analyzed separately for successful and unsuccessful projects. By this approach, it becomes possible to assess whether different temporal patterns of campaign launches appear depending on the project outcome.

Variables were assigned numerical values for processing, they are categorical rather than interval based. The analysis was conducted using IBM SPSS 30.0. A series of cross-tabulations were generated to examine the relationship between temporal factors and project success. In the first phase, the Pearson chi-square test of independence was employed to determine whether a statistically significant association exists between the launch day of the week and the month of the year across the projects. Because of the presence of cells with low expected frequencies in some segments of the dataset, which could violate the assumptions of the standard asymptotic chi-square test, the Monte Carlo simulation method was applied. This approach ensures more reliable p-values by generating many random permutations of the data, thus providing a robust basis for hypothesis testing even in sparse tables. As the second step, the strength of the identified associations was measured using Cramér's V.

3. Results

The empirical analysis is focused on identifying systematic temporal patterns in crowdfunding activity by examining the relationship between the day of the week and the month of the year. In the first stage, the Pearson chi-square test is applied to the total dataset ($N = 5,272$). The results indicate a statistically significant dependency between launch day and month ($\chi^2 = 95.458$, $p = 0.013$). Since the Monte Carlo significance is below the 0.05 threshold, the data suggests that project creators do not launch campaigns randomly across the calendar but exhibit systematic temporal behavior. A more targeted examination was conducted on successful projects ($n = 2737$) to evaluate performance linked timing. The analysis revealed a statistically significant relationship between the launch day and month ($\chi^2 = 95.682$, $p = 0.013$). The Monte Carlo 99% confidence interval for this significance ranges from 0.004 to 0.022, giving a solid basis for this finding. These results confirm that successful campaigns are associated with specific launch periods, indicating that timing may be used strategically. In the final part, the distribution of unsuccessful projects ($n = 2535$) was analyzed. Unlike the successful campaigns, the relationship between launch day and month for unsuccessful projects did not reach statistical significance ($\chi^2 = 84.497$, $p = 0.075$). As the p-value is above the 0.05 level, the results suggest that for unsuccessful projects, the launch day and month behave as independent factors.

Table 1. Chi-square test results for the relationship between launch day and month

Projects		Value	df	Asymptotic Significance (2-sided)	Monte Carlo Sig. (2-sided)		
					Significance	99% Confidence Interval	
						Lower Bound	Upper Bound
All projects	Pearson Chi-Square	95.458	66	0.010	0.013	0.004	0.022
Successful	Pearson Chi-Square	95.682	66	0.010	0.013	0.004	0.022
Unsuccessful	Pearson Chi-Square	84.497	66	0.062	0.075	0.054	0.096

Following the identification of statistically significant dependencies, the strength of these associations was quantified using Cramér's V. For the total population of projects, the calculated Cramér's V was 0.055, indicating a statistically significant but weak association between the month of the year and the day of the week. This suggests that while project creators do not distribute their launches randomly across the calendar, the temporal coordination is not a dominant factor. Instead, it likely reflects a subtle preference for specific periods, potentially driven by platform norms or broad seasonal trends, though these account for only a small portion of the overall variance in launch distribution.

A focused assessment of successful projects yielded a Cramér's V of 0.076. Although this value confirms a statistically significant relationship, the magnitude of the effect remains in the weak category. In the context of crowdfunding performance, this indicates that while successful creators are more likely to align their launches with specific temporal windows—suggesting a degree of strategic planning, this timing is merely one small component of a broader success strategy. The low effect size implies that other variables, such as project

quality, social capital, or marketing efforts, likely exert a far more substantial influence on the outcome than the specific combination of day and month alone.

Finally, for the unsuccessful projects, Cramér's V value was 0.075. This low coefficient signifies a negligible or non-existent association between independent temporal variables. This lack of a clear relationship suggests that unsuccessful projects are launched more randomly in terms of timing. Unlike successful campaigns, which show a clear and consistent pattern in their timing, unsuccessful launches tend to be more widely dispersed across the calendar without regard for the potential synergies between day and the month of campaign start.

Table 2. Cramér's V analysis of the association between launch day and month

Funded		Value	Approximate Significance	Monte Carlo Significance		
				Significance	99% Confidence Interval	
					Lower Bound	Upper Bound
Total	Cramer's V	0.055	0.010	0.013	0.004	0.022
1	Cramer's V	0.076	0.010	0.013	0.004	0.022
0	Cramer's V	0.075	0.062	0.075	0.054	0.096

Based on those results our hypotheses are as follows:

- H_1 : The frequency of project launches is independent of the combination of the day of the week and the month of the year. REJECTED
- H_2 : For successful projects, there is no statistically significant relationship between the launch day and the launch month. REJECTED
- H_{03} : For unsuccessful projects, the launch day and the launch month are independent factors. RETAINED

4. Discussion

The primary objective of this study was to evaluate the extent to which temporal factors, specifically the launch day of the week and the launch month of the year, influence the success of crowdfunding campaigns on HitHit, the leading platform in the Czech Republic. The analysis of 5,272 completed projects suggests that the temporal characteristics of crowdfunding project launches cannot be considered a fully neutral factor, particularly in the case of successful projects and the overall sample of campaigns. While, for unsuccessful projects, no statistically significant relationship between the day of the week and the month of launch was confirmed, for successful projects this dependence appeared consistently across the applied tests. This finding can be interpreted in such a way that temporal factors alone are unlikely to cause project failure; however, they may contribute to project success, especially in combination with other determinants, such as project quality and marketing communication.

Certain identified combinations of days and months exhibit systematic deviations from expected frequencies, which may reflect varying levels of contributor motivation across different periods. Although literature often emphasizes the positive effect of the beginnings of temporal cycles, the results of this study indicate that such an effect is not universal, and

its influence is conditioned by specific combinations of calendar characteristics. An important aspect of the discussion is also the very low value of association measures, particularly Cramér's V, which in all cases indicates only a weak relationship. This fact highlights the distinction between statistical and practical significance. Even though some relationships are statistically significant, their economic and managerial relevance remains limited. For project founders, therefore, no clear recommendation can be made that selecting a specific day or month will substantially increase the probability of success. Rather, it appears that inappropriate timing may, in certain cases, slightly reduce the chances of a project, whereas appropriate timing may function as a supportive, but not decisive, factor.

From a methodological perspective, it is necessary to address the limitations arising from the categorical nature of the data and from the uneven distribution of frequencies in contingency tables. Although these limitations were partially mitigated using Monte Carlo approximation and exact tests, it cannot be excluded that some of the identified effects are sensitive to the data structure or to the length of the observed period. At the same time, the analysis adopts only a two-dimensional perspective, not accounting for other potentially significant variables, such as project type, target funding amount, or campaign duration.

5. Conclusions

By analyzing a comprehensive dataset of 5,272 projects from the HitHit platform, it has been demonstrated that temporal factors, namely the launch day of the week and the month of the year, are not entirely random in their distribution and, to a limited extent, are associated with project outcomes. It was found that, within the overall sample as well as among successful projects, statistically significant relationships between launch timing variables do exist. In contrast, for unsuccessful projects, this relationship was not confirmed, suggesting that structured timing is more typical for successful campaigns than for failed ones. This difference may indicate that more capable or better-prepared creators are more aware of strategic factors, including the importance of choosing the right time to launch their campaigns. At the same time, however, the magnitude of these relationships remains consistently low, as indicated by Cramér's V coefficients. From this perspective, it must be emphasized that statistical significance does not translate into strong practical impact. The role of timing, therefore, should be understood as complementary rather than decisive. In such way, timing can be perceived as a marginal optimization tool, which, when combined with high-quality project design, effective communication, and strong social capital, may slightly enhance the probability of success.

The findings also contribute to the discussion of the "fresh start effect" in digital economic environments. Certain temporal patterns are observable, their influence appears to be conditional and dependent on context rather than universal. It is suggested that psychological mechanisms linked to temporal landmarks do play a role, but their effect is moderated by other structural and behavioral variables.

From a practical standpoint, the results imply that project creators should not rely on timing as a primary success factor. Instead, timing decisions should be integrated into a broader strategic framework, where they function as a low-cost adjustment rather than

a central determinant. Future research, it is recommended, should extend this analysis by incorporating additional explanatory variables, such as project category, funding target, campaign duration, and marketing intensity. Furthermore, using multivariate models or machine learning methods could offer a deeper understanding of how important timing is compared to other factors. An analysis across different national platforms would also be valuable, as it would allow for the identification of cultural or institutional factors shaping crowdfunding dynamics.

In conclusion, timing in crowdfunding should not be ignored, but its overall impact is relatively limited and depends on the context. It represents only one smaller factor within a broader set of influences that together determine whether a campaign becomes successful.

Acknowledgments: The research/work was supported by the internal project “SPEV – Economic challenges and opportunities associated with investment mechanisms in the digital economy, 2026, University of Hradec Králové, Faculty of Informatics and Management, Czech Republic.

Conflict of interest: none

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Costs of Assessment and Additional Assessment of Corporate Income Tax

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Abstract: The paper focuses on analyzing the costs associated with assessing and additional assessing corporate income tax in the Czech Republic between 2021 and 2023. The purpose is to identify the main cost components, analyze their structure and regional differences, and evaluate the overall effectiveness of tax administration. The research is based on the theoretical foundations of tax administration, the legislative framework, and data from the Czech Financial Administration. The methodology combines quantitative analysis of cost items, including personnel, IT infrastructure, and operational expenses, with a comparative assessment of tax collection effectiveness. The results show that while absolute administrative costs rose to 3.21 billion CZK in 2023, the efficiency of tax collection significantly improved. The cost-to-collection ratio decreased from 1.63% in 2021 to 1.13% in 2023, driven by a robust increase in tax revenue and digitalization. The study concludes that modernizing tax processes helps optimize costs and provides recommendations for further improvements in tax administration efficiency.

Keywords: corporate income tax; tax administration; costs; collection efficiency; tax assessment

JEL Classification: H25; H26; H83

1. Introduction

Taxes are a fundamental pillar of public expenditure financing and, at the same time, one of the most important instruments of state economic policy. Effective tax administration affects not only the stability of public finances, but also the confidence of citizens and businesses in the fairness of the tax system, which is considered a key determinant of voluntary tax compliance (Alm & McClellan, 2012; Slemrod, 2019). A key role in this process is played by the assessment and Additional Assessment of corporate income tax – procedures used to determine the correct amount of tax liability and correct any discrepancies (Slemrod & Weber, 2012). Every administrative step, from business registration to tax return processing to possible tax additional assessment, incurs financial costs, which are referred to in the professional literature as tax administration and tax compliance costs (OECD, 2022; Okunogbe & Pouliquen, 2022). These costs can significantly affect the efficiency of the tax system and the business environment.

In recent years, tax administration has changed dramatically as a result of digitisation and process automation. Electronic filing, automated checks and online communication with the tax authorities reduce the administrative burden and speed up tax proceedings, as confirmed by empirical studies analysing the impact of digitisation on tax collection and tax compliance (Okunogbe & Pouliquen, 2022). At the same time, however, these changes require high investments in technological and security infrastructure, which is in line with the OECD's (2022) conclusions on the cost of modernising tax administrations. Tax assessment and additional assessment is therefore not just a technical process, but a reflection of the functioning of the entire tax system. Properly set up processes can reduce the administrative burden on businesses, increase the efficiency of public administration and limit the scope for tax evasion, as confirmed by extensive research and analysis in the field of tax enforcement (Beer et al. 2020; Johannesen et al., 2020).

Conversely, inefficient tax administration can lead to legal disputes, increased public expenditure and a weakening of business confidence in the tax system. As Wattel (2018) points out, direct taxation remains the primary instrument of fiscal policy in modern economies, and effective tax administration must reflect both national and international tax frameworks. This conclusion corresponds with foreign studies that emphasise the growing importance of international tax coordination in response to the globalisation of business activities (Devereux & Vella, 2014; Dharmapala, 2014).

The tax system is constantly evolving in line with legislative changes and international commitments, with the main emphasis on simplicity, fairness and efficiency of tax collection (Ministry of Finance of the Czech Republic, 2023). In the European context, there is an effort to harmonise tax policies and eliminate tax barriers within the single market (Wattel, 2018). Tax administration is carried out by public authorities responsible for registering taxpayers, assigning tax identification numbers and supervising the fulfilment of tax obligations. According to Section 10 of the Tax Code (Czech Rep., 2009), tax administration is carried out primarily by financial and customs authorities, or other administrative authorities if so provided by a special law. The basic powers of the tax administrator include conducting tax and related proceedings, search and control activities, imposing obligations on tax entities and ensuring the payment of taxes. The tax administrator is also authorised to establish and maintain registers and records of taxpayers and their tax obligations (Czech Rep., 2009). International cooperation with the EU and the OECD, which focuses on the exchange of information, the fight against tax evasion and the harmonisation of tax collection rules, also plays an important role (OECD, 2023). The role of the tax administrator within the tax system consists not only in the control and administration of taxes, but also in active cooperation with national and international institutions. Its activities are governed by tax regulations and other legal provisions that define the scope of its powers and responsibilities. The digitisation of tax administration is a key trend in modern tax administration. The introduction of digital tools enables more efficient processing of tax obligations, reduces errors and increases the transparency of the system, as confirmed by empirical analyses by Okunogbe & Pouliquen (2022). At the same time, digitisation allows financial administration resources to be shifted to analytical and control activities with higher added value (OECD, 2023).

Tax administration costs can be divided into several main categories that reflect key areas of tax administration. The most significant cost items include personnel costs, investments in digitisation, administrative expenses and control activities. Effective tax administration is reflected in the ability to optimise these expenses while ensuring smooth tax collection and minimising tax evasion (Hamerníková, 2017). Tax assessment is a fundamental process of tax administration, in which the tax administrator determines the amount of tax liability on the basis of a tax return or its own investigation. This process involves analysing the documents submitted, checking the accuracy of the data and applying the relevant tax laws (Financial Administration of the Czech Republic, 2025). Tax assessment involves administrative and personnel costs, which include staff salaries, office operating costs and technical equipment. It also includes expenses for postal services related to the delivery of tax assessments and decisions by the tax administrator. Another significant component is the cost of information systems that enable the digital processing of tax returns (Vančurová, 2020). Tax additional assessment is a more complex and costly process than tax assessment, as it involves detailed control and legal procedures. Tax additional assessment is considered a key tool for reducing information asymmetry between taxpayers and tax administrators, particularly in the area of transfer pricing and international tax planning (Beer & Loeprick, 2015). The importance of judicial review of additional assessment decisions is considered a fundamental element in protecting the legal certainty of taxpayers.

In an international context, tax administration is increasingly focused on harmonising rules and combating aggressive tax planning. European Union and OECD initiatives aim to limit profit shifting and enhance transparency, which has a direct impact on corporate income tax assessment and additional assessment processes (Devereux & Vella, 2014; Dharmapala, 2014).

The tax system is constantly evolving in line with legislative changes and international commitments, with the main emphasis on simplicity, fairness and efficiency of tax collection. The aim of this paper is to analyze the administrative costs associated with the assessment and additional assessment of corporate income tax (CIT) in the Czech Republic between 2021 and 2023 and to evaluate the efficiency of these processes in relation to the tax collected. To achieve this, the paper examines the cost structure (personal, IT, and operational) and assesses how digitalization has influenced the cost-to-collection ratio.

In this context, it is necessary to unify the terminology used. Tax assessment refers to the primary procedure of determining the tax liability based on a regular tax return. Additional assessment represents the process of correcting or determining a new tax liability, typically following a tax audit or the discovery of new facts by the tax administrator.

2. Methodology

The costs associated with the individual procedural steps of corporate income tax administration were evaluated for the Czech Republic with an emphasis on regional comparisons and the evaluation of tax collection efficiency in the period 2021-2023.

The analysis focuses on calculating the costs associated with assessing and additional assessing corporate income tax. As part of the analyses, the costs were divided into several

categories according to their nature and purpose: human resources, IT infrastructure, office and premises, and operating expenses. Human resources include the salaries of financial administration employees, training costs and employee benefits. IT infrastructure represents expenses related to software, servers, data storage and licence fees. Office space includes rental costs, operating expenses related to energy and maintenance. Operating expenses consist of administrative costs, material equipment and external services necessary for the functioning of the tax administration.

Available data from the Czech Financial Administration and internal reports on tax administrator expenditure were used to evaluate tax administration costs. As some data are not publicly available, it was necessary to estimate it based on secondary data sources. Estimates were made using relative proportions of known values, particularly for personnel costs and IT infrastructure. The methodology of proportional distribution of costs among regions is based on relevant variables such as the number of employees, registered entities, and total collection. Due to the unavailability of granular public data on specific tax types, this study employs expert estimates derived from the internal organizational structure of the Financial Administration. For example, the 25% allocation to personnel costs reflects an expert estimate of the capacity needed to administer corporate income tax compared to other major taxes such as VAT.

The following formulas were used to calculate the individual cost categories.

Human resource costs in individual regions (C_{HR}) were determined according to the following formula:

$$C_{HR} = C_S \times \frac{P_{NE}}{P_{TNE}} \quad (1)$$

C_{HR} represents human resources costs in the region,

C_S is the total amount paid in salaries,

P_{NE} is the number of employees in the region,

P_{TNE} is the total number of employees in the financial administration.

This formula shows the proportional distribution of labor costs based on the share of workers in each region in the total number of employees.

IT infrastructure costs in individual regions (C_{IT}) were determined according to the following formula:

$$C_{IT} = B_{ITB} \times \frac{R_{ENT}}{T_{ENT}} \quad (2)$$

C_{IT} is the cost of IT infrastructure in the region,

B_{ITB} is the total IT infrastructure budget,

R_{ENT} is the number of registered tax entities in the region,

T_{ENT} is the total number of registered tax entities in the Czech Republic.

The allocation of 20–25% for IT and operational expenses is derived from the proportional representation of corporate income tax entities within the total tax registry, while specifically accounting for the higher administrative complexity and technical demands associated with managing these subjects compared to simpler tax agendas (e.g., flat-rate tax regime or physical persons with single income sources).

The costs of office space (C_{SC}) were divided equally among all regions according to the following ratio:

$$C_{SC} = \frac{C_{TSC}}{N_{REG}} \quad (3)$$

C_{SC} office space costs in the region,

C_{TSC} represents total office space costs,

N_{REG} is the number of regions.

The equal distribution of office space costs among regions is applied because these expenses are treated as fixed overheads related to the basic operational infrastructure that must be maintained in each regional headquarters. This simplification reflects the fact that the Financial Administration operates a standardized network of buildings where maintenance, energy, and security costs are centrally allocated to ensure basic accessibility of tax services in all regions, regardless of the specific volume of tax subjects in a given location.

Due to the unavailability of detailed data on the costs of individual components of tax administration, it was necessary to work with estimated values calculated based on available aggregate data. The calculations are based on a methodology of proportional distribution of costs among regions based on relevant variables such as the number of financial administration employees, the number of registered tax entities, and total tax collection in individual regions.

Within the scope of this issue, the success rate of collection transactions, i.e. the effectiveness of tax collection in relation to the costs incurred, was also analysed. For this purpose, an analysis was carried out of the ratio of successfully collected taxes to assessed amounts in individual regions. This approach made it possible to assess the effectiveness of the current tax system and identify areas where there are the greatest differences between expected and actual tax revenue.

3. Results

The costs associated with the process of assessing and additional assessing corporate income tax were calculated based on data collected from the annual reports of the Czech Financial Administration (2021–2023), publicly available databases of the Czech Ministry of Finance (2023) and internal reports on the costs of the tax administrator.

3.1. Human Resource Costs Associated with Tax Administration

Human resources represent a key component of tax administration costs. The total number of employees of the Czech Financial Administration was approximately 13,800 in 2023. Of these, up to 25% are involved in corporate income tax (CIT) administration. These figures are used to estimate the number of employees in each region who are involved in corporate income tax (CIT) administration and their corresponding wage costs (Table 1). The total estimated cost of salaries and contributions for employees involved in corporate income tax is CZK 1,842,217,872. Estimates of total annual wage costs in the previous years 2021 and 2022 were almost identical, as were the total wage costs for all employees in this period (Financial Administration of the Czech Republic, 2024).

Table 1. Estimated wage costs for corporate income tax administration in individual regions in 2021–2023

Tax office (region)	Number of employees at corporate income tax	Average salary (CZK)	Monthly wage costs (CZK)	Annual wage costs (CZK)
Specialised tax office	80	60,000	6,422,400	77,068,800
Prague	450	45,000	27,094,500	325,134,000
Central Bohemia	260	40,000	13,915,200	166,982,400
South Bohemia	150	38,000	7,626,600	91,519,200
Moravian-Silesian	330	39,000	17,220,420	206,645,040
South Moravian	310	41,000	17,005,980	204,071,760
Pilsen	150	37,000	7,425,900	89,110,800
Karlovy Vary	80	36,000	3,853,440	46,241,280
Ústí nad Labem Region	200	37,500	10,035,000	120,420,000
Liberec	130	36,800	6,400,992	76,811,904
Hradec Králové	140	37,200	6,968,304	83,619,648
Pardubice	130	36,900	6,418,386	77,020,632
Vysočina	130	36,500	6,348,810	76,185,720
Zlín	130	36,600	6,366,204	76,394,448
Olomouc	170	37,000	8,416,020	100,992,240

Note: regional distribution is estimated based on proportional allocation of aggregate data

The time required for corporate income tax assessment and additional assessment procedures depends on the complexity of the specific case, regional differences and the technological tools available. While standard tax returns can be processed within a few hours, the review of more complex cases, particularly those involving large legal entities, requires the involvement of multiple experts and may take several days. Labour costs in tax proceedings vary depending on the type of task (Table 2).

Based on analyses of data from 2021–2023, it was found that the time required for complex cases remained stable, unlike the regular agenda, where the full digitisation of routine tasks led to faster processing. In 2023, automation resulted in time savings for routine tasks compared to 2021, as most of these submissions are now processed by automated systems that only alert officials to obvious logical errors (validation). Complex tax returns require individual expert assessment and human intervention, which keeps their time consumption at the same level. The process of preparing for tax additional assessment, which

is a key stage between the completion of the audit and the issuance of the payment assessment, remains the same in terms of personnel and time requirements, as it requires precise legal and factual justification of the differences found.

Table 2. Costs of actions in tax proceedings in 2021 and 2023

Type of action	Number of employees involved	Role in the process	Total time per action (hours)		Labour costs per task (CZK)
			2021	2023	
Processing a simple tax return	1	Administrative worker	2-4	1-2	400-800
Processing of complex tax returns (companies with international elements, deductions)	2	Specialists	10-16	10	4,000-6,400
Standard tax audit	3	Team of auditors	30	25	12,000-24,000
Comprehensive tax audit	3	Team of specialists/lawyers	90-200	80	36,000-80,000
Preparation for additional assessment	2	Specialist + Manager	30	25	12,000-20,000

Regular training and professional development of employees are essential to maintaining the efficiency and expertise of the financial administration. Training for financial administration employees focuses on three main areas: amendments to tax regulations, technological innovations and cybersecurity, as well as the development of managerial and communication skills. In 2023, there was a noticeable increase in spending on employee training (Table 3). In 2023, a record 66,069 people were trained, but the total cost was lower than in 2021 (Table 3). A key factor was the transition to digital education. The financial administration is undergoing a transformation, where online training has enabled the remaining staff to quickly adapt to the growing workload.

Table 3. Costs of training financial administration employees in 2021–2023

Year	Number of employees in training			Online training number of employees	Total number of employees trained	Total training costs (CZK million)
	Internal training for civil servants	External training for civil servants	Financial administration employees			
2021	28,042	4,762	3,119	28,325	35,923	85
2022	23,430	942	1,686	10,862	26,058	82
2023	59,478	3,320	2,325	34,280	66,069	80

3.2. Operating and Investment Costs

Operating costs cover a wide range of expenses, including energy costs, building maintenance, communication with taxpayers, and legal services. These expenses represent a significant part of the financial administration budget and showed an upward trend between 2021 and 2023, mainly due to rising energy prices and increasing inflation (Table 4). In addition to energy, legal and administrative services accounted for a significant portion of operating costs. The growing volume of tax cases and more complex tax agendas led to increased spending on legal advice and administrative support. While expenditure on legal

advice amounted to CZK 725.1 million in 2021, it rose to CZK 771.8 million in 2023. Similarly, expenditure on expert consultations also increased, reaching CZK 341.2 million in 2023 (Table 4). The more complex structure of tax cases required the expansion of expert consultations, particularly in the areas of international tax law, transfer pricing and specific interpretations of tax regulations.

Table 4. Estimated structure of the financial administration's operating costs for CIT in 2021–2023

Year	Purchase of water, fuel and energy (CZK million)	Postage (CZK million)	Telephone services (CZK million)	Legal advice (CZK million)	Expert consultations (CZK million)
2021	163.9	1,461.7	1,910.6	725.1	312.5
2022	182.9	1,504.6	1,907.9	748.4	325.6
2023	236.9	1,564.8	1,987.0	771.8	341.2

Investment costs mainly represent investments in IT infrastructure. The development of expenditure in 2021–2023 reflects an increased emphasis on automation, strengthening cyber security and modernising key systems. Investments in IT were also affected by the COVID-19 pandemic, which required the accelerated digitisation of processes and the transition to electronic tax administration. This situation led to greater investments in online services, which was subsequently reflected in the IT infrastructure budget. A significant item of capital expenditure was the modernisation of tax information systems, in particular the automation of tax return evaluation and the digitisation of control processes. Cyber security was also strengthened in response to the growing risks associated with the digitisation of tax databases (Table 5).

IT expenditure in financial administration showed significant year-on-year differences. In 2021, it reached CZK 930.7 million, with most of the budget going towards current expenditure, such as the operation of tax systems and IT infrastructure management. In 2022, there was a significant decline in investment, mainly due to the temporary restriction of large IT projects and a reduction in capital expenditure to CZK 116 million (Table 5). In contrast, 2023 saw a record increase in IT infrastructure expenditure as a result of extensive investments in the modernisation of key tax systems, cyber security and IT infrastructure.

Table 5. Structure of IT infrastructure costs of the Financial Administration of the Czech Republic in 2021–2023

Year	Total IT expenditure (CZK million)	Current expenditure (CZK million)	Capital expenditure (CZK million)	Investment in the ADIS tax system (CZK million)	Licences (CZK million)	Operating expenditure (CZK million)	Hardware and technology (CZK million)
2021	930.7	680.2	250.2	588.1	-	-	-
2022	731.8	615.8	116.0	-	-	-	-
2023	1,567.5	965.6	601.9	588.1	222.4	459.2	142.9

3.3. Collection of Corporate Income Tax in the Context of Cost Estimates

The success rate of corporate income tax collection is a key indicator of tax administration efficiency. This indicator reflects not only the tax discipline of business

entities, but also the efficiency of the tax assessment and additional assessment processes themselves (OECD, 2023; Ministry of Finance of the Czech Republic, 2023). Between 2021 and 2023, the success rate of tax collection remained almost stable (Table 6). The slight decline in 2023 is related to the higher volume of additional tax assessments, the enforcement of which is more time-consuming. This reflects the overall situation, where stricter tax controls and a higher volume of additional tax assessments are leading to an increase in the number of companies that pay their tax liabilities late or take advantage of payment schedules.

Table 6. Collection rate for assessed/additional and collected corporate income tax

Year	Assessed/additional tax (CZK billion)	Actual tax collection (CZK billion)	Collection rate
2021	195.96	184.52	94.2%
2022	228.68	215.30	94.2%
2023	340.09	284.95	93.7%

The total wage costs for employees involved in the assessment and additional assessment of corporate income tax are based on the estimate in Table 1. These costs in the period 2021-2022 do not differ from those in 2023, as the number of employees involved in corporate income tax has decreased slightly, but their salaries have increased. Employee training costs are determined based on an expert estimate of the number of employees working on corporate income tax, i.e. 25% of the total training costs for all employees. IT infrastructure and operating costs are based on the number of entities administered and the complexity of administering this tax, and are determined on the basis of an expert estimate as 20% of total costs. The costs of legal services and expert consultations for corporate income tax are estimated at 25% of the total costs of these services, taking into account the number of entities and the need for these services in assessing and additional assessing corporate income tax. The individual types of estimated costs are calculated in Table 7.

Table 7. Estimated total costs of assessing and additional assessing corporate income tax

Year	Wage costs (CZK)	Training costs (CZK)	IT costs (CZK)	Operating costs (CZK)	Legal services and consulting costs (CZK)
2021	1,842,218,000	21,250,000	186,140,000	707,240,000	259,400,000
2022	1,842,218,000	20,500,000	146,360,000	719,080,000	268,500,000
2023	1,842,218,000	20,000,000	313,500,000	757,740,000	278,250,000

The costs of tax assessment and additional tax assessment (Table 8) show a fluctuating trend with an overall increase in the period under review. In 2022, there was a slight decrease in costs (compared to 2021). In the last year under review, costs rose to CZK 3,211,708 thousand, representing an increase of 6.48% compared to the previous year. This growth may reflect inflationary pressures and increased spending on digitisation mentioned in previous analyses. While costs rose slightly, the values of assessed tax and actual collection recorded a sharp increase in 2023. The amount of assessed tax increased by almost 73.55% in 2023 compared to 2021. We see a similar trend in tax collection, which increased from CZK 184,520,000 thousand to CZK 284,950,000 thousand in 2023. The fact that assessed tax is

growing faster than collection indicates an increase in the volume of additional assessments or future receivables.

A positive finding is the steady decline in the share of costs in total collection, which indicates the growing efficiency of the Financial Administration. The share of costs in assessed tax has improved dramatically from 1.54% in 2021 to just 0.94% in 2023. This means that the overhead costs per assessed tax crown are getting lower and lower. Despite the growth in absolute costs, their share of corporate income tax collected fell from 1.63% to 1.13%.

Table 8. Costs of assessing and reassessing corporate income tax in the context of collection

Year	Costs (CZK)	Assessed/additional tax (CZK)	Share of assessed/ additional tax	Collection	Share of collection
2021	3,016,248,000	195,960,000	1.54%	184,520,000	1.63%
2022	2,996,658,000	228,680,000	1.31%	215,300,000	1.39%
2023	3,211,708,000	340,090,000	0.94%	284,950,000	1.13%

4. Discussion

The analysis of the costs associated with the assessment and additional assessment of corporate income tax (CIT) in the Czech Republic between 2021 and 2023 reveals a significant shift in the efficiency of tax administration. While the absolute administrative costs for this specific agenda rose from CZK 3.02 billion in 2021 to CZK 3.21 billion in 2023, the relative burden in proportion to tax revenue followed a sharply declining trajectory.

Interpretation of Efficiency and Digitalization

A primary finding is the reduction of the cost-to-collection ratio from 1.63% in 2021 to 1.13% in 2023. Although absolute costs increased by 6.48% in 2023—driven largely by significant investments in IT infrastructure and expert consultations—the relative costs fell due to a robust increase in total tax collection. While a direct causal link between digitalization and efficiency requires further empirical isolation from other macroeconomic factors (such as inflation or corporate profitability), the data suggests that digital systems like ADIS allow the Financial Administration to handle a substantially higher volume of assessed and additionally assessed tax without a linear increase in personnel. This can be interpreted as an „economy of scale“ facilitated by technological modernization.

Cost Structure and Human Resources

The cost structure remains highly rigid, with personnel expenses consistently representing the dominant component, exceeding 57% in 2023. However, the strategic shift toward online training highlights a qualitative improvement in resource management. In 2023, a record number of employees were trained despite a decrease in total training expenditure, demonstrating that digital transformation offers not only operational savings but also broader accessibility to professional development.

Regional Nuances and Specialized Administration

Regional differences in costs, particularly the higher expenses noted in Prague and at the Specialised Tax Office, correspond to the inherent complexity of the entities managed in these jurisdictions. These offices handle sophisticated tax agendas, including transfer pricing and international transactions, which naturally require more expensive expert consultations and legal support. Nevertheless, these higher costs are justified by the disproportionately higher volume of tax collected in these regions, reinforcing the overall productivity of the system.

Strategic Implications

The surge in IT expenditure in 2023 (a 114% year-on-year increase for the CIT portion) reflects a necessary capital investment into cybersecurity and system modernization. In the context of the research objective, this investment appears effective as it has supported a 73% increase in the volume of assessed and additionally assessed tax between 2021 and 2023. To further improve efficiency, it is recommended that the Financial Administration continues to transition from routine manual processing toward automated analytical tools focused on high-value control activities. This development is in line with the conclusions of international studies (OECD, 2023; Okunogbe & Pouliquen, 2022), which confirm the positive relationship between digitisation, higher tax compliance and lower administrative costs.

5. Conclusions

The study evaluated the cost efficiency of corporate income tax (CIT) administration in the Czech Republic from 2021 to 2023. The research objective was met by identifying the key cost drivers and analysing their regional distribution. The findings confirm that while the absolute financial requirements for tax administration are increasing due to necessary investments in modern infrastructure, the relative efficiency of tax collection is improving significantly.

The analysis shows that the Czech tax system is successfully transitioning toward a more digitized model, which allows for a substantial increase in tax revenue management without a corresponding increase in personnel capacity. A significant finding is the role of the Specialised Tax Office and the Prague region, where higher administrative costs are justified by the high complexity of the tax subjects and the disproportionately larger volume of tax collected.

Despite the positive trends in efficiency, the cost structure remains rigid, with personnel expenses being the most significant burden. To ensure long-term sustainability and further cost optimization, it is recommended that the Financial Administration prioritizes the automation of routine assessment processes and enhances the use of advanced analytical tools for tax audits. Future research should focus on a more detailed longitudinal analysis of IT investment returns to further isolate the impact of digitalization from broader macroeconomic trends.

Conflict of interest: none

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Revenue Potential of Real Estate Tax: A Case Study in Selected Municipalities of the Czech Republic

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Abstract: The use of coefficients in real estate tax in the Czech Republic is a topical and increasingly discussed issue. The aim of this paper is to evaluate the use of coefficients in real estate tax in selected municipalities in the Central Bohemian Region as a potential source of higher real estate tax revenues. Municipalities make very limited use of this option. This is mainly because they do not want to increase the tax burden on their residents and try to obtain revenue for municipal budgets from other sources. In connection with the possible use of coefficients, model calculations are performed with the maximum setting of coefficients for individual types of real estate, and the maximum revenue potential in individual municipalities is determined. The results show that there is considerable untapped potential for real estate tax revenue (50% - 75%) in all the municipalities analysed. Further results show a low share of tax revenue in the total and tax revenues of the municipalities concerned. This indicates a considerable dependence of municipalities on shared taxes.

Keywords: real estate tax; municipality; coefficient; revenue

JEL Classification: H71; H21; H24

1. Introduction

Municipal governments at various levels provide their residents with various types of local public goods and services. Municipalities participate in nationally collected taxes for part of their tax revenues, but they can also collect local taxes and fees. As stated by Moravec et al. (2022), local fees are one of the sources of the municipal budget and are regulated by decrees issued by the municipal council. The importance of local fees as a source of financing for municipal activities in Slovakia is also confirmed by Vartašová & Červená (2023). As Moravec et al. (2022), the collection of fees is also associated with the costs of their collection, and these costs are influenced by a number of factors. According to Papčunová & Nováková (2019), democratic countries use a model of fiscal federalism, which examines the optimal distribution of responsibility for financing public goods and the optimal allocation of revenues and expenditures within the budgetary system. Interregional fiscal redistribution from richer to poorer areas is a contentious issue in any federation (Jacques et al., 2021). When measuring and comparing the degree of fiscal decentralisation, basic indicators such as the share of tax revenues of local government budgets in the total revenues of local government

or the share of specific tax revenues in the total tax revenues of local government can be used (Papčunová & Nováková, 2019).

Property taxes are part of public revenues and play an important role in the decentralisation and autonomy of local governments, but its significance may be limited. According to Románová et al. (2019), taxation can be considered one of the instruments of state revenue, but precise limits must be set for property taxes because this instrument concerns property rights. Románová et al. (2019) compare in detail the various aspects of local tax regulation using the Czech Republic and Slovakia as examples. The advantage of collecting this tax is that it is easy to identify the property (central register) and the taxpayer. In some countries, a separate land value tax may also be collected as an economically efficient and beneficial form of taxation that promotes land development. As Hughes et al. (2020), there is a strong theoretical justification for land value taxation, yet this tax is not used by most states.

The issue of optimal selection and correct setting of all factors influencing this tax is the subject of a number of professional studies. Fu (2022) analyses in detail the process of determining the tax base for real estate and its valuation in the context of the Chinese digital economy. Economic factors such as interest rates, inflation, unemployment rates and exchange rates can also influence the estimation of property values for the correct setting of taxes (Unel & Yalpir, 2023). Italy currently uses a cadastral valuation system to determine tax liabilities on real estate. This tax is unpopular because it places a disproportionate tax burden on the socially disadvantaged (Cammeraat & Crivelli, 2020). According to a survey by Levinson (2020), young people with lower incomes and less wealth pay higher property taxes in the US. Cammeraat & Crivelli (2020) state that there is great potential for better use of property tax by replacing the current cadastral property valuation system with a market-based property valuation system.

Property tax is not a major source of revenue for public budgets in most countries and taxpayers do not always perceive it as a tool for improving local infrastructure (Sobotovičová & Janoušková, 2020; Pfeiferová et al., 2020; Cammeraat & Crivelli, 2020; Levinson, 2020). As Sobotovičová & Janoušková (2020) point out, it is in the interest of local government representatives to explain to their taxpayers what specific consideration they have received. Malkowska et al. (2020) point to a direct link between the property tax rate and the political cycle in Poland. Local taxes are also a useful tool for politicians seeking re-election, as they bring direct and visible benefits to the largest possible number of voters. In addition to political factors, local tax policy can also be influenced by economic factors, in particular unemployment in individual regions (Malkovska et al., 2020). An analysis of the development of real estate tax in the Czech Republic in the period 1993–2024 (Krajňák, 2024) shows that, despite repeated tax reforms, there has been a real decrease in the tax burden on most properties due to the long-term absence of inflationary indexation of rates, which has had a negative impact on municipal tax revenues.

The purpose of real estate tax is to tax land, buildings and flats located in the Czech Republic (Kukalová et al., 2021b; Pfeiferová et al., 2020; Sobotovičová & Janoušková,

2020). The coefficients that can be adjusted by municipalities in the Czech Republic are an effective way of securing additional tax revenue. They can be set by municipalities to consider the positive and negative externalities associated with the use of real estate. According to Kukalová et al. (2021), the share of real estate tax in total municipal revenues is low, and the coefficients for increasing it are not widely used. Zelenská (2024) states that the local coefficient was introduced into Czech legislation in 2009, but only 389 municipalities opted to apply it in practice in 2010; the main motive for its introduction was the fiscal interest of municipalities, and her research also suggests the existence of a spatial effect, whereby municipalities often imitate the approach of neighbouring local governments when deciding on the application of the coefficient. Bečica (2014) also addressed the issue of the introduction of the local coefficient and its subsequent impact on real estate tax revenue for municipalities in the Czech Republic in his paper, pointing out its insufficient use. According to an analysis by Zdražil & Pernica (2018), the introduction of the local coefficient in selected municipalities affects the quality of life in the areas of education, healthcare, public transport and safety.

The aim of this paper is to evaluate the use of coefficients in real estate tax in selected municipalities in the Central Bohemian Region as a potential source of higher real estate tax revenues.

2. Methodology

The evaluation of the potential of real estate tax coefficients is carried out in selected municipalities in the Central Bohemian Region. These municipalities were selected to represent different size categories and different economic areas of the region. This diversified sample composition allows for analyses across diverse locations in the Central Bohemian Region. The selected municipalities correspond to the division of municipalities into individual categories according to population size (Table 1).

Table 1. Municipalities analysed by population (Czech Statistical Office, 2024)

Municipality	Population (2024)	Category
Senice (SE)	202	up to 499
Kostelní Lhota (KL)	853	500–999
Sadská (SA)	3,271	1,000–4,999
Český Brod (CB)	7,261	5,000–9,999
Nymburk (NB)	14,797	10,000–24,999
Kolín (KO)	31,950	over 25,000

Data from the database of the Financial Administration of the Czech Republic (Tax Office for the Central Bohemian Region) for 2024 and data from the Ministry of Finance of the Czech Republic (Monitor) were used to analyse the use of coefficients and yields from real estate tax in individual municipalities. The data for 2024 was fully available and relevant at the time of the analysis. The data obtained had to be separated and organised according to individual municipalities. Data on real estate tax revenues and the use of coefficients were further sorted for the municipalities in terms of the share of individual types of real estate in the total real estate tax revenue, according to the codes of specific

types of real estate (Table 2). The table shows the tax rates for individual types of real estate and the options for using the municipal coefficient based on population size (CP) and local coefficient (LC).

Table 2. Types and codes of real estate with assigned rates and possible coefficients (Financial Administration, 2024)

Code	Type of real estate	Tax rate CZK/m ²	CP	LC
A	Farmland	1.35	-	0.5 – 1.5
B	Permanent grassland	0.45	-	0.5 – 1.5
C	Commercial forest	0.45	-	0.5 – 1.5
E	Built-up area and courtyard	0.35	-	0.5 – 5.0
F	Building land	3.50	1.0 – 5.0	0.5 – 5.0
G	Other land	0.35	-	0.5 – 5.0
Q	Other land with specified use: miscellaneous land	0.35	-	0.5 – 5.0
W	Other land – non-productive: unproductive land, field margin, hillside, waterlogged area, and vegetation cover	0.08	-	0.5 – 5.0
X	Paved area (business in agriculture, etc.)	1.80	-	0.5 – 5.0
Y	Paved area (other types of business)	9.00	-	0.5 – 5.0
H	Residential building	3.50	1.0 – 5.0	0.5 – 5.0
I	Building – outbuildings to H	3.50	1.0 – 5.0	0.5 – 5.0
J	Cottage	1.00	-	0.5 – 5.0
K	Outbuildings to J	3.50	-	0.5 – 5.0
L	Garage	14.50	-	0.5 – 5.0
M	Building used for business (agriculture, etc.)	3.50	-	0.5 – 5.0
N	Building used for business (industry, construction, transport, energy, or other agricultural production)	18.00	-	0.5 – 5.0
O	Building used for business (other types of business)	18.00	-	0.5 – 5.0
P	Other taxable construction	11.00	-	0.5 – 5.0
R	Apartment (for living)	3.50	1.0 – 5.0	0.5 – 5.0
S	Apartment (for business – in agriculture, etc.)	3.50	-	0.5 – 5.0
T	Apartment (for business – industry, construction, transport, energy, or other agricultural production)	18.00	-	0.5 – 5.0
U	Apartment (for other types of business)	18.00	-	0.5 – 5.0
V	Unit used as a garage	14.50	-	0.5 – 5.0
Z	Another unit	3.50	1.0 – 5.0	0.5 – 5.0

For all municipalities analysed, the coefficients set in the municipalities for individual types of real estate for 2024 were determined from the Financial Administration data (2024) (Tables 3 to 8). The determination of the potential revenue from real estate tax in the municipalities was based on tax revenue in 2024. The revenue potential was determined for 2025, considering changes in the determination of coefficients in 2025. Therefore, it was necessary to adjust the revenue without changes in coefficients for revenue arising from the determination of a coefficient of 1.5 for certain types of real estate (garages, commercial buildings, etc.). In some municipalities, there would be a decline in real estate tax revenue in 2025 if the coefficients were not adjusted. The

potential revenue in 2025 is based on comprehensive data from 2024 and includes changes in the possibilities for determining and adjusting the coefficients applicable in 2025. Calculations of potential revenues for 2025 were made using the maximum possible coefficients. This phase included a detailed analysis of the status of local coefficient utilisation in 2024 and the adjustment of revenues to eliminate the impact of coefficients. Revenues for 2025 were calculated based on 2024, but with new rules for the use of coefficients. These changes mainly include a new method of adjusting CP. Subsequently, the unused potential was determined, both in absolute values and as a percentage, and the share of actual and potential real estate tax revenues in the total and tax revenues of the analysed municipalities was determined.

3. Results

The analysis of the potential for setting and adjusting real estate tax coefficients in selected municipalities shows that local governments have significant opportunities to increase their tax revenues. However, as the data indicates, most of the municipalities analysed do not fully exploit these options, leaving a substantial portion of potential revenue untapped.

3.1. Real Estate Tax Revenue with Maximum Use of Coefficients

The detailed analysis of individual real estate types across all municipalities reveals several key trends:

- Residential Buildings and Units (H, I, R, Z): Across all size categories, the highest untapped revenue potential is consistently found in residential property. For example, in Kolín, the potential increase from residential buildings alone exceeds CZK 38 million. However, increasing this burden is often politically sensitive.
- Business Properties (M, S, N, T, O, U): These properties represent the second most significant source of potential growth. Setting maximum coefficients for buildings used for industry, energy, or other business activities offers a more politically acceptable path for municipalities to increase revenue.
- Farmland (A): In smaller municipalities like Senice and Kostelní Lhota, a large share of current revenue comes from farmland, where the potential for further increase is limited by a maximum local coefficient of 1.5.

Full utilization of these coefficients would fundamentally change the structure of municipal budgets, significantly increasing the share of real estate tax in total tax revenues and reducing dependence on shared taxes. For instance, in Senice, the share of real estate tax in tax revenues could rise from 12.13% to over 30%.

Table 3. Potential revenue from real estate tax with maximum use of coefficients – municipality of Senice

Code	Coefficients 2024			Revenue 2024 (CZK)	Revenue 2025 (no coefficient change) (CZK)	Maximum coeff. 2025		Potential tax revenue 2025 (CZK)	Change in revenue 2025 (CZK)
	CP	1.5	LC			CP	LC		
A	-	-	1.0	757,139	757,139	-	1.5	1,135,709	378,570
B	-	-	1.0	72	72	-	1.5	108	36
W	-	-	1.0	501	501	-	1.5	752	251
C	-	-	1.0	0	0	-	5.0	0	0
E	-	-	1.0	18,960	18,960	-	5.0	94,800	75,840
F	1.0	-	1.0	6,182	6,182	1.4	5.0	43,274	37,092
G	-	-	1.0	18,812	18,812	-	5.0	94,060	75,248
Q	-	-	1.0	14,753	14,753	-	5.0	73,765	59,012
X	-	-	1.0	0	0	-	5.0	0	0
Y	-	-	1.0	801	801	-	5.0	4,005	3,204
H, I	1.0	-	1.0	72,501	72,501	1.4	5.0	507,507	435,006
R, Z	1.0	-	1.0	1,306	1,306	1.4	5.0	9,142	7,836
J, K	-	1.0	1.0	10,921	10,921	-	5.0	54,605	43,684
L, V	-	1.0	1.0	6,252	6,252	-	5.0	31,260	25,008
M, S	-	1.0	1.0	43,124	43,124	-	5.0	215,620	172,496
N, T	-	1.0	1.0	0	0	-	5.0	0	0
O, U	-	1.0	1.0	44,658	44,658	-	5.0	223,290	178,632
P	-	-	1.0	330	330	-	5.0	1,650	1,320
Total				996,312	996,312			2,489,546	1,493,250

Table 4. Potential real estate tax revenue with maximum use of coefficients – municipality of Kostelní Lhota

Code	Coefficients 2024			Revenue 2024 (CZK)	Revenue 2025 (no coefficient change) (CZK)	Maximum coeff. 2025		Potential tax revenue 2025 (CZK)	Change in revenue 2025 (CZK)
	CP	1.5	LC			CP	LC		
A	-	-	1.0	351,257	351,257	-	1.5	526,886	175,629
B	-	-	1.0	3,336	3,336	-	1.5	5,004	1,668
W	-	-	1.0	95	95	-	1.5	143	48
C	-	-	1.0	10,494	10,494	-	5.0	52,470	41,976
E	-	-	1.0	36,553	36,553	-	5.0	182,765	146,212
F	1.0	-	1.0	6,203	6,203	1.4	5.0	43,421	37,218
G	-	-	1.0	25,054	25,054	-	5.0	125,270	100,216
Q	-	-	1.0	11,841	11,841	-	5.0	59,205	47,364
X	-	-	1.0	0	0	-	5.0	0	0
Y	-	-	1.0	17,316	17,316	-	5.0	86,580	69,264
H, I	1.0	-	1.0	226,076	226,076	1.4	5.0	1,582,532	1,356,456
R, Z	1.0	-	1.0	6,975	6,975	1.4	5.0	48,825	41,850
J, K	-	1.0	1.0	10,815	10,815	-	5.0	54,075	43,260
L, V	-	1.0	1.0	27,010	27,010	-	5.0	135,050	108,040
M, S	-	1.0	1.0	13,675	13,675	-	5.0	68,375	54,700
N, T	-	1.0	1.0	23,328	23,328	-	5.0	116,640	93,312
O, U	-	1.0	1.0	67,946	67,946	-	5.0	339,730	271,784
P	-	-	1.0	14,743	14,743	-	5.0	73,715	58,972
Total				852,717	852,717			3,500,685	2,647,968

Table 5. Potential real estate tax revenue with maximum use of coefficients – municipality of Sadská

Code	Coefficients 2024			Revenue 2024 (CZK)	Revenue 2025 (no coefficient change) (CZK)	Maximum coeff. 2025		Potential tax revenue 2025 (CZK)	Change in revenue 2025 (CZK)
	CP	1.5	LC			CP	LC		
A	-	-	1.0	1,638,302	1,638,302	-	1.5	2,457,453	819,151
B	-	-	1.0	24,856	24,856	-	1.5	37,284	12,428
W	-	-	1.0	3,826	3,826	-	1.5	5,739	1,913
C	-	-	2.0	16,440	16,440	-	5.0	41,100	24,660
E	-	-	2.0	139,412	139,412	-	5.0	348,530	209,118
F	1.4	-	2.0	24,936	24,936	1.6	5.0	71,246	46,310
G	-	-	2.0	132,896	132,896	-	5.0	332,240	199,344
Q	-	-	2.0	87,736	87,736	-	5.0	219,340	131,604
X	-	-	2.0	698	698	-	5.0	1,745	1,047
Y	-	-	2.0	726,860	726,860	-	5.0	1,817,150	1,090,290
H, I	1.4	-	2.0	1,813,510	1,813,510	1.6	5.0	5,181,457	3,367,947
R, Z	1.4	-	2.0	130,626	130,626	1.6	5.0	373,217	242,591
J, K	-	1.5	2.0	412,682	275,122	-	5.0	687,803	412,681
L, V	-	1.5	2.0	297,262	198,175	-	5.0	495,437	297,262
M, S	-	1.5	2.0	6,228	4,152	-	5.0	10,380	6,228
N, T	-	1.5	2.0	2,343,090	1,562,060	-	5.0	3,905,150	2,343,090
O, U	-	1.5	2.0	1,589,978	1,059,986	-	5.0	2,649,963	1,589,977
P	-	-	2.0	332,718	332,718	-	5.0	831,795	499,077
Total				9,722,056	8,172,311			19,467,029	11,294,718

Table 6. Potential real estate tax revenue with maximum use of coefficients – municipality of Český Brod

Code	Coefficients 2024			Revenue 2024 (CZK)	Revenue 2025 (no coefficient change) (CZK)	Maximum coeff. 2025		Potential tax revenue 2025 (CZK)	Change in revenue 2025 (CZK)
	CP	1.5	LC			CP	LC		
A	-	-	1.0	726,392	726,392	-	1.5	1,089,588	819,196
B	-	-	1.0	4,400	4,400	-	1.5	6,600	2,200
W	-	-	1.0	6,633	6,633	-	1.5	9,950	3,317
C	-	-	2.5	1,232	1,232	-	5.0	2,464	1,232
E	-	-	2.5	172,134	172,134	-	5.0	344,268	172,134
F	2.0	-	2.5	69,567	69,567	2.0	5.0	139,134	69,567
G	-	-	2.5	229,551	229,551	-	5.0	459,102	229,551
Q	-	-	2.5	67,829	67,829	-	5.0	135,658	67,829
X	-	-	2.5	0	0	-	5.0	0	0
Y	-	-	2.5	1,259,533	1,259,533	-	5.0	2,519,066	1,259,533
H, I	1.4	-	2.5	3,746,796	4,282,053	2.0	5.0	10,705,131	6,423,078
R, Z	1.6	-	2.5	1,159,797	1,159,797	2.0	5.0	2,899,493	1,739,696
J, K	-	1.5	2.5	28,806	19,204	-	5.0	38,408	19,204
L, V	-	1.5	2.5	982,635	655,090	-	5.0	1,310,180	655,09
M, S	-	1.5	2.5	24,194	16,129	-	5.0	32,259	16,129
N, T	-	1.5	2.5	1,887,819	1,258,546	-	5.0	2,517,087	1,258,546
O, U	-	1.5	2.5	4,951,608	3,301,072	-	5.0	6,651,374	3,350,302
P	-	-	2.5	332,531	332,531	-	5.0	665,062	332,531
Total				15,651,453	13,561,693			29,524,823	15,827,376

Table 7. Potential real estate tax revenue with maximum use of coefficients – municipality of Nymburk

Code	Coefficients 2024			Revenue 2024 (CZK)	Revenue 2025 (no coefficient change) (CZK)	Maximum coeff. 2025		Potential tax revenue 2025 (CZK)	Change in revenue 2025 (CZK)
	CP	1.5	LC			CP	LC		
A	-	-	1.0	1,215,149	1,215,149	-	1.5	1,822,724	607,575
B	-	-	1.0	13,207	13,207	-	1.5	19,811	6,604
W	-	-	1.0	12,956	12,956	-	1.5	19,434	6,478
C	-	-	2.0	12,102	12,102	-	5.0	30,255	18,153
E	-	-	2.0	190,346	190,346	-	5.0	475,865	285,519
F	2.5	-	2.0	175,550	175,550	2.5	5.0	438,875	263,325
G	-	-	2.0	440,542	440,542	-	5.0	1,101,355	660,813
Q	-	-	2.0	341,170	341,170	-	5.0	852,925	511,755
X	-	-	2.0	22,312	22,312	-	5.0	55,780	33,468
Y	-	-	2.0	4,938,906	4,938,906	-	5.0	12,347,265	7,408,359
H, I	2.5	-	2.0	5,727,084	5,727,084	2.5	5.0	14,317,710	8,590,626
R, Z	2.5	-	2.0	5,621,182	5,621,182	2.5	5.0	14,052,955	8,431,773
J, K	-	1.0	2.0	71,324	71,324	-	5.0	178,310	106,986
L, V	-	1.0	2.0	1,323,278	1,323,278	-	5.0	3,308,195	1,984,917
M, S	-	1.0	2.0	81,476	81,476	-	5.0	203,690	122,214
N, T	-	1.0	2.0	9,294,632	9,294,632	-	5.0	23,236,580	13,941,948
O, U	-	1.0	2.0	6,971,350	6,971,350	-	5.0	17,428,375	10,457,025
P	-	-	2.0	308,522	308,522	-	5.0	771,305	462,783
Total				36,761,088	36,761,088			90,661,408	53,900,320

Table 8. Potential real estate tax revenue with maximum use of coefficients – municipality of Kolín

Code	Coefficients 2024			Revenue 2024 (CZK)	Revenue 2025 (no coefficient change) (CZK)	Maximum coeff. 2025		Potential tax revenue 2025 (CZK)	Change in revenue (CZK)
	CP	1.5	LC			CP	LC		
A	-	-	1.0	1,345,305	1,345,305	-	1.5	2,017,958	672,653
B	-	-	1.0	68,005	68,005	-	1.5	102,008	34,003
W	-	-	1.0	44,279	44,279	-	1.5	66,419	22,140
C	-	-	2.0	50,494	50,494	-	5.0	126,235	75,741
E	-	-	2.0	348,642	348,642	-	5.0	871,605	522,963
F	2.5	-	2.0	519,252	519,252	3.5	5.0	1,817,382	1,298,130
G	-	-	2.0	640,446	640,446	-	5.0	1,601,115	960,669
Q	-	-	2.0	733,178	733,178	-	5.0	1,832,945	1,099,767
X	-	-	2.0	17,180	17,180	-	5.0	42,950	25,770
Y	-	-	2.0	13,138,988	13,138,988	-	5.0	32,847,470	19,708,482
H, I	1.6	-	2.0	9,112,338	11,390,423	3.5	5.0	49,833,098	38,422,675
R, Z	2.5	-	2.0	11,309,122	11,309,122	3.5	5.0	39,581,927	28,272,805
J, K	-	1.0	2.0	49,448	49,448	-	5.0	123,620	74,172
L, V	-	1.0	2.0	2,415,340	2,415,340	-	5.0	6,038,350	3,623,010
M, S	-	1.0	2.0	20,424	20,424	-	5.0	51,060	30,636
N, T	-	1.0	2.0	16,755,072	16,755,072	-	5.0	41,937,680	25,162,608
O, U	-	1.0	2.0	13,016,648	13,016,648	-	5.0	32,541,620	19,524,972
P	-	-	2.0	639,302	639,302	-	5.0	1,598,255	958,953
Total				70,243,463	72,052,083			213,031,696	140,510,149

3.2. Evaluation of the Potential of Real Estate Tax in the Municipalities Concerned

All the municipalities analysed show significant untapped potential (Table 9). The highest untapped potential is in the municipality of Kutná Hora (KH, 75.6%), while the lowest untapped potential is in the municipalities of Sadská (SA, 50%) and Český Brod (CB, 53.6%). The municipality of SA makes the most effective use of the potential of real estate tax coefficients among the municipalities surveyed.

Table 9. Evaluation of the potential revenue from real estate tax in the municipalities

Municipality	Number of inhabitants	Total real estate tax revenue without changes in coefficients (CZK)	nd 2025 potential yield (CZK) with maximum utilisation of coefficients	Unused potential (CZK)	Unused potential
SE	202	996,312	2,489,546	1,493,234	60.0%
KL	853	852,717	3,500,685	2,647,968	75.6%
SA	3,271	9,722,056	19,467,029	9,744,973	50.0%
CB	7,261	15,651,453	29,524,823	15,827,376	53.6%
NB	14,797	36,761,088	90,661,408	53,900,320	59.4%
KO	31,950	70,243,463	213,031,696	140,510,149	66.0%

If the analysed municipalities took advantage of the possibility to adjust and set coefficients, the increased real estate tax revenues would be reflected in higher municipal budget revenues, and the structure of budget revenues would change (Table 10). An increase in real estate tax revenues increases the share of real estate tax in tax revenues and reduces municipalities' dependence on shared taxes.

Table 10. Share of real estate tax revenues in total and tax revenues of budgets in given municipalities

Municipality	Total budget revenue (CZK)	Share of real estate tax revenue without changes in coefficients in total revenue	Share of potential real estate tax revenue with max. use of coefficients in total revenue	Budget tax revenue (CZK)	Share of real estate tax revenue without changes to coefficients in tax revenue	Share of potential real estate tax revenue with max. use of coefficients in tax revenue
SE	15,184,257	6.56%	16.40%	8,212,404	12.13%	30.31%
KL	34,370,261	2.48%	10.19%	19,692,008	4.33%	17.78%
SA	89,346,941	10.88%	21.79%	80,293,432	12.11%	24.24%
CB	419,749,379	3.73%	7.03%	203,407,959	7.69%	14.52%
NB	930,006,630	3.95%	9.75%	415,857,920	8.84%	21.80%
KO	1,787,368,991	3.93%	11.92%	871,291,901	8.06%	24.45%

4. Discussion

The results of the model calculations clearly demonstrate that the revenue potential of real estate tax in the Czech Republic remains largely untapped. Increasing the coefficient according to the number of inhabitants and setting a local coefficient is an interesting and relatively simple option for municipalities to obtain missing funds for their budgets. According to Zelenská (2024), tax changes have also led to the local coefficient beginning to

play the role of a key corrective tool through which municipalities can adjust the resulting real estate tax, both upwards and downwards, including the taxation of agricultural land. Nevertheless, most municipalities in the Czech Republic do not use this option (Kukalová et al., 2021a; Kukalová et al., 2021b; Bečica, 2014). While the theoretical potential for revenue increase ranges between 50% and 75% in the studied municipalities, the practical application of higher coefficients remains an exception rather than the rule. Kukalová et al. (2021a) state that in 2019, the untapped potential of the local coefficient in the Czech Republic was 93%. Compared to 2019, the use of the local coefficient has increased. For example, in the Central Bohemian Region, 198 municipalities (17% of the total) had a local coefficient set in 2019, but in 2024, 359 municipalities, or 31% of the total number of municipalities in the Central Bohemian Region, were already using the local coefficient (Financial Administration of the Czech Republic, 2024).

The significant gap between potential and actual revenue can be attributed to several factors. Firstly, real estate tax is one of the most visible taxes. Unlike income tax, which is often withheld at the source, real estate tax must be paid actively by the taxpayer, making it politically sensitive for local representatives. Our findings align with the "political budget cycle" theory—mayors are reluctant to increase tax burdens on their residents, fearing negative electoral consequences (as previously noted by Sedmíhradská, 2021).

From a policy perspective, our study suggests that municipalities should focus on a more selective application of coefficients. Instead of a blanket increase for all residents (which causes the most resistance), municipalities could strategically increase the Local Coefficient (LC) for specific categories, such as business properties (codes M, S, N, T) or second homes/recreational properties. This approach would allow for revenue growth while mitigating the social impact on permanent residents.

In comparison with other EU countries, the Czech Republic's reliance on shared taxes (*sdílené daně*) remains exceptionally high. The untapped potential of 50–75% identified in our study suggests that if the central government continues to reduce municipal shares of VAT or income tax, local governments have a viable, albeit politically challenging, internal reserve to maintain fiscal stability.

A limitation of this study is its focus on a specific region (Central Bohemia). Future research should expand the analysis to structurally disadvantaged regions, where the revenue potential might be significantly lower due to different property values. Furthermore, an investigation into the correlation between the level of tax coefficients and the quality of local public services would provide deeper insights into the "tax-benefit" link at the local level.

5. Conclusions

Real estate tax in municipalities in the Czech Republic has been gaining importance in recent years. The growing significance of this tax is also reflected in municipal strategic planning, where it is becoming an important tool for ensuring long-term financial stability and municipal development. There has been a significant shift in the perception and use of this tax as an important tool for municipal budgets. Real estate tax represents a stable and

predictable source of income that is directly linked to the municipality's territory. However, tax increases are a very sensitive issue, and therefore the maximum use of coefficients is only theoretical, as most municipalities have not had the courage to take this step in the past. Where coefficients have been increased, this has mainly affected owners of commercial properties or buildings used for recreational purposes. Over the years, this potential, with the possibility of optimal adjustment by the municipality, has been increasingly exploited. This development indicates an effort by municipalities to use the local coefficient as an effective tax policy tool, probably in response to the growing need to increase municipal budget revenues. Although real estate tax collection is growing year on year, its share of total revenues is declining. This is due to the greater growth dynamics of shared taxes, in particular value added tax, which significantly affect the total revenue of municipalities.

A comparison of the results of the analysis for individual municipalities suggests that municipalities have significant scope to increase their revenues by adjusting real estate tax coefficients, but for various reasons (social, political, economic) they are not yet fully exploiting this potential. The results can serve as a basis for strategic decisions by municipalities in tax policy and contribute to a better understanding of the role of real estate tax in municipal budgets.

Conflict of interest: none

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Quantifying Reputational Risk in MedTech: The Impact of Notoriety Bias on Stock Volatility and Adverse Event Reporting

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Abstract: Quality control and reputational risk management are critical factors for medical device manufacturers. This paper investigates the phenomenon of "Notoriety Bias", a situation where the volume of adverse event reports (MDR) is driven by media attention rather than solely by product failure rates. Using the 2021, Philips Respironics, ventilator recall as a case study, we analyze the temporal relationship between three variables: (1) the external shock (Recall event), (2) consumer reaction (FDA MAUDE database reports), and (3) capital market reaction (stock price volatility). Methodologically, the study employs STL decomposition and ARIMAX modeling to quantify the structural break in reporting, and Granger Causality tests to verify the direction of information flow. These findings are contrasted with an Event Study of abnormal stock returns. The results reveal a significant temporal decoupling: while the capital market reacts immediately (efficient market hypothesis), the consumer reaction (reporting spike) exhibits a significant lag of 10–12 months. The study demonstrates the utility of OpenFDA Big Data for modeling corporate risk dynamics.

Keywords: MAUDE; adverse event; ARIMAX; Granger causality

JEL Classification: M21; L1; G17

1. Introduction

Quality control and reputational risk management are paramount for manufacturers in the healthcare sector. A robust quality culture is essential not only for ensuring patient safety but also for saving costs and protecting a brand's reputation. In the medical device industry, postmarket safety surveillance is crucial given the limitations of premarket evidence. A central tool for this surveillance in the United States is the Food and Drug Administration's (FDA) Manufacturer and User Facility Device Experience (MAUDE) database. While this system allows for the detection of safety issues, it relies on passive reporting from external individuals and organizations, making it susceptible to inaccuracies, incompleteness, and reporting biases.

A critical challenge in passive surveillance is discerning whether a surge in adverse event reports reflects a genuine increase in device failures or is driven by external factors such as media attention—a phenomenon known as "notoriety bias". Notoriety bias is a selection bias

where a case has a greater chance of being reported if the subject is exposed to a factor known or thought to cause the event, often triggered by safety alerts or media coverage. Conversely, recent investigations have revealed significant issues with late reporting; nearly a third of manufacturer reports to the MAUDE database are not submitted within the required 30-day window, with some delayed by more than six months. This raises the question: to what extent does the volume of adverse event reports correlate with actual product failure versus public awareness and corporate reporting delays, and how does this dynamic interact with the company's market value?

While the financial impact of product recalls on shareholder wealth is well-documented, with studies confirming significant negative stock market reactions to recall announcements, the temporal relationship between the financial shock and the regulatory reporting surge is less understood. Existing research has examined the impact of product recalls on stock prices across various sectors, finding that the automotive and pharmaceutical industries experience significant losses due to high regulation and hazard levels. However, there is a need to quantify the specific lag between the immediate capital market reaction and the potentially delayed consumer and regulatory reaction manifesting in surveillance databases.

This study aims to quantify the magnitude and delay of notoriety bias using the 2021 Philips Respironics ventilator recall as a case study. By employing advanced time-series analysis, we seek to model the structural breaks in reporting and contrast them with market volatility to better understand the decoupling of financial and regulatory risks.

Spontaneous reporting systems like FAERS and MAUDE are fundamental to pharmacovigilance but face challenges such as underreporting and stimulated reporting. Historically, the "Weber Effect" suggested that adverse event reporting peaks at the end of the second year after regulatory approval and then diminishes. However, Hoffman et al. (2014) analyzed modern reporting patterns and found little evidence of this trend, suggesting that reporting counts tend to increase over the first three quarters and then remain constant.

More recently, attention has shifted to "notoriety bias" or stimulated reporting triggered by safety alerts and media coverage. Neha et al. (2021) define this as a bias where exposure to a factor known to cause an event increases the likelihood of reporting. While their study on the FAERS database found that overreporting due to notoriety bias did not consistently alter signal strength for all drugs, they noted that specific safety alerts could drive increased reporting. The influence of media is further highlighted by Al-Ali et al. (2022), who noted that media attention regarding rare adverse events post-vaccination contributed to widespread hesitancy and controversy, suggesting a link between public publicity and the perception of risk. Furthermore, Everhart et al. (2025) highlight the prevalence of late adverse event reporting in the medical device sector, noting that late reports are often released in large batches, which can obscure the timely identification of safety concerns.

To statistically model the impact of external shocks—such as a recall announcement—on time-series data, this study draws on the foundational work of Box and Tiao (1975). Their methodology for "Intervention Analysis" provides a framework for analyzing whether a specific event (intervention) causes a step change or a pulse in a stochastic process, allowing researchers to distinguish between noise and actual structural shifts in data. This approach

allows for the modeling of dynamic responses, such as immediate step changes or gradual "ramp" responses following an intervention.

The study's financial analysis is grounded in the efficient market hypothesis, which posits that an efficient market reacts instantaneously to new information, such as a product recall, by adjusting stock prices. Bernon et al. (2018) employed event study methodology to confirm that product recalls generate negative stock market reactions, with the magnitude of the loss influenced by the industry sector and the hazard level of the product. Specifically, recalls involving severe hazards (Class I) lead to greater reductions in share price due to perceived litigation costs and reputational damage. Similarly, Kim and Noh (2025) found that delayed recall decisions can lead to substantial negative stock returns, emphasizing the market's sensitivity to the timing and management of safety issues.

2. Methodology

The primary data source for this study is the Manufacturer and User Facility Device Experience (MAUDE) database, managed by the U.S. Food and Drug Administration (FDA). This passive surveillance system aggregates Medical Device Reports (MDRs) from mandatory reporters (manufacturers, importers) and voluntary reporters (healthcare professionals, patients) under 21 CFR Part 803. To ensure data integrity and reproducibility, raw data were not manually exported but acquired programmatically via the "openFDA API" (<https://api.fda.gov/device/event.json>). This RESTful API allows for precise server-side filtering and structured JSON output. The extraction strategy employed the `search` parameter to filter records by manufacturer and date range, utilizing pagination (`limit`, `skip`) to bypass the default 1000-record query limit.

The analysis focuses on Philips Respironics as a case study, specifically examining the impact of the June 2021 Class I Recall regarding sound abatement foam degradation. The observational period spans from January 1, 2018, to December 31, 2023.

The dependent variable is the aggregate monthly count of adverse event reports. A critical methodological decision was to utilize the `date\_received` (the date the FDA received the report) rather than the `date\_of\_event` (when the incident occurred). This distinction is vital for analyzing "Notoriety Bias," as `date\_received` reflects the temporal reaction of the public and reporters to external stimuli (media coverage, recalls), whereas `date\_of\_event` is subject to "back-filling" bias and does not accurately capture the reporting behavior triggered by the recall news.

2.1. Statistical Framework

To isolate the underlying signal from noise, the time series was decomposed using STL Decomposition (Seasonal and Trend decomposition using Loess). We assessed the series for three components: Trend, Seasonality, and Residuals. The strength of the trend and seasonality were calculated to determine the necessity of seasonal adjustment in subsequent modeling.

The core analysis employs the Box-Jenkins methodology (ARIMA) to model the baseline reporting behavior. Stationarity was verified using the Augmented Dickey-Fuller (ADF) test.

Where non-stationarity was detected (unit root presence), the series was stabilized via differencing.

To quantify the impact of the recall, we utilized Intervention Analysis (ARIMAX). The recall event was modeled as an exogenous binary variable. Two intervention functions were considered:

- Pulse Function: Represents a temporary shock.
- Step Function: Represents a structural break or permanent shift in reporting levels.

To address the potential delay between the recall announcement and the surge in reporting, we performed a Lag Analysis. Multiple ARIMA models were fitted with intervention delays ranging from 0 to 12 months. The optimal lag was selected by minimizing the Akaike Information Criterion (AIC) to prevent overfitting and identify the most statistically probable reaction time.

To verify the directionality of information flow, specifically, that the recall event predicts the reporting surge and not vice versa, we employed the Granger Causality test based on Vector Autoregression (VAR). The test evaluates whether past values of the recall binary variable provide statistically significant information for forecasting future reporting volumes beyond what is contained in the history of variable itself. Robustness was checked by testing lag lengths of 1 to 18 months to ensure results were not artifacts of arbitrary lag selection.

All data processing and statistical analyses were conducted in R version 4.5.1 using following packages:

- Data Acquisition & Manipulation: ``httr`` and ``jsonlite`` for API interaction; ``tidyverse`` (``dplyr``, ``lubridate``) for data aggregation.
- Modeling: ``forecast`` package for ARIMA/STL; ``lmtest`` and ``tseries`` for residual diagnostics (Ljung-Box test) and stationarity testing.
- Causality: ``vars`` package for VAR and Granger testing.

Model adequacy was rigorously validated by analyzing residuals to ensure they approximate white noise (Ljung-Box Q-test, $p > 0.05$).

3. Results

To isolate the underlying drivers of the incident reporting volume, we performed an STL decomposition (Seasonal and Trend decomposition using Loess) – see figure 1. The analysis quantified the strength of the trend (FT) and seasonal (FS) components on a scale of 0 to 1. The results indicate a strong trend component ($FT = 0.74$), confirming that the time series is driven primarily by long-term directional shifts and external shocks rather than random noise. Conversely, the seasonal component was found to be weak ($FS=0.19$). This suggests that the dynamics of reporting for Philips Respironics are not significantly influenced by administrative cycles or calendar effects, justifying the focus of the subsequent ARIMA modeling on trend and intervention variables.

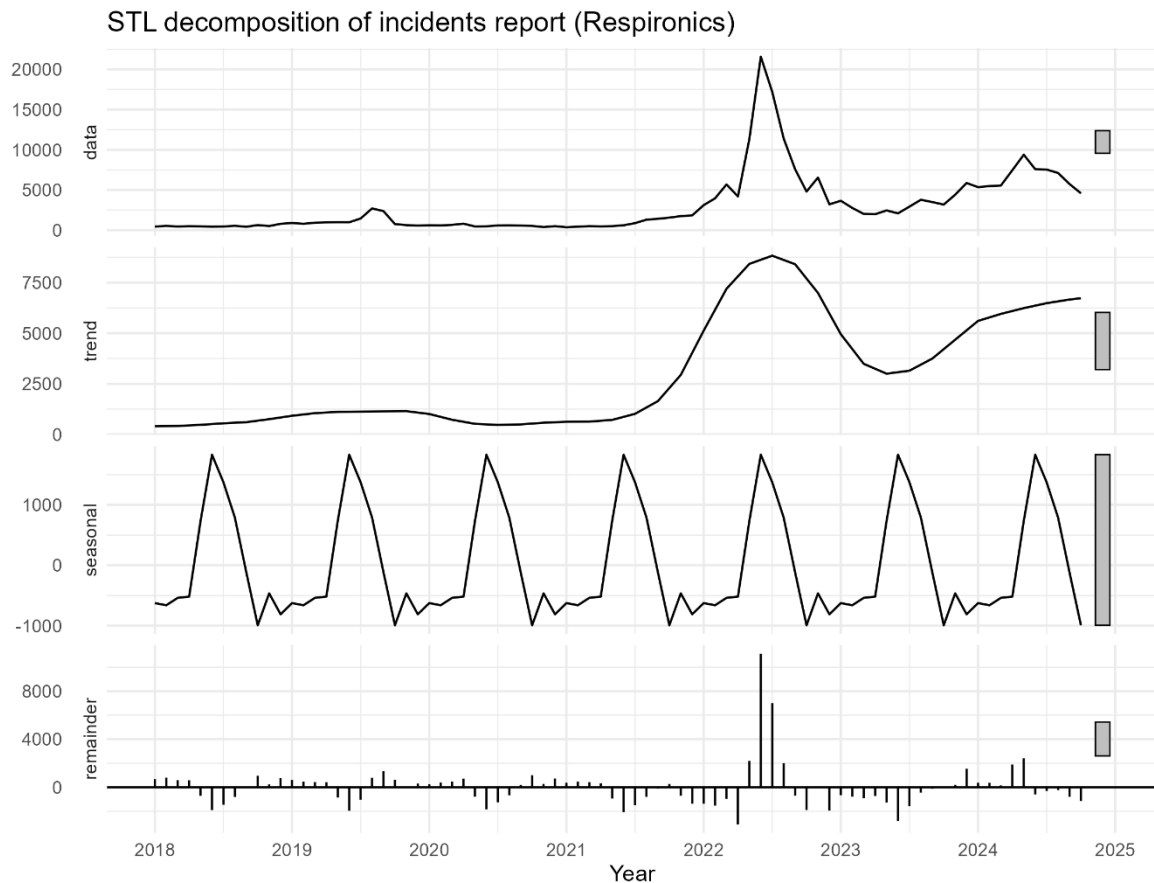


Figure 1. STL decomposition of incident report for Respironics company

3.1. Intervention Analysis

The Delayed Notoriety Bias We utilized an ARIMAX model to test the hypothesis that the Class I Recall announcement (June 2021) acted as an immediate structural break (Step Function) in the reporting volume. The initial model (Table 1) estimated a positive intervention coefficient of approximately 2,328 additional reports per month following the recall. However, this immediate impact was not statistically significant ($p \approx 0.09$). While the residual diagnostics (Ljung-Box $Q = 10.2$, $p > 0.05$) confirmed the model's technical validity, the lack of significance suggests that the "Notoriety Bias" did not manifest immediately in the MAUDE database.

Table 1. Intervention model parameters estimation

Parameter	Estimate	Std. Dev.	Z-value	Pr > z
ar1	0.65	0.11	5.84	5e-09
ma1	0.59	0.13	4.4	9e-06
Intercept	1800	1030	1.75	0.08
xreg	2328	1363	1.71	0.09

To address the potential temporal decoupling, we conducted a Lag Analysis, fitting models with intervention delays ranging from 0 to 12 months. The optimization criterion was the minimization of the Akaike Information Criterion (AIC). We saw three important areas of assessed lag (see fig. 2):

- Immediate Impact (Lags 0–3): The intervention variable remained statistically insignificant ($p > 0.05$).
- Onset of Significance (Lag 4): A statistically significant increase in reporting was first detected with a 4-month lag ($p = 0.010$).
- Peak Model Fit (Lag 11): The model achieved the lowest AIC (1,426.95) and the highest statistical significance ($p < 0.001$) at a lag of 11 months.

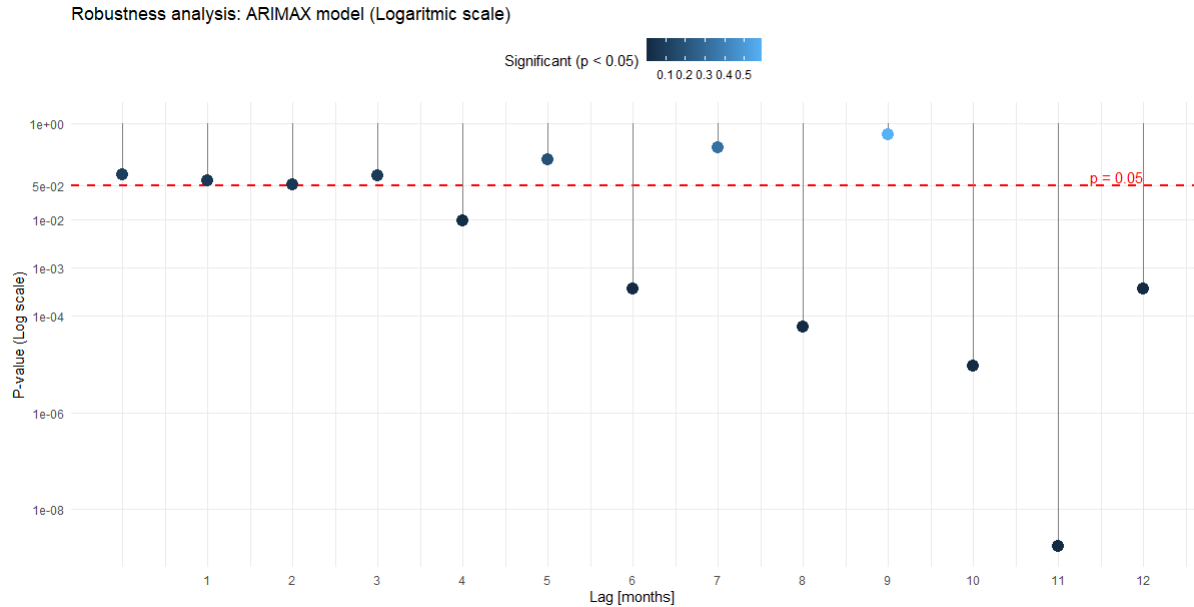


Figure 2. Robustness analysis ARIMAX model

This analysis reveals that while the recall eventually triggered a massive surge in reporting (Notoriety Bias), there was a substantial latency period. The structural break in the data is most accurately modeled as occurring nearly a year after the public announcement.

3.2. Causality and Information Flow

To robustly verify that the recall event serves as a predictor for the reporting surge (and not merely a coincident trend), we employed the Granger Causality test based on Vector Autoregression (VAR). A robustness analysis was performed for lag lengths $k \in \{1, 18\}$ months to rule out arbitrary lag selection artifacts (Figure 3).

- Short-term (1–9 months): The null hypothesis (H_0 : Recall does not Granger-cause Reporting) could not be rejected ($p > 0.05$).
- Long-term (10+ months): The relationship becomes statistically significant at Lag 10 ($p < 0.05$) and highly significant for lags 11–18 ($p < 0.01$). This confirms a causal, predictive relationship where the recall news drives the volume of adverse event reports, but strictly with a delay of approximately 10 months.

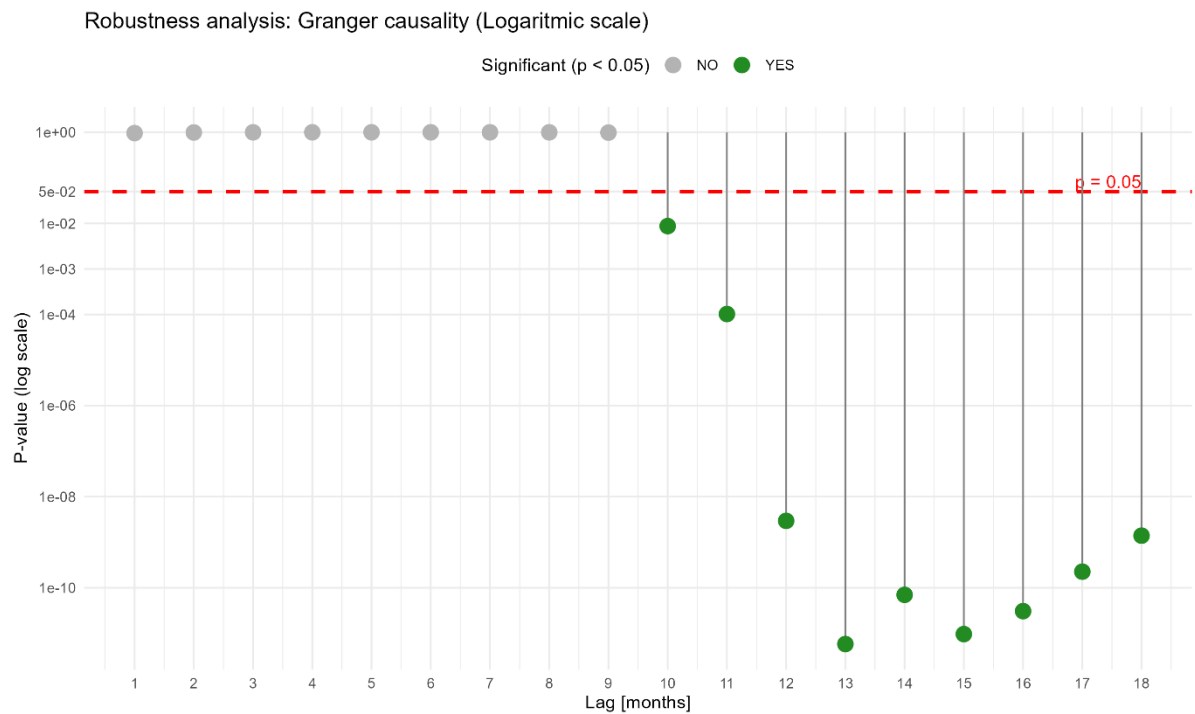


Figure 3. Granger test: Robustness analysis

The delayed reaction observed in the consumer/regulatory data stands in stark contrast to the capital market reaction. As illustrated in the comparative analysis (Figure 4), the cumulative returns of Philips stock decoupled from the S&P 500 market index immediately following the June 2021 announcement. While the financial markets priced in the reputational risk instantaneously (consistent with the Efficient Market Hypothesis), the "Notoriety Bias" in the FDA MAUDE database exhibited a significant inertia, materializing as a structural break only after the complex logistics of the recall and media cycle had fully permeated the patient and provider population.



Figure 4. Respironics recall effect on the financial markets (Phillips vs Market)

4. Discussion

The primary finding of this study is the significant temporal decoupling between the external shock (the Class I Recall announcement) and the manifestation of "Notoriety Bias" in regulatory data. While the recall was publicized in June 2021, the intervention analysis reveals that the structural break in adverse event reporting did not become statistically significant until approximately four months later, peaking with a lag of 10 months.

This contradicts the assumption that media attention drives an *immediate* panic-induced spike in reporting (a "Pulse" effect). Instead, the data suggests a "Step" effect with high inertia. The delay likely reflects the complex logistics of the medical device ecosystem: it takes time for information to permeate from manufacturers to healthcare providers and finally to patients. Furthermore, the 10-month lag aligns with the typical timeline for the formation of class-action lawsuits and intensified media cycles, which reinforce the "availability heuristic" – leading patients to attribute previously ignored symptoms to the recalled device long after the initial news breaks.

A critical insight emerges when contrasting the regulatory data with the capital market reaction. As illustrated in Figure 4, the cumulative returns of Philips stockholders decoupled from the S&P 500 index immediately following the June 2021 announcement. The financial markets, acting in accordance with the Efficient Market Hypothesis, priced in the reputational and litigation risk instantaneously.

In contrast, the FDA MAUDE database as a primary tool for post-market surveillance exhibited a "regulatory latency" of nearly a year. This discrepancy suggests that while capital markets are predictive and immediate, passive surveillance systems are reactive and sluggish. For risk managers, this implies that stock price volatility may serve as a leading indicator for future regulatory compliance burdens, whereas MAUDE data is a lagging indicator.

The interpretation of these findings is subject to limitations inherent in passive surveillance data. The most significant constraint is the absence of a "denominator" i.e. the total number of devices in use. Without sales or usage data, it is impossible to calculate the true Incidence Rate (absolute risk).

However, the magnitude of the relative increase in reports (from hundreds to tens of thousands per month) is so substantial that it cannot be attributed solely to a sudden degradation in manufacturing quality ten months post-recall. The sheer volume confirms that the signal is driven by behavioral changes in reporting (stimulated reporting) rather than a fundamental shift in device reliability. A secondary limitation is the single-case nature of the study; while the Philips Respironics case provides a clear example of Notoriety Bias, further research across multiple Class I recalls is necessary to generalize these temporal dynamics.

The study demonstrates that the MAUDE database is highly susceptible to Notoriety Bias, which can obscure genuine safety signals. A sudden, massive increase in reports may be an artifact of public attention rather than a new safety threat. Consequently, regulatory bodies and manufacturers should incorporate "media weighting" or time-series intervention

models when analyzing safety data during high-profile recalls, to distinguish between actual device failures and the noise generated by the notoriety of the event.

Acknowledgments: This contribution was supported by the internal funding of the University of Hradec Králové, Faculty of Informatics and Management, from the resources of Specific Student Research (SPEV) and DKRVO (Long-Term Conceptual Development of Research Organization) in 2026.

Conflict of interest: none

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Bibliometric Analysis of Intangible Assets Research, Extending to Their Value-drivers Landscape

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Abstract: Study aims to map the overall state of research on intangible assets and their value drivers. A secondary objective is to evaluate the magnitude of scientific blind spot with provision of empirical support. The analysis utilized 146 articles published in English from the Scopus and Web of Science database, focusing on key metrics like publication volume, authorship, and thematic trends. The results suggest that this research area may remain underexplored, as the most productive year yielded only 13 publications. The results further indicate that the highest publication output originates from the United States, Italy, and the United Kingdom. The cluster analysis indicates that intangible assets are most frequently examined in relation to value creation in digital economy, also corporate behavior and firm performance, as well as within the domain of knowledge- and data-driven management. Although the results point to limited scholarly coverage within this thematic domain, a notable increase in research interest and a gradual narrowing of existing research gaps can be anticipated, driven by the generally growing discourse on knowledge-based economies. Furthermore, continuing emergence and availability of data sources capable of supporting the identification and quantification of non-financial determinants relevant to intangible asset valuation can be expected.

Keywords: non-financial influence; market value; knowledge economy; bibliometric analysis

JEL Classification: O34; G32

1. Introduction

As an introduction, insights from the following ten highly influential studies indexed in Web of Science are first reviewed. These studies collectively underscore that intangible assets (and value-drivers) remain insufficiently conceptualized, while simultaneously emphasizing their critical role in the creation of firm value. A brief overview of the key issues addressed within this research area is presented below.

Intangible assets, including intellectual property such as patents and trademarks, have become central to achieving and sustaining competitive advantage and represent an important determinant of corporate profitability. At the same time, these assets provide multinational enterprises with significant scope for profit reallocation, largely as a result of opaque transfer pricing mechanisms (Dischinger, 2011).

Another study proposed a set of seven operational knowledge assets, representing an initial effort to address the limited understanding of which knowledge-based resources managers must effectively exploit at the most granular operational level (Andreou, 2007).

Another strand of literature has focused on the role of intangible assets in a distinct organizational context. Meaning in the context of mergers and acquisitions, brands often represent a substantial yet variable share of total deal value. While existing marketing research primarily examines the determinants of brand-related financial value under stable ownership conditions, M&A transactions introduce additional complexity, as brand value is influenced by the extent to which acquiring firms are able to effectively exploit and integrate the acquired brands (Bahadir, 2008).

Beyond the specific context of mergers and acquisitions, prior research has also examined other categories of intangible assets and their implications for firm-level outcomes. Study based on a dataset of 452 firms demonstrated that human capital efficiency represents the primary determinant of a robust corporate reputation, while also enabling the attribution of specific intellectual capital components to a range of financial performance indicators (Ginesti, 2018).

Another stream of literature has addressed intangible assets from a different analytical perspective. Intangible assets are of particular relevance to transfer pricing, as subsidiaries lacking intangible property exhibit a lower propensity to engage in profit reduction compared to subsidiaries that hold intangible assets (Beer, 2015).

Related empirical evidence can be found in studies examining corporate tax behavior in a broader organizational setting. Evidence based on a sample of 200 Australian firms indicates that tax havens are more frequently utilized by companies that extensively engage in transfer pricing practices, hold significant intangible assets such as patents and brands, operate as multinational enterprises, and employ performance-based managerial compensation schemes (Taylor, 2015).

In a different institutional and organizational context, attention has also been directed toward the accounting treatment of intangible assets. This study indicates that firms adopting a standardized and consistent accounting taxonomy for intangible assets are better able to recognize and record a broader range of intangible assets within their accounting systems (Green, 2005).

Beyond accounting-related considerations, prior research has also examined intangible assets in the context of broader firm-level attributes. Corporate reputation represents an intangible asset that exerts a direct influence on a firm's market value. It is formed through sustained ethical conduct and the consistent development of trust among key stakeholders, including customers, investors, employees, and business partners (Gaultier-Gaillard, 2006).

Additional non-financial aspects of firm behavior have been examined in related strands of the literature. Noteworthy non-financial factor concerns the geographic proximity of investors, as closer spatial ties between investors and firms are associated with more positive firm-level outcomes (Chang, 2020).

Further evidence has been provided in studies examining firm performance and value creation in alternative performance contexts. The findings indicate that firms may exhibit low

or even negative profitability; however, substantial investments in intangible assets and digital markets are associated with increasing equity market valuations (Balzer, 2020).

Again - due to the high level of abstraction surrounding intangible assets, the domain of non-financial performance has not yet been adequately conceptualized or operationalized. The vast majority of intangible asset studies concur on the existence of so-called value drivers—non-financial determinants that are considered relevant to asset valuation yet remain resistant to systematic standardization and harmonized measurement. Consequently, valuers continue to rely primarily on accumulated professional experience and on defensible value-driver assumptions that can be empirically or narratively justified within individual valuation engagements.

International valuation standards (IVS), as incorporated into International Financial Reporting Standards (IFRS), most commonly apply established approaches in which value drivers may be only indirectly or partially reflected, typically through discounted cash-flow models or market-based valuation methods using comparable asset transactions under sufficiently similar conditions. Addressing this gap is also relevant for capital market stability, particularly in relation to stock exchanges, where informational opacity contributes to asset overvaluation and bubble formation, and for transfer pricing practices, where non-standardized intangible valuation increases opportunities for tax-motivated asset relocation within multinational corporate groups.

To date, only one highly relevant empirical research stream has originated outside traditional academic environments, conducted by the U.S. research division of Ernst & Young. This series of studies achieved comparatively robust progress in quantifying non-financial performance signals of intangible assets. The first study documented that, at the time, managers across multiple sectors were frequently making strategic decisions under substantial informational uncertainty. The study also identified an explicit managerial demand for additional—preferably non-financial—indicators, reflecting a widespread belief that such effects were material, observable, and actively influencing firm performance, despite being omitted from formal valuation frameworks (Cohen, 2001).

The second study implemented a survey targeting senior managers from firms listed in the S&P 500 index, with the objective of identifying perceived value drivers of intangible assets. The analysis resulted in the definition of nine core drivers, including innovation intensity, employee relations, and other organizational performance signals (Cohen, 2001).

The third study assigned weights to the identified value drivers and further analyzed IPO (Initial Public Offering) valuations of newly listed firms. The difference between the initial IPO valuation and the firm's subsequent market valuation after a defined trading period was regressed against the survey-derived value drivers. This procedure was applied across 24 industry sectors in the United States (Gu, 2011).

2. Methodology

Bibliometric analysis is a systematic approach employed to detect and interpret structural and developmental patterns within scientific fields. It enables researchers to trace research trends across journals and articles, map collaborative networks, and identify core

and emerging topics within a defined knowledge domain. This method capitalizes on large-scale datasets—often comprising hundreds to thousands of records—to evaluate objective indicators such as citation impact, publication productivity, and keyword frequency. Complementarily, bibliometric analysis integrates interpretive components, including thematic synthesis and clustering, which are derived through reproducible and transparent analytical protocols. When rigorously implemented, the method can expose layered knowledge trajectories and subtle developmental inflections, even in well-established disciplines. By delivering a holistic and data-grounded representation of the field, bibliometric analysis contributes to disciplinary advancement through the identification of knowledge gaps and by stimulating novel research directions (Donthu et al., 2021).

2.1. Defining Searching Terms and Search Delimiting Criteria

In order to get relevant data from the Scopus database for this analysis, the following query string was formulated:

TITLE-ABS-KEY ("intangible asset" AND ("valuation" OR "value" OR "pricing" OR "market value") AND ("driver*" OR "non-financial influence*" OR "nonfinancial influence*" OR "non-financial factor*" OR "nonfinancial factor*"))*

Which resulted in 175 documents. Subsequently, a set of predefined filters was applied to refine the results. The filtering criteria included language (English) and subject areas (Business, Management and Accounting; Economics, Econometrics and Finance). This further refined the search output to 134 documents.

Subsequently, bibliographic data were retrieved from the Web of Science database. Due to minor differences in search functionality compared to the Scopus database, the search query was adjusted to preserve an equivalent logical structure of the retrieval strategy.

TS = ("intangible asset" AND ("valuation" OR "pricing" OR "market value") AND ("driver*" OR "non-financial influence*" OR "nonfinancial influence*" OR "non-financial factor*" OR "nonfinancial factor*"))*

That resulted in 40 documents and subsequent filters were also language (English) and categories (Management, Business, Business Finance, Economics) bringing results down to 32 documents.

Altogether, this resulted in a total of 166 documents; however, it was necessary to compare both datasets to identify overlapping records, which were subsequently removed to eliminate duplicates. A total of 20 duplicates were identified, resulting in a final dataset comprising 146 documents.

3. Results

3.1. Publications by Year

The results of the first methodological section present a descriptive analysis of a dataset comprising 146 documents, evaluated by their annual publication counts.

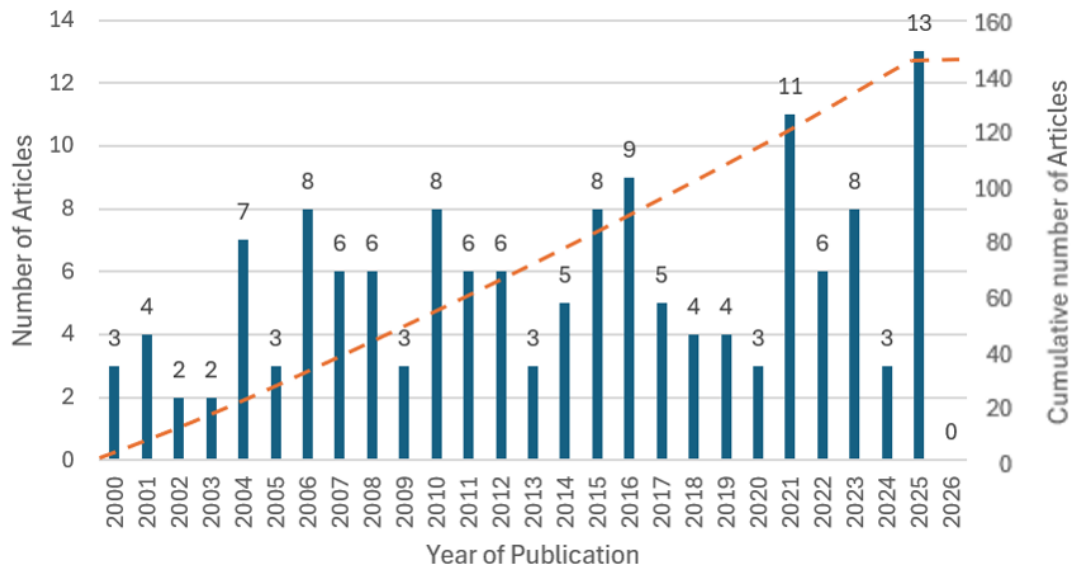


Figure 1. Cumulative and annual numbers of publications

In 2000, the first publications addressing this topic began to emerge, with a total of three articles published that year. Over the entire observation period, the average annual output was 5,6 articles. Although the relative year-to-year increases appear substantial, their impact in absolute terms remains limited. The highest number of articles on the subject was published in 2025 (13). Beyond this peak, the data demonstrates persistent long-term fluctuations, predominantly ranging between three and eight articles per year. When assessed in cumulative counts, the overall trend follows a second-order polynomial function. While the curve may initially resemble a linear trajectory, closer inspection reveals a slight but discernible inflection. Collectively, these findings may indicate that the topic of intangible assets and their value drivers is either insufficiently attractive to the research community or characterized by comparatively high publication barriers due to its conceptual and methodological complexity.

3.2. Publications by Country

Geographical distribution of publications on the topic of board diversity is further analyzed.

It should be noted that a subset of documents lacked an affiliation country after export from the Scopus database, reducing the sample size for this figure from 146 to 142 records. The highest publication output was observed in the United States (21 records, 14.79%), followed by Italy (17 records, 11.97%) and the United Kingdom (13 records, 9.15%). Beyond Germany (10 records, 7.04%) and India (6 records, 4.23%), all remaining regions—defined by their considerable heterogeneity—account for only marginal shares, reflecting negligible research activity on this topic. Overall, the results indicate that publication output in this domain is dominated by Anglo-Saxon countries and nations with comparable cultural and legal heritage.

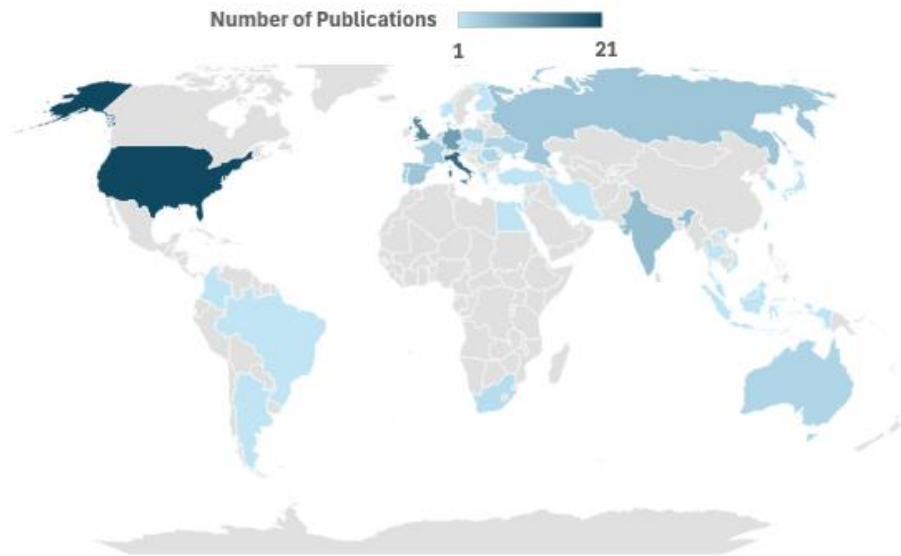


Figure 2. Publications by country

3.3. Leading Authors

We further examined the publication record at the author level to identify the most frequent contributors within this research domain.

Table 1. Top publishing authors by record count

Authors	Record count
Marr, B.	6
Green, A.	4
Cricelli, L.	3
Grimaldi, M.	3
Kijek, T.	3
Zakrzewska, A.	3
Battagello, F.	2
Derun, I.	2
Hübscher, M.C.	2
Lopes, I.T.	2
Louisot, J.-P.	2
Low, J.	2
Mysaka, H.	2
Roos, G.	2
Timmer, M.P.	2
Užík, M.	2

The resulting author analysis indicates that Marr, B. is the most prolific contributor, with a total of six publications. Marr, B. is an academic affiliated with Columbia University in New York, a finding that aligns with our previous results indicating that the highest publication output on this topic originates from the United States. Although this number may not be considered high in general bibliometric terms, it represents a substantial output within this specific research domain, particularly given that the second-ranked authors—Green, A. has only 4 published articles in given domain. Cricelli, L.; Grimaldi, M.; Kijek, T.; and Zarkewska, A.—have published only three articles each. The remaining 10 authors in the sample have

contributed two publications each, further underscoring the relatively concentrated authorship structure in this field.

3.4. Keyword Analysis

Table 2 presents the top 25 keywords ranked by the frequency of their occurrence, enabling the identification of key trends (or their lack) and dominant areas of focus.

Table 2. Top 25 keywords by the frequency of their occurrence

Keyword	Occurrences
intangible assets	59
intellectual capital	31
knowledge management	9
value drivers	7
performance	6
financial performance	6
human capital	6
competition	5
competitive advantage	5
balanced scorecard	4
corporate reputation	4
disclosure	4
goodwill	4
industry	4
innovation	4
management	4
value creation	4
brand equity	4
business valuation	4
intangibles	4
patents	4
analytic network process	3
global value chains	3
human resource management	3
industrial economics	3

It is somewhat surprising that intangible assets have not attracted greater scholarly attention, given their critical role in building knowledge-based economies—an agenda that, at least rhetorically, is promoted as a strategic priority by modern nation-states. Based on keyword frequency, only the top five terms within the Top 25 list can be considered individually noteworthy; however, their full interpretive value emerges only when examined alongside the remaining 20 keywords, which provide essential contextual framing. The results further suggest that intangible asset research is predominantly conceptualized within corporate environments, a pattern that is logically consistent, as firms operate under strong decision-making pressures that require managers to access accurate information rapidly in order to support high-quality and timely strategic judgments.

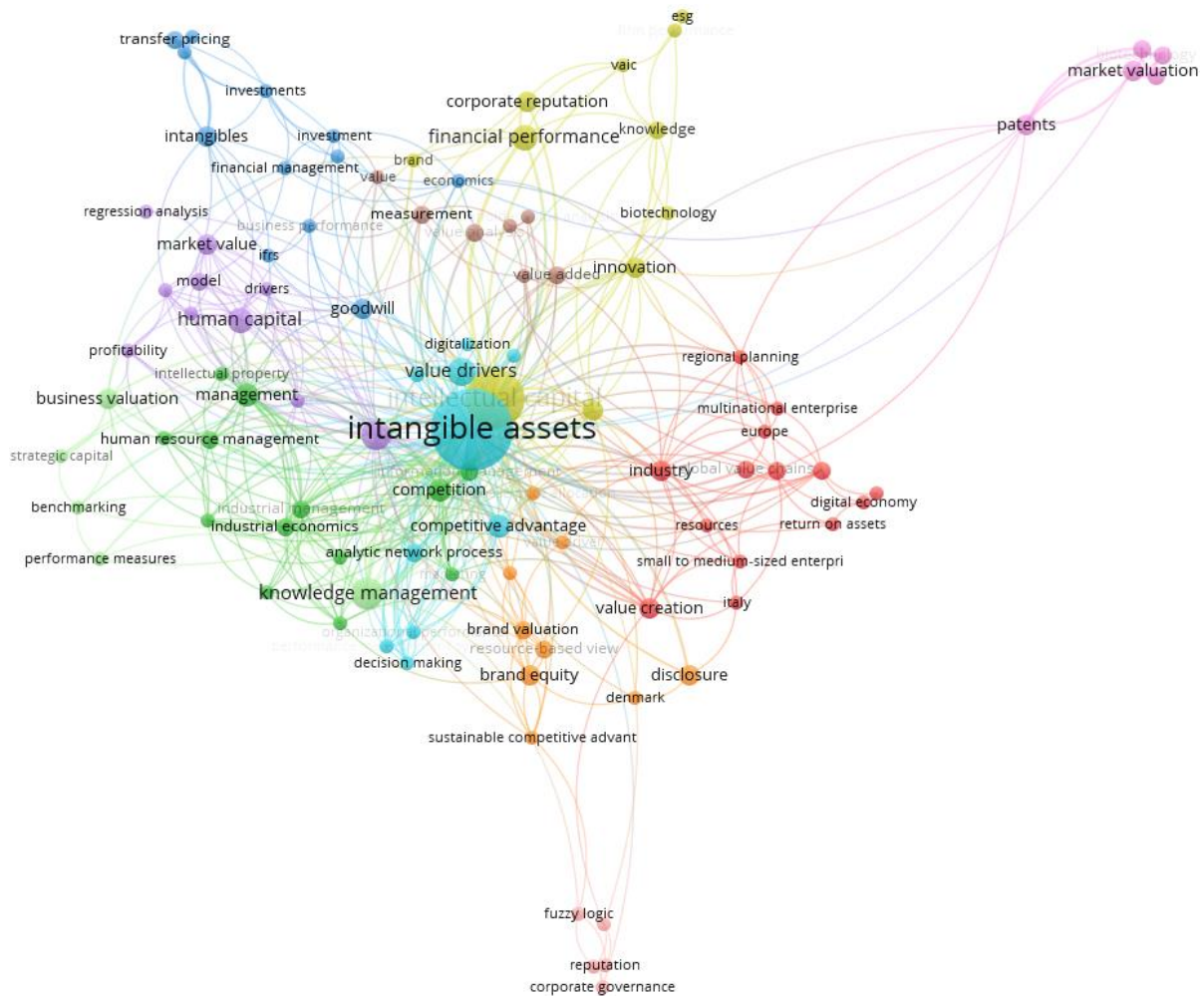


Figure 3. Cluster analysis of keywords

VOSviewer categorized the keyword network into eleven distinct clusters. The first cluster, comprising 14 items (red), reflects Multinational Enterprises and Value Creation in the Digital Economy. The second cluster, consisting of 13 keywords (green), represents Knowledge-Based Management and Intellectual Capital, emphasizing evidence-based decision-making and organizational learning processes. The third cluster, including 12 keywords (dark blue), captures the domain of business performance and financial management.

Concepts such as *intangible assets*, *intellectual capital*, *informational management*, *performance*, *value drivers* and *competition* constitute central nodes that interconnect and bridge the majority of thematic clusters across the keyword network. No other keywords exhibit a comparably dominant or structurally central position within the network.

Two relatively isolated keyword groups can be observed—one located in the upper-right section of the visualization and the other located down are indicating comparatively weaker co-occurrence links. Notably, terms such as *fuzzy logic* and *biotechnology firm* exemplify these low-connectivity clusters, reflecting limited thematic integration within the broader keyword network.

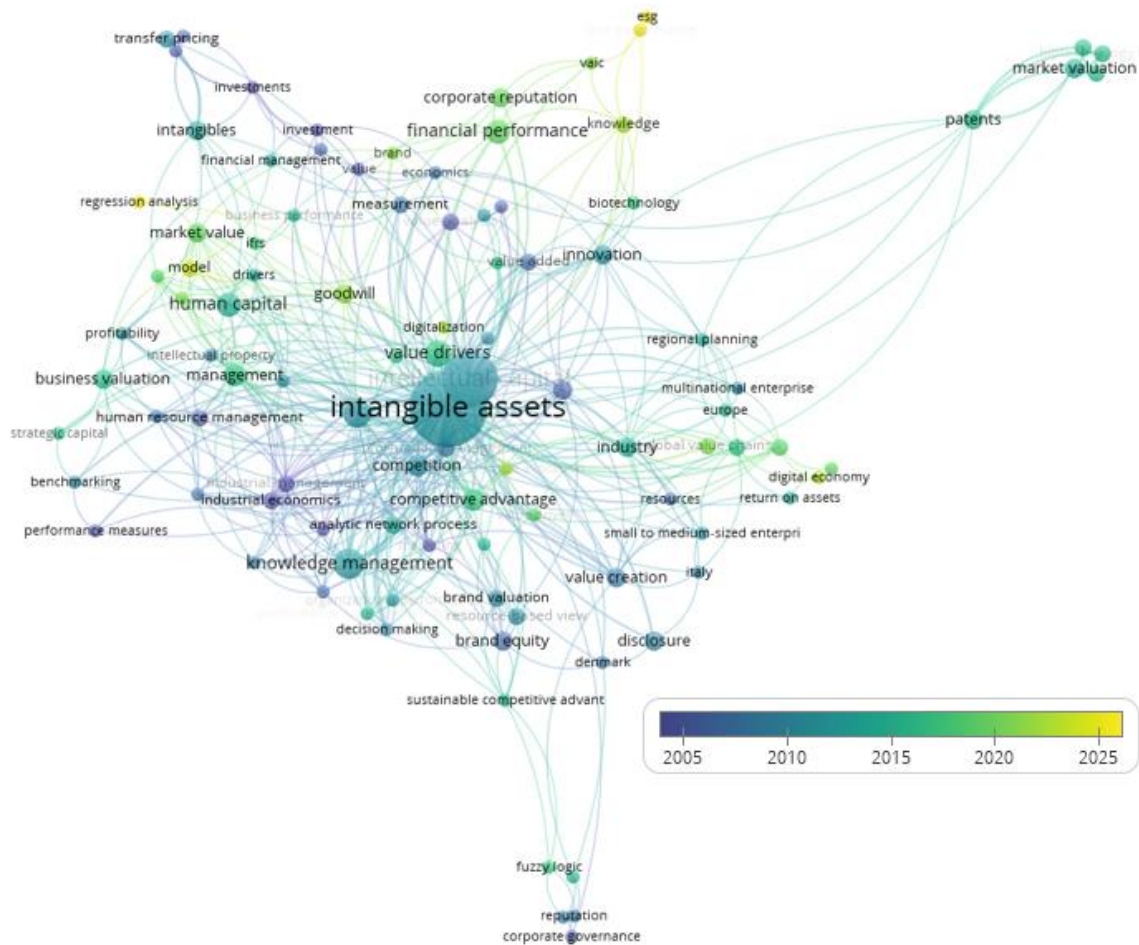


Figure 4. Cluster analysis of keywords by year

VOSviewer filtered the dataset to include publications from 2005 to 2025 and applied a temporal color gradient to the keyword map, where colors correspond to the publication year of the source article in which a given keyword appeared. A preliminary visual inspection suggests that the full temporal spectrum is relatively evenly represented. The strongest and most central nodes are concentrated near the midpoint of the temporal scale, whereas more peripheral and spatially distant keyword clusters tend to align with the more recent end of the gradient, a distribution that is conceptually coherent.

3.5. Publications by Citation Count

Table 3 presents the three most influential articles based on the number of citations.

The most-cited article is also the most recent one, with ESG (Environmental, Social, and Governance) representing its central and thematically defining focus. The high citation rate can therefore be attributed to the substantial rise in ESG-related research and public discourse in recent years, driven by the topic's rapid expansion, strong academic uptake, and polarized perception across both institutional and societal domains. In contrast, the citation impact of the remaining articles can be primarily explained by their earlier publication dates, which provided a longer temporal window for citation accumulation and scholarly diffusion within the field.

Table 3. Top 5 articles by the number of citations

Publication	Year	Authors	Citations	
			Average per year	Total
The end of ESG	2023	Edmans, A.	141,50	283
Drivers of corporate voluntary disclosure: A framework and empirical evidence from Italy and the United States	2007	Boesso, G. Kumar, K.	15,44	278
The dynaics of value creation: Mapping your intellectual performance drivers	2004	Marr, B. Neely, A. Schiuma, G.	11,90	250

Finally, it should be noted that although the article by Edmans, A. is the most highly cited in absolute terms, it cannot be considered an outlier with respect to total citation counts. However, when assessed using average annual citations, the study clearly represents an outlier. Importantly, this did not distort or materially affect the results of the bibliometric analysis.

4. Discussion

The findings derived from the bibliometric analysis are consistent with the trends outlined in the introductory section. Intangible assets remain inherently abstract and difficult to quantify—particularly when non-financial determinants are considered, which likely contributes to the relatively limited volume of scholarly output in this research domain.

Nevertheless – a study conceptually comparable to the present research was identified. Previous bibliometric study of value drivers literature (e.g., Figari, 2022) typically map broad determinants of firm value across multiple domains, including governance, disclosure, and sustainability-related factors. In contrast, the present study narrows this perspective by focusing specifically on intangible assets and their valuation-relevant non-financial drivers. By isolating the intangible-asset dimension and examining its thematic structure and publication dynamics, this paper provides a more targeted view of how value-driver research is organized within this specific domain, allowing the identification of fragmentation and research gaps that broader value-driver mappings may not fully capture (Figari, 2022).

5. Conclusions

The annual publication counts revealed only a modest upward trend, indicating slow growth in research activity. The most active publishing countries were the United States (21), Italy (17), and the United Kingdom (13). At the author level, Marr, B. (United States) was identified as the most prolific contributor, with a total of six publications, which remains a comparatively low output in broader bibliometric terms.

The keyword analysis demonstrated that concepts such as informational management, intellectual capital, and value drivers are recurrently associated with intangible asset research, reflecting the dominant conceptual lenses applied in the field. The cluster analysis further showed that keyword occurrences are temporally balanced across the 2005–2020 period, with no single time-specific thematic surge observed. Intangible assets form cross-

cluster linkages, most prominently with thematic groupings representing corporate behavior and firm performance, and knowledge- and data-driven management, both emphasizing evidence-based decision-making and organizational learning.

Finally, the most highly cited articles were either published in earlier years or address widely adopted research agendas—such as ESG, which naturally attract higher citation traction due to their broader disciplinary and societal relevance, rather than due to a concentrated research interest in intangible assets themselves.

In relation to the secondary objective of this analysis, it should be noted that the examined research domain exhibits signs of fragmentation and systematic omission, likely attributable to the inherent challenges associated with its quantification and conceptualization, thereby giving rise to numerous research gaps.

Conflict of interest: none

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A Multi-Criteria Evaluation of Technical Faculty Choice in the Czech Republic from the Applicant's Perspective

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Abstract: Choosing a technical faculty represents a complex decision process in which applicants balance multiple academic, institutional, and economic criteria. This paper presents a multi-criteria decision-making framework for evaluating and ranking selected technical faculties in the Czech Republic from the applicant's perspective. The proposed model integrates the Analytic Hierarchy Process (AHP) to determine the relative importance of decision criteria and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to generate a transparent ranking of alternatives. Five faculties are assessed using criteria derived from the literature on higher education choice and engineering education, operationalized through publicly available institutional data and city-level cost-of-living indicators. To capture heterogeneity in applicant preferences, two contrasting weighting scenarios are constructed: an academically oriented profile and a practically and economically oriented profile. The results indicate that faculty rankings are highly sensitive to preference structures, with different institutions emerging as optimal choices under each scenario. The study highlights the usefulness of multi-criteria modelling for analysing higher education choice and provides a replicable analytical framework that can be extended with empirically elicited preferences and additional indicators of institutional quality.

Keywords: multi-criteria decision-making; analytic hierarchy process; TOPSIS; higher education choice; technical universities; Czech Republic

JEL Classification: I23; C44; M31

1. Introduction

1.1. Context and Relevance of the Problem

The choice of a higher education programme represents a complex decision for applicants, as it simultaneously involves academic, economic, social, and institutional aspects. In the field of technical education, this choice is further shaped by specific student expectations (e.g. future employability, study difficulty, and the quality and prestige of the programme) and takes place in an environment of increasing competition among universities for qualified applicants. Empirical research focusing on students' decision-making processes shows that the choice of a technical school is the result of the influence of multiple groups of factors and cannot be explained by a single criterion (Gille et al., 2022). From the perspective of research on recruitment into technical fields, it is therefore crucial to understand how students weigh

different factors and how these factors may come into mutual conflict (e.g. prestige and quality versus the financial costs of study).

1.2. Motivation of the Paper and Broader Research Context

In recent years, the importance of higher education branding has increased, referring to the ways in which institutions build and communicate their identity, reputation, and value proposition to prospective students. Brand-related communication may influence perceived prestige, credibility, and the overall “fit” between the applicant and the institution, thereby contributing to the formation of the student’s decision-making process as one of the relevant factors. From the perspective of research on study choice, branding is therefore understood as part of a broader set of determinants that applicants consider when comparing alternatives.

The motivation of this paper is to verify the applicability and suitability of selected multi-criteria decision-making methods for modelling the process of technical faculty choice from the applicant’s perspective. The paper is conceived as the design and pilot application of a decision-making model whose objective is not to capture actual student preferences through empirical research, but to test a methodological approach that allows the structuring of a decision problem, the simultaneous consideration of multiple criteria, and the generation of a transparent ranking of alternatives.

The chosen approach reflects the fact that applicants’ decision-making is a complex process that cannot be adequately described by a single indicator. Multi-criteria decision-making methods provide tools for formalising this process and enable the systematic capture of relationships among individual criteria, including potential conflicts between them. In this sense, they represent a suitable analytical framework for examining factors influencing the choice of higher education study.

At the same time, the paper is understood as a methodological preparation and exploration of research procedures that may be further developed in the future within a doctoral dissertation focused on the branding of Czech higher education institutions. Although branding is not operationalised in this paper as a standalone decision criterion, the proposed multi-criteria decision-making model creates a framework into which factors related to perceived reputation, image, and communication strategy of universities can be systematically incorporated in subsequent research.

1.3. Why MCDA and AHP–TOPSIS

As the choice of a technical faculty can be understood as a decision involving multiple (often conflicting) criteria, the use of multi-criteria decision-making methods (MCDM/MCDA) is appropriate, as these methods allow criteria to be structured transparently, their relative importance to be taken into account, and a ranking of alternatives to be derived. A systematic review mapping the use of MCDM methods in educational research shows that methods such as AHP and TOPSIS are among the most frequently applied and that typical tasks in this field include ranking and choice problems (Maral & Özdemir, 2025).

The selected combination of AHP–TOPSIS corresponds to the logic of the problem-solving process: AHP is used to determine the weights of criteria, while TOPSIS enables the ranking of

alternatives according to their closeness to an ideal solution. The approach is designed as a “framework” that can be further extended in subsequent research and supplemented with deeper empirical evidence on student preferences.

1.4. Aim of the Paper and Research Intention

The aim of the paper is to propose and demonstrate the application of a multi-criteria decision-making model for the choice of a technical faculty in the Czech Republic using a set of five alternatives: FEL ZČU, FEL ČVUT, FEKT VUT, FEI VŠB-TUO, and FEI UPCE. The model works with a set of criteria derived from the literature on the choice of technical schools and the choice of higher education institutions (Gille et al., 2022; Moody, 2020).

The paper is conceived as the design of a methodological procedure; at the same time, its ambition is to create a reproducible basis for future extensions within doctoral research.

Unlike many existing AHP–TOPSIS applications in higher education, which aim to normatively recommend a single optimal institution, this paper adopts a decision-support perspective reflecting heterogeneous applicant preferences. The scenario-based weighting is not intended to produce a universal ranking, but to illustrate how different preference profiles lead to different outcomes. The contribution of the study is therefore methodological and illustrative rather than predictive.

2. Theoretical Background

2.1. Technical Faculty Choice as a Multi-criteria Decision Problem

Decision-making regarding the choice of a technical faculty represents a complex process influenced by a set of interrelated factors of different nature. Research focusing on the choice of technical and engineering fields shows that applicants simultaneously take into account academic, institutional, economic, and individual aspects in their decision-making, with none of these factors acting in isolation (Gille et al., 2022). The choice of a school is thus the result of balancing multiple criteria, which may differ in their importance and, in some cases, may also be mutually conflicting.

The study by Gille et al. (2022), which specifically focuses on the choice of a technical (engineering) school, identifies four main groups of determinants influencing students' decision-making processes: individual factors (e.g. personal interests and abilities), social factors (the influence of family, peers, or teachers), economic factors (costs associated with study and future employment), and institutional factors (characteristics of the school itself and the study programme). The authors emphasise that it is precisely the combination of these groups of factors that shapes the final decision and that their relative importance may vary among individual applicants (Gille et al., 2022).

Similarly, in her doctoral dissertation, Moody (2020) summarises that students' decisions regarding the choice of a higher education institution are determined by a set of academic characteristics (programme offerings and teaching quality), reputational and institutional aspects, student support services, and the economic conditions of study. The results of these

studies confirm that the choice of a higher education institution cannot be reduced to a single criterion, but must be understood as a multidimensional decision problem.

A systematic review by Maral and Özdemir (2025) further shows that a similarly complex character applies to many decision-making tasks in the educational context, particularly at the level of higher education. The authors state that the selection and evaluation of study programmes, institutions, or educational pathways belong among the most frequent types of problems addressed using multi-criteria decision-making methods, with typical tasks being choice and ranking of alternatives. These tasks are characterised by the need to work with multiple criteria simultaneously and with differing levels of importance assigned to individual factors.

Based on these findings, the choice of a technical faculty from the applicant's perspective can be considered a typical case of a multi-criteria decision problem, in which it is necessary to systematically structure relevant criteria and take their relative importance into account. This nature of the problem creates methodological scope for the use of multi-criteria decision-making tools, which enable transparent and reproducible comparisons of alternatives based on multiple evaluation criteria.

2.2. Multi-criteria Decision-making Methods in Educational Research

Multi-criteria decision-making methods (multi-criteria decision-making, MCDM/MCDA) are described in the academic literature as analytical tools designed to solve decision problems in which it is necessary to simultaneously consider multiple evaluation criteria that cannot be reduced to a common unit of measurement and that may be mutually conflicting. A systematic review focusing on the use of MCDA in educational research shows that decision-making tasks characterised by a high degree of complexity and multidimensionality, particularly at the level of higher education, represent a typical application area for these methods. In this context, the most frequently addressed types of tasks are choice and ranking of alternatives, which corresponds to the nature of decision-making regarding the choice of a study programme or a higher education institution (Maral & Özdemir, 2025).

With regard to specific methods, the most frequently applied approaches in educational research include the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), as well as their modifications. These methods are used in the literature both independently and in combination, with the combined approach allowing the phase of determining the relative importance of criteria to be separated from the phase of evaluating and ranking alternatives. The review further states that the use of multiple methods within a single decision-making model is common practice in educational research, particularly in cases where the aim is to increase the transparency and interpretability of results (Maral & Özdemir, 2025).

In the context of students' decision-making regarding the choice of study, multi-criteria decision-making methods are primarily used as a tool for structuring a complex decision-making process and for systematically comparing alternatives based on multiple factors. The application of these methods makes it possible to explicitly work with the relative importance

of individual criteria and provides a clear output in the form of a ranking of alternatives, which is suitable both for analytical purposes and for further interpretation in subsequent research.

3. Methodology

3.1. Definition of the Decision Problem and Alternatives

This paper proposes a multi-criteria decision-making model for the evaluation and ranking of selected technical faculties in the Czech Republic from the perspective of prospective students. The decision problem is formulated as a ranking of alternatives, the aim of which is to determine the order of faculties based on a set of evaluation criteria.

The objective of the decision-making process is to compare and rank the available alternatives in such a way that the model output provides a transparent and interpretable ordering of the evaluated faculties. Given the nature of the paper as a design and pilot application of methods, the aim is not to capture empirical student preferences, but to demonstrate the structure of the decision framework and its methodological feasibility.

The alternatives are defined as five technical faculties in the Czech Republic that are compared within the model:

- A1: University of West Bohemia in Pilsen – Faculty of Electrical Engineering (FEL ZČU)
- A2: Czech Technical University in Prague – Faculty of Electrical Engineering (FEL ČVUT)
- A3: Brno University of Technology – Faculty of Electrical Engineering and Communication Technologies (FEKT VUT)
- A4: VSB – Technical University of Ostrava – Faculty of Electrical Engineering and Computer Science (FEI VŠB-TUO)
- A5: University of Pardubice – Faculty of Electrical Engineering and Informatics (FEI UPCE)

The unit of evaluation is the faculty as an organisational and educational unit. The model therefore does not compare entire universities, but specific faculties with comparable disciplinary orientation, to which the selection of evaluation criteria in the following subsection is adapted.

The faculties were deliberately selected to represent comparable fields of study (electrical engineering and informatics) across the major technical universities in the Czech Republic.

3.2. Evaluation Criteria and Their Derivation from the Literature

The selection of evaluation criteria is based on literature focusing on students' decision-making regarding the choice of a technical school and a higher education institution. Previous studies show that applicants take into account multiple groups of factors in their decision-making, relating both to the institution and the study programme itself as well as to the broader conditions of study (Gille et al., 2022; Moody, 2020). Based on these findings, this paper proposes a set of criteria that reflects the main dimensions of the decision-making process while allowing for their practical operationalisation using available data.

For clarity, the proposed criteria are structured into thematic groups. This structure serves primarily to systematise the decision framework and does not affect the calculation of results.

Group A: Characteristics of the faculty and study offer

This group includes criteria related to academic and institutional characteristics of the faculty, which are repeatedly identified in the literature as key factors in the choice of a technical school (Gille et al., 2022; Moody, 2020).

- C1 – Academic reputation and characteristics of the study programme:
This criterion reflects the perceived quality and reputation of the faculty or study programme. The literature indicates that reputational aspects and programme characteristics belong among the significant determinants of students' choice (Gille et al., 2022). Within the model design, this criterion is understood in general terms, with the possibility of future operationalisation through publicly available indicators.
- C2 – Employment opportunities and links to practice:
Graduate employability, cooperation with industrial partners, and the existence of practice-oriented forms of study are identified in the literature as important factors, particularly in technical fields (Gille et al., 2022; Moody, 2020). This criterion captures the relationship between the faculty and professional practice and the labour market.

Group B: Study conditions and institutional support

The second group of criteria focuses on institutional study conditions and support mechanisms that may influence the attractiveness of a faculty from the applicant's perspective (Moody, 2020).

- C3 – Study and support services:
This criterion includes the availability and scope of student support services, such as academic counselling, career services, or adaptation mechanisms. These aspects are identified in the literature as part of institutional factors influencing decisions about school choice (Moody, 2020).
(Note: This criterion was excluded during the pilot application due to zero discriminatory power; see Section 3.4.1.)
- C4 – International opportunities and mobility:
Opportunities for study abroad, participation in international programmes, and mobility schemes are perceived as factors increasing the attractiveness of study, particularly in technical and natural science fields (Moody, 2020). This criterion reflects the openness of the faculty to international cooperation.

Group C: Economic conditions of study

Economic aspects represent a distinct dimension of decision-making, which is identified in the literature as particularly significant in the context of long-term educational investments (Gille et al., 2022).

- C5 – Economic demands of study:
This criterion includes financial aspects associated with study, in particular the cost of

living in the place of study. In the model, this criterion is treated as a cost criterion (the lower the value, the more favourable the alternative).

The criterion of economic demands of study (C5) is operationalised using a cost-of-living index for the city in which the faculty is located. The values were taken from the Numbeo database (Numbeo, 2024), which provides comparable estimates of living costs at the city level. The overall cost-of-living index excluding rent was used. For cities not listed separately in the database, the nearest available reference value was applied. The criterion is treated as a cost criterion in the model (a lower value is preferred).

The proposed set of criteria represents a conceptual framework that will be further refined in subsequent steps of the study with regard to data availability and comparability. As the paper is conceived as a design and pilot application of methods, emphasis is placed on transparency and methodological feasibility of the model rather than on comprehensive coverage of all potential factors.

The operationalisation of individual criteria is based on publicly available information presented on the official websites of the faculties. All indicators were defined in a uniform manner across alternatives (e.g. only accredited study programmes of the faculty were included, explicitly listed industrial partners were counted, and formally declared international cooperations were considered). Nevertheless, it should be emphasised that the indicators used represent deliberately simplified proxy variables suitable for a pilot application of the methods.

3.3. Methods and Solution Procedure

Based on the definition of the decision problem, alternatives, and evaluation criteria, this paper proposes a solution procedure founded on a combination of multi-criteria decision-making methods. The selection of methods is derived from the nature of the decision task, which consists in ranking alternatives while taking multiple criteria into account, and corresponds to common practice in educational research, where such tasks are addressed using MCDA methods (Maral & Özdemir, 2025).

The proposed procedure combines the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). These methods are employed in complementary roles: AHP is used to determine the relative importance of the evaluation criteria, while TOPSIS is applied to the evaluation and ranking of alternatives based on these weights.

Scenario-based approach to criteria weighting

Given that the preferences of applicants for higher education may differ significantly, a scenario-based approach to weighting the evaluation criteria was adopted in this study. The aim was not to determine an “optimal” or universal ranking of faculties, but to demonstrate how the resulting evaluation changes depending on the type of applicant and their preferences.

Two basic scenarios representing different decision-making strategies of applicants were defined. These scenarios serve as model situations rather than as an empirical description of a specific group of students.

1. Scenario A – academically oriented applicant

Scenario A represents an applicant who places primary emphasis on the academic quality of study and long-term professional development. For this type of applicant, the breadth and structure of study programmes, the existence of doctoral studies, and the international dimension of study are of key importance. Economic considerations play a secondary role in the decision-making process.

In line with these preferences, higher weights were assigned to criteria C1a (study programme offer), C1b (existence of doctoral studies), and C4 (international opportunities), while criteria focused on economic aspects and links to practice were evaluated as less important.

2. Scenario B – practically and economically oriented applicant

Scenario B represents an applicant for whom practical applicability of study and economic accessibility are the main priorities. This type of applicant places emphasis on the faculty's links to practice, cooperation with companies, and the overall costs associated with study. Academic prestige and research background play a less important role in their decision-making.

In this scenario, higher weights were assigned to criteria C2a (cooperation with industrial partners), C2b (extent of the partner network), and C5 (costs), while academically oriented criteria were evaluated as less important.

In the proposed model, the AHP method is used exclusively for determining the weights of the criteria. Its application makes it possible to express the relative importance of individual criteria in a structured manner through pairwise comparisons and to transform qualitative preferences into quantitative form.

The calculation of criteria weights was carried out in the R environment using a custom script based on the principal eigenvector method. To increase transparency, consistency indicators (λ_{max} , CI , and CR) are also reported for each scenario, providing information on the internal consistency of the pairwise comparisons. This approach corresponds to common practice in the application of MCDA methods in design-oriented and methodological studies (Maral & Özdemir, 2025).

Evaluation and ranking of alternatives using TOPSIS

For the evaluation of alternatives and their ranking, the TOPSIS method is applied in the proposed procedure. This method enables alternatives to be compared based on their distance from the ideal and the worst solution, taking into account both the values of individual criteria and their relative weights determined in the previous step. The output of the method is a ranking of alternatives that allows for clear interpretation of results within individual scenarios.

The use of TOPSIS is particularly appropriate in situations where the objective is a transparent ranking of alternatives based on multiple criteria, which corresponds to the nature of the decision problem addressed in this paper. The combination of AHP and TOPSIS also makes it possible to separate the phase of criteria weighting from the phase of alternative evaluation, thereby increasing the clarity and interpretability of the proposed decision-making framework (Maral & Özdemir, 2025).

3.4. Construction of the Decision Matrix and Data Sources

For the application of the TOPSIS method, a decision matrix was constructed in which the alternatives (faculties A1–A5) are evaluated according to the operationalised criteria. Given that the paper has the character of a design and pilot application, data for the criteria are drawn from publicly available sources and are selected so as to be comparable across alternatives and transparently verifiable.

Operationalisation of criteria

For the purposes of the pilot model, the conceptual criteria defined in Section 3.2 are operationalised using the following indicators:

- C1a – number of accredited study programmes (Bachelor's + Master's):
A quantitative indicator expressing the breadth of the study offer at the level of bachelor's and follow-up master's programmes as presented in publicly available faculty information.
- C1b – existence of a doctoral programme:
A binary indicator (1/0) expressing whether the possibility of doctoral study is publicly communicated by the faculty; in the pilot phase, the value is based on the traceability of this information on the faculty website.
- C2a – existence of systematic cooperation with industry:
A binary indicator (1/0) expressing whether the faculty publicly presents organised cooperation with industry (e.g. a dedicated section, a long-term partner network, or regularly described forms of cooperation).
- C2b – number of industrial partners listed on the faculty website:
A quantitative indicator based on the publicly published list of cooperating entities (partners).
- C3 – study and career counselling:
A binary indicator (1/0) expressing the availability of information on counselling services (academic and/or career) in the faculty's public sources.
- C4 – number of partner universities (Europe and worldwide):
A quantitative indicator expressing the number of published partner institutions, which represent an applicant-interpretable approximation of the "breadth of mobility opportunities". In the pilot phase, the indicator is used without distinguishing between types of agreements; the aim is to capture the availability and scope of partnerships in public sources.

- C5 – city cost-of-living index:

An economic indicator at the level of the city in which the faculty is located; in the model, it is considered a cost criterion (a lower value is preferred). The data were obtained from the Numbeo database (Numbeo, 2024), which provides comparable data for cities in the Czech Republic.

The values of criteria C1a, C1b, C2a, C2b, C3, and C4 were obtained through manual content analysis of publicly available websites of the individual faculties (January 2025). The values of criterion C5 are based on the Numbeo database (Numbeo, 2024).

Prior to the construction of the final decision matrix, a basic variability check of individual criteria across the evaluated alternatives was conducted within the pilot application of the model. It was found that criterion C3 (availability of study and career counselling) exhibits the same value for all assessed faculties. The criterion therefore has no discriminatory power and does not contribute to differentiating alternatives in the decision-making process. For this reason, criterion C3 was excluded from the final decision matrix. This procedure corresponds to common practice in multi-criteria decision-making, where criteria without variability across alternatives are removed from the model, as their inclusion would be merely formal and would have no effect on the resulting ranking of alternatives. The decision matrix used for the TOPSIS calculation is presented in Table 1.

Table 1. Decision matrix – values of criteria for the evaluated faculties

Faculty	C1a	C1b	C2a	C2b	C4	C5
FEL ZČU	18	1	1	130	83	51.1
FEL ČVUT	22	1	1	35	131	60.2
FEKT VUT	38	1	1	56	150	53.4
FEI VŠB-TUO	11	0	0	0	0	50.8
FEI UPCE	8	1	0	0	277	50.1466

4. Results

This chapter presents the results of determining the weights of criteria using the AHP method and the subsequent ranking of alternatives using the TOPSIS method. In line with the design-oriented nature of the paper, the criterion weights are derived using a scenario-based approach (hypothetical applicant preferences), while the decision matrix of alternatives remains identical in both scenarios.

4.1. AHP Results: Criteria Weights and Consistency

The resulting weights of the evaluation criteria determined using the AHP method for both scenarios are summarised in Table 2, while the values of the consistency indicators of the pairwise comparisons (λ_{max} , CI , and CR) are presented in Table 3.

Using the AHP method, the weights of the evaluation criteria were determined on the basis of pairwise comparisons for two scenarios representing different applicant preferences. Following the variability check of criteria (Section 3.4.1), criterion C3 was excluded from the final model, and the weights were therefore calculated for six criteria (C1a, C1b, C2a, C2b, C4, and C5).

In Scenario A (academically oriented applicant), the highest weight was assigned to criterion C1a (breadth of study programmes; $w = 0.4277$), followed by criterion C4 (international opportunities; $w = 0.2601$) and criterion C1b (existence of doctoral studies; $w = 0.1399$). Criteria related to links with practice, C2a and C2b, both received lower and identical weights ($w = 0.0669$), while the cost criterion C5 exhibited the lowest weight ($w = 0.0384$).

In Scenario B (practically and economically oriented applicant), the cost criterion C5 dominated ($w = 0.4015$), followed by criterion C2a (systematic cooperation with industry; $w = 0.2377$) and criterion C2b (number of industrial partners; $w = 0.1800$). Criteria related to the academic profile, C1a and C1b, had lower weights in this scenario ($w = 0.0664$ and $w = 0.0393$, respectively).

The values of the consistency ratio (CR) in both scenarios did not exceed the recommended threshold of 0.10, indicating an acceptable level of internal consistency of the pairwise comparisons.

Table 2. Weights of evaluation criteria in Scenarios A and B

Criterion	Weight_A	Weight_B
C1a	0.42773272	0.06640741
C1b	0.1399153	0.03927434
C2a	0.06692895	0.23772168
C2b	0.06692895	0.17996037
C4	0.26009586	0.07514606
C5	0.03839821	0.40149014

Table 3. Consistency indicators of pairwise comparisons

Scenario	lambda_max	CI	RI	CR
A	6.4734	0.0947	1.24	0.0764
B	6.3729	0.0746	1.24	0.0602

4.2. TOPSIS Results: Ranking of Alternatives in Scenarios A and B

The TOPSIS method was applied to the decision matrix, with criteria C1a–C4 treated as benefit criteria (higher = better) and criterion C5 treated as a cost criterion (lower = better). The output of the method is a closeness coefficient to the ideal solution in the interval $(0;1)$, on the basis of which the ranking of alternatives is derived.

Scenario A

In the academically oriented Scenario A, the highest value of the closeness coefficient was achieved by the alternative FEKT VUT (TOPSIS = 0.7467), which indicates the best compromise with respect to the emphasis on the academic profile and the international dimension. This is followed by FEL ČVUT (0.4919) and FEI UPCE (0.4459). FEL ZČU ranked fourth in this scenario (0.3930), while FEI VŠB-TUO recorded the lowest value (0.0741).

Table 4. TOPSIS results – Scenario A

Alternative	TOPSIS	d_pos	d_neg	Rank
FEKT VUT	0.746717828750397	0.100028469886802	0.294900511467461	1
FEL ČVUT	0.491935787016526	0.18118544906015	0.17543374282543	2
FEI UPCE	0.445852306433639	0.269481732822709	0.216817742843046	3
FEL ZČU	0.392993218415076	0.225127950629867	0.1457541506245	4
FEI VŠB-TUO	0.0741465783905349	0.326775495929269	0.0261696769267281	5

Scenario B

In the practically and economically oriented Scenario B, FEL ZČU achieved the best result (TOPSIS = 0.8129), which corresponds to the high weight assigned to the cost criterion and to criteria related to links with practice. Second place was taken by FEKT VUT (0.6322), followed by FEL ČVUT in third place (0.5384). FEI UPCE and FEI VŠB-TUO ranked in the last positions in this scenario (0.2484 and 0.1252, respectively).

Table 5. TOPSIS results – Scenario B

Alternative	TOPSIS	d_pos	d_neg	Rank
FEL ZČU	0.812903486727149	0.0495794455206414	0.215414512161175	1
FEKT VUT	0.632207875690717	0.0959187519035501	0.164877348838646	2
FEL ČVUT	0.538432556786303	0.127811281998947	0.149095774332955	3
FEI UPCE	0.248433592991268	0.214962040417546	0.0710566512282188	4
FEI VŠB-TUO	0.125224168187366	0.223168922771996	0.0319466333008838	5

4.3. Comparison of Scenarios and Sensitivity to Criteria Weights

The comparison of scenarios demonstrates the sensitivity of the resulting faculty ranking to applicant preferences represented by the weights of the evaluation criteria. While in Scenario A, which places emphasis on academic characteristics of study, the alternative with the strongest combination of academic and international attributes (FEKT VUT) dominates, in Scenario B, oriented towards economic accessibility and links to practice, the first position shifts to the alternative favoured by a combination of more favourable economic demands and application-oriented characteristics (FEL ZČU).

The high ranking of FEKT VUT in Scenario A can be explained primarily by the combination of strong values in criteria C1a (broad range of study programmes), C4 (extensive network of partner universities), and C1b (existence of doctoral studies), which exhibit the highest weights in this scenario. In contrast, the success of FEL ZČU in Scenario B reflects in particular the significantly lower cost of living in the city of Pilsen compared to Prague or Brno (criterion C5), which has a dominant weight in this scenario ($w = 0.4015$), together with relatively strong values in criteria related to links with practice.

The scenario-based approach thus demonstrates that even with an identical decision matrix, different applicant preferences may lead to different recommendations of the “most suitable” alternative. From a methodological perspective, this result confirms the appropriateness of the AHP–TOPSIS combination for capturing the complexity of the

decision-making process, in which there is no universally “best” school, but rather a school that best corresponds to a specific preference profile.

A clear comparison of the resulting faculty rankings in Scenarios A and B is presented in Table 6, which allows for a direct comparison of changes in the evaluation of individual alternatives depending on the configuration of criteria weights.

Table 6. Comparison of faculty rankings in Scenarios A and B

Faculty	Rank – Scenario A	TOPSIS – Scenario A	Rank – Scenario B	TOPSIS – Scenario B
FEKT VUT	1	0.7467	2	0.6322
FEL ČVUT	2	0.4919	3	0.5384
FEI UPCE	3	0.4459	4	0.2484
FEL ZČU	4	0.393	1	0.8129
FEI VŠB-TUO	5	0.0741	5	0.1252

5. Discussion and Limitations

5.1. Limitations of the Pilot Application and the Data Used

The results of the study must be interpreted with regard to its pilot and design-oriented character. The aim of the paper was not to empirically capture the actual preferences of a specific group of applicants, but to verify the methodological feasibility of the combined AHP–TOPSIS approach in modelling decision-making related to the choice of a technical faculty and to demonstrate the sensitivity of results to different configurations of criteria weights. The resulting rankings of alternatives therefore cannot be understood as normative recommendations for real applicants, but rather as an illustration of the behaviour of the decision-making model under different preference scenarios.

The decision matrix was constructed on the basis of publicly available sources, while the scope, structure, and level of detail of the presented information differ across individual faculties. This limitation may be particularly evident in indicators based on the traceability of information on faculty websites, whether in the form of binary criteria or in the determination of quantitative values derived from publicly presented lists (e.g. industrial partners or partner universities). In this sense, the pilot model partially captures not only institutional characteristics of the faculties, but also the degree of transparency of their online communication from the applicant’s perspective.

The pilot application further revealed limited discriminatory power of some binary indicators. Criterion C3 (availability of study and career counselling) exhibited identical values for all evaluated faculties and was therefore excluded from the final decision matrix. Similarly, limited variability was observed for other binary criteria: criterion C1b (existence of doctoral studies) had a value of 1 for four out of five faculties, and criterion C2a (systematic cooperation with industry) for three out of five faculties. This limited variability reduces the discriminatory power of the criteria and, in future research, should be replaced by finer-grained scales or composite indicators that would allow differences among faculties to be captured more effectively.

The use of binary indicators represents a deliberate simplification appropriate for a pilot application, but it also limits the discriminatory power of the model. In subsequent research, such criteria may be replaced or complemented by ordinal or composite indicators capturing the intensity or scope of the respective characteristics.

5.2. Methodological Limitations and Possibilities for Further Extension

In this study, the determination of criteria weights using the AHP method was implemented through a scenario-based approach working with hypothetical decision situations. The consistency of pairwise comparisons was verified for both scenarios using the indicators λ_{max} , CI , and CR , with the values of the consistency ratio CR remaining below the recommended threshold of 0.10 . This indicates an acceptable level of internal consistency of the stated preferences and confirms the methodological correctness of the criteria weighting within the pilot application.

It should, however, be emphasised that the scenarios used in this study do not represent empirically derived preferences of real applicants, but rather analytical constructs serving to test the sensitivity of the model. In subsequent research, it would be appropriate to replace scenario-based weighting with empirical data, for example through a questionnaire survey among applicants or students in technical fields, and to verify the stability of results when involving a larger number of respondents.

The proposed model also does not include some potentially relevant dimensions of decision-making, particularly subjectively perceived brand, institutional reputation, or emotional aspects of study choice. These factors play an important role in real applicants' decision-making, but their operationalisation within MCDA requires different approaches and a combination of quantitative and qualitative methods. The integration of these dimensions into an extended decision-making framework represents one of the main directions for further research.

6. Conclusion

This study presented the design and pilot application of a multi-criteria decision-making model for the evaluation and ranking of technical faculties in the Czech Republic from the perspective of prospective students. By combining the AHP and TOPSIS methods, a transparent and reproducible analytical framework was developed that enables the structuring of a complex decision problem, the simultaneous consideration of multiple evaluation criteria, and the systematic analysis of the influence of their relative importance on the resulting ranking of alternatives.

The pilot application of the model demonstrated its methodological feasibility and internal consistency. The determination of criteria weights using AHP achieved an acceptable level of consistency in both scenarios ($CR < 0.10$), and the subsequent application of the TOPSIS method revealed a pronounced sensitivity of the results to changes in criteria weights. The differing rankings of faculties in Scenarios A and B confirm that there is no universally "best" technical faculty, but that the resulting evaluation depends on the applicant's preference profile and decision-making strategy.

At the same time, the pilot phase identified limitations related to the operationalisation of criteria and data availability. In particular, the limited discriminatory power of some binary indicators was revealed, including the criterion of availability of study and career counselling, which was excluded from the final model. These findings are not interpreted as a weakness of the proposed approach, but rather as an important outcome of the pilot phase that provides concrete guidance for further methodological refinement of the model.

The main contribution of the paper lies in the proposal of a structured decision-making framework that can serve as a methodological basis for subsequent empirical research in the area of technical faculty choice. In a future phase, the model may be extended to incorporate preferences of real applicants, more fine-grained and multidimensional indicators of study quality, and additional decision-making dimensions, including the operationalised branding of higher education institutions. The proposed approach thus represents a starting point for the systematic examination of competition and differentiation among higher education institutions from the perspective of prospective students.

Conflict of interest: none

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Work–Life Balance in the Digital Age: Working with Needs and Boundaries from the Perspective of Pesso-Boyden Psychomotor Therapy

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Abstract: Digital transformation is fundamentally changing the nature of the work environment and placing greater demands on employees, particularly managers. The constant availability required and the gradual blurring of the boundaries between work and personal life are significantly increasing the risk of technostress and burnout. Theoretical frameworks such as the Job Demands–Resources model, Conservation of Resources theory and Boundary Theory describe the cognitive, emotional and behavioral mechanisms involved in achieving work–life balance. In this context, work–life balance is understood as the subjective perception of harmony between an individual's work and personal roles. This literature review integrates these approaches with principles derived from Pesso-Boyden Psychomotor Therapy, a somatically oriented method that focuses on boundaries, basic psychological needs and internalized behavioral patterns. The proposed theoretical model, which presents integration of Pesso-Boyden Psychomotor Therapy into the work–life balance in the digital age provides a conceptual framework for leadership development, coaching and mental well-being interventions. It emphasizes the importance of boundary control, developing body awareness, and restoring personal resources as key factors in preventing burnout and ensuring long-term sustainable work performance.

Keywords: work–life balance; Pesso-Boyden psychomotor therapy; boundary management; JD-R model; digital work; psychological needs

JEL Classification: I31; J28; M12

1. Introduction

Digital transformation and the associated development of remote work have fundamentally changed the relationship between work and personal life. For managers responsible for team performance, availability and coordination, digitization offers flexibility but also presents significant psychosocial risks (Kossek, 2016; Scholze & Hecker, 2024). Constant connectivity via smartphones, email and collaboration platforms disrupt traditional temporal and spatial work boundaries and can lead to long-term psychological stress (Kossek & Ozeki, 1998).

The concept of work–life balance (WLB) has therefore become a key topic in organizational psychology and management research (Greenhaus & Beutell, 1985). The current concept of WLB considers it to be a complex psychological process involving three

intertwining levels: cognitive evaluation, emotional response and behavioral boundary management strategies (Greenhaus et al., 2003; Kossek & Ozeki, 1998).

In this context, approaches that enable work with internal boundaries, emotions, and basic psychological needs are growing in importance. One such approach is Pesso-Boyden psychomotor therapy (PBSP), a body-oriented psychotherapeutic approach focused on corrective emotional experience and the restoration of the internal structure of behavior (Gray, 2018; Sirinek, 2025; Slaninova & Kucerova, 2017). Although PBSP is not primarily intended for organizational environments, its principles can offer an innovative approach to managing WLB in the digital age.

The aim of this article is to present the current theoretical foundations of the psychological aspects of work–life balance in digital work and to show how digitization is changing the role of boundaries, needs, and professional identity of managers. Based on a literature review, an integrative theoretical model is proposed that links PBSP with WLB theoretical frameworks. The research questions were formulated based on three levels of psychological mechanisms:

RQ1: Which cognitive processes influence managers' experience of work–life balance in digital work?

RQ2: How do emotional states mediate the relationship between work demands and work–life balance?

RQ3: What boundary management and recovery strategies do managers use in conditions of constant connectivity?

This article's theoretical contribution lies in integrating the Job Demands–Resources model (JD-R), Conservation of Resources (COR) and Boundary Theory models with the principles of Pesso-Boyden psychomotor therapy. In terms of practical contributions, the article proposes recommendations for leadership, coaching and organizational interventions aimed at preventing burnout and supporting sustainable performance.

2. Literature Review Methodology

The study uses a focused narrative literature review design. Rather than aiming to map all available studies, the review focuses on a conceptual analysis of the key theoretical approaches and psychological mechanisms relevant to work–life balance (WLB) in digital work environments. This approach was selected in line with the theoretical orientation of the article, which aims to integrate established work psychology frameworks with principles derived from Pesso-Boyden Systemic Psychomotor Therapy. The primary source of the search was the Web of Science Core Collection database. The search, which was conducted on December 10, 2025, was structured according to three thematic areas that corresponded to the article's focus. The following search terms were applied to the Title field:

- "Pesso-Boyden" OR "Pesso Boyden" OR "PBSP" (106 results)
- ("work–life balance" OR "work life balance" OR "boundary management") AND (digital OR "remote work" OR telework OR "online availability") (727 results)
- (somatic OR "body-oriented" OR psychomotor OR sensorimotor) AND (intervention OR therapy) AND (work OR workplace OR burnout) (3 214 results)

A total of 4,047 records were identified. Due to the large volume of results, additional selection criteria were applied, and only open-access articles were retained, resulting in 2,129 records. This represents a pragmatic limitation and may have led to the exclusion of some influential publications. However, it was considered sufficient for capturing the main conceptual streams relevant to the study's theoretical aims. In the next phase of the search, the same search terms were applied to Author Keywords field, resulting in 163 articles. These articles were screened for relevance to the defined objectives and research questions. Included were publications addressing work–life balance in digitally mediated work, with a specific focus on boundary regulation, psychological resources, and somatically oriented approaches relevant to work and organizational contexts. Duplicate records, studies unrelated to work or organizational settings, and publications focused exclusively on clinical psychotherapy without implications for applied or organizational practice were excluded. The primary time frame covered the period from 2010 to 2025, however, older key theoretical works were also included due to their fundamental importance for the given concepts (Demerouti et al., 2001; Greenhaus & Beutell, 1985; Hobfoll, 1989; Kossek & Ozeki, 1998; Lazarus & Folkman, 1984). A total of 29 key sources were selected for in-depth content analysis.

A thematic approach was used to analyze the literature and identify cognitive, emotional and behavioral mechanisms relevant to work-life balance. The Job Demands–Resources, Conservation of Resources and Boundary Theory models were used as a theoretical framework to interpret these mechanisms and answer the research questions. These theories led to the formulation of an integrative theoretical model, which is elaborated on further in the following chapters.

3. Theoretical Framework of Work–life Balance in the Digital Age

Greenhaus et al. (2003) defined work–life balance as a subjectively perceived state of equilibrium between work and personal roles, characterized by a low level of conflict and a high level of enrichment between the areas of work and private life. To understand this balance, it is useful to combine three complementary perspectives: the JD-R model, Conservation of Resources theory, and Boundary Theory.

3.1. *Job Demands–Resources Model*

As Demerouti and Bakker (2011, 2017) state in their articles, the current Job Demands–Resources model distinguishes between job requirements and job resources. Job demands include physical, psychological, social, and organizational aspects of work that require sustained physical or mental effort and are associated with certain physiological and psychological costs, such as high levels of responsibility, emotional strain, or constant connectivity. In contrast, job resources are the physical, psychological, social, and organizational aspects of work that support the achievement of work goals, reduce job demands, and stimulate personal development. Examples include autonomy, status, social support and performance feedback (Bakker & Demerouti, 2017; Demerouti & Bakker, 2011).

Other authors distinguish between two parallel processes within the JD–R model: the health impairment process and the motivational process (Demerouti et al., 2001; Powell & Greenhaus, 2010). The health impairment process manifests itself in the form of work–family conflict (WFC), where high work demands lead to exhaustion and the risk of burnout. In contrast, the motivational process, referred to as work–family enrichment (WFE), emphasizes the role of available resources in supporting work engagement and leading to positive work and personal outcomes.

As the Demerouti et al. (2001) point out, managerial positions are particularly sensitive to these processes because they combine high work demands with significant work resources. However, Powell and Greenhaus (2010) argue that achieving work–life balance is not just as a matter of reducing demands. Rather, it is primarily the result of the availability and effective use of work resources, particularly autonomy and supportive leadership.

3.2. Conservation of Resources Theory

In his article, Hobfoll (1989) presents the COR theory, which complements the JD–R model by providing an explanation of the dynamics of motivation and stress within the framework of human resource management. The author states that individuals strive to acquire, maintain and protect resources, including energy, time, self-esteem and social support. Stress arises when these resources are threatened or lost, or when they are not replenished quickly enough.

Hobfoll (2001) further emphasizes that managers, who often face high demands and emotional labor, are prone to spirals of resource loss, manifesting exhaustion and burnout. Conversely, spirals of resource gain promote positive development. For instance, successfully establishing boundaries between work and personal life can reduce cognitive overload and enhance sleep quality, thereby facilitating further resource accumulation (Hobfoll, 2001).

3.3. Boundary Theory

Kossek and Ozeki (1998) focus their articles on the behavioral management of work and home life through boundary control, i.e., the ability to regulate the permeability and flexibility between work and personal life (Kossek et al., 2006; Kossek & Ozeki, 1998). As the authors state, the degree to which preferred and actual boundary styles align is a strong predictor of work–life balance satisfaction. As digital work becomes more prevalent, managing boundaries has become an important psychological task for managers, as the physical separation of work and home becomes increasingly unrealistic (Demerouti et al., 2001; Kossek, 2016).

4. Results: Psychological Mechanisms of Work–life Balance Management

Based on the above theoretical frameworks, the psychological mechanisms that shape work–life balance can be divided into three interconnected levels: cognitive, emotional, and behavioral. Analyzing professional literature according to these levels provides answers to three defined research questions.

4.1. Cognitive Mechanisms

The cognitive level includes processes of evaluation, interpretation, and decision-making that play a key role in shaping how managerial job translate into work–life balance outcomes (Greenhaus et al., 2003). In this context, the following research question was formulated: RQ1: Which cognitive processes influence managers' experience of work–life balance in digital work?

Lazarus and Folkman emphasize that the way managers evaluate job demands is crucial and influences whether the workload is perceived as a challenge or a threat. Managers who perceive high workload as an opportunity for development show greater engagement and positive work–life enrichment. Conversely, those who perceive the demands as a threat experience stress and are more prone to work-family conflict and burnout. This process is not static but depends on the available resources and the manager's previous experiences. Subjective appraisal of demands turns out to be a stronger predictor of stress than objective job demands, such as long working hours or high workload (Lazarus & Folkman, 1984).

Querstret and Cropley (2012) define work rumination as constantly thinking about work-related matters during one's free time. Amstad et al. (2011), along with Querstret and Cropley (2012) describe it as a major obstacle to psychological detachment, while Sonnentag (2018) emphasizes that rumination interferes with effective psychological rest. According to Kossek et al. (2006) managers may be prone to ruminative thinking due to a strong professional identity and internalized high-performance expectations. Querstret and Cropley (2012) further distinguish two types of work rumination: emotional and cognitive. Emotional rumination is characterized by repetitive negative thoughts, while cognitive rumination involves attempting to solve work-related problems. It has been shown that emotional rumination is more strongly associated with negative outcomes relating to work–life balance. The constant connectivity provided by digital technologies makes it even more difficult to achieve cognitive disconnection (Amstad et al., 2011; Querstret & Cropley, 2012).

Kossek and Lautsch (2012) emphasize that managers often have a strong managerial identity and internalize high-performance norms, such as perfectionism and excessive commitment. This can result in self-imposed demands, such as believing that they must always be available or that delegation is a sign of weakness (Kossek & Lautsch, 2012). As Vahle-Hinz et al. (2017) state, these internal demands often represent a stronger source of WFC than external organizational pressures, creating a conflict between the identities of the 'ideal worker' and the 'ideal family member'. This conflict is a major source of psychological strain and guilt (Vahle-Hinz et al., 2017).

4.2. Emotional Processes

As Greenhaus et al. (2003) state, the emotional level refers to the regulation of emotions and motivational states. It influences the cognitive appraisal of job demands and well-being outcomes. The following research question was defined: RQ2: How do emotional states mediate the relationship between job demands and work–life balance?

According to Demerouti et al. (2001), emotional exhaustion is the most reported emotional consequence of chronic WFC and is a fundamental component of burnout

syndrome. Bakker and Demerouti (2017), using the JD-R model, explain that emotional exhaustion is the result of a health impairment process, where high demands deplete a manager's emotional resources faster than they can be replenished. The authors state that chronic WFC is therefore strongly associated with emotional exhaustion, which impairs a manager's ability to function effectively in both work and family contexts (Bakker & Demerouti, 2017; Greenhaus et al., 2003).

According to Hobfoll (1989), guilt is a specific emotional intermediate stage arising from the conflict between internalized roles and actual behavior. Greenhaus and Beutell (1985) state that this mechanism is particularly common among managers and stems from the perception that expectations associated with the roles of the 'ideal employee' and 'ideal family member' have not been met. The emotional tension associated with guilt often manifests as negative affective transfer, further worsening the quality of interactions within the family and deepening work conflicts.

Affective transfer refers to the transfer of mood or emotions from one area of life to another. Edwards and Rothbard (2000) emphasize that negative affective transfer, such as transferring stress or frustration from work to family life, is a direct emotional mechanism that reduces the quality of family interactions and increases conflict between work and family life. This process demonstrates how managers' internal emotional states can influence their daily roles and impact their work–life balance (Edwards & Rothbard, 2000).

4.3. Behavioral Level

The behavioral level reflects the specific strategies and actions through which managers actively influence work–life balance (Greenhaus et al., 2003). The research question was formulated as follows: RQ3: What boundary management and recovery strategies do managers use in conditions of constant connectivity?

The authors agree that key factors include the degree of boundary control and the alignment of preferred and actual boundary management styles (Friedman & Greenhaus, 2000; Kossek et al., 2006; Perrigino & Raveendhran, 2025). The results of French et al.'s (2018) study suggest that managers who can align their boundary preferences with their actual behavior are more satisfied with their work–life balance (French et al., 2018).

According to Greenhaus and Powell (2006), the key behavioral mechanisms for replenishing work resources are psychological detachment and recovery-focused activities.(Greenhaus & Powell, 2006) These include physical exercise, activities that provide a sense of control over the situation and relaxation techniques that replenish depleted resources and reduce the effects of emotional exhaustion and rumination. Sonnentag (2018) emphasizes that recovery is an active process, not merely the absence of work(Sonnentag, 2018).

Research by Lazarus and Folkman (1984) suggests that managers who perceive control over stressors predominantly use problem-focused coping styles, such as delegating tasks or time management. This approach is usually associated with a better work–life balance. However, when faced with uncontrollable demands, they often resort to less effective emotion-focused coping strategies, such as avoidance, which can further increase tension (Lazarus & Folkman, 1984).

5. Pesso-Boyden Psychomotor Therapy as an Integrative Element

Several authors describe Pesso-Boyden psychomotor therapy as a body-oriented therapeutic approach that focuses on satisfying five basic developmental needs: place, support, nurture, protection, and limits (Gray, 2018; Sirinek, 2025; Slaninova & Kucerova, 2017). Failure to fulfil these needs may result in internalized behavioral patterns that manifest in adulthood as difficulties in setting boundaries and coping with stress. Key PBSP principles relevant to WLB include:

- *Micro-tracking*: developing bodily awareness and the ability to recognize stress signals in a timely manner.
- *Self-determination theory (SDT)*: the ability to act in accordance with one's own needs and to establish healthy limits.
- *Corrective emotional experience*: creating supportive conditions to restore psychological resources.

Compared to cognitive or behavioral approaches to work–life balance, PBSP emphasizes embodied experiences, implicit emotional patterns, and early internalized needs that often shape managerial behavior beyond conscious control. PBSP thus extends existing models by addressing not only conscious stress and boundary regulation strategies, but also deeper somatic and emotional mechanisms that influence the long-term sustainability of work performance.

In organizational practice, PBSP principles can be transferred primarily into leadership development, executive coaching, and workplace well-being programs, where they support bodily awareness, early recognition of overload signals, and the development of functional boundaries between work and non-work roles. Empirical studies support the effectiveness of body-centered, psychomotor, and digitally mediated interventions in reducing stress, anxiety, and burnout-related symptoms, particularly in healthcare settings (Veiga et al., 2019; Zhang et al., 2024). Rosendahl et al. (2021) confirmed in their study that body-focused psychotherapy had a modest effect on psychopathology and psychological distress in people with mental health problems. Similarly, a pilot-controlled study by Veiga et al. (2019) showed that an eight-week psychomotor relaxation program significantly reduced emotional exhaustion, depressive symptoms, and indicators of physiological stress in nurses. The results of another study (Zhang et al., 2024) confirmed that mental health interventions had a significant impact on stress and anxiety, as well as a modest effect on depression and emotional exhaustion in healthcare workers.

5.1. Integrating PBSP into the WLB Model in the Digital Age

The digital work environment is characterized by high work demands, constant availability, and fragmented attention, which, according to the JD–R model, are key stressors that increase the risk of burnout and disrupt work–life balance (Demerouti et al., 2001; Hobfoll, 1989). These demands create a need for targeted intervention that would not only reduce stress but, above all, strengthen managers' personal resources and support their ability to regenerate.

An integration model, shown in Figure 1, was proposed based on an analysis of professional literature. This model illustrates a cyclical process in which PBSP functions as an intervention that strengthens personal resources within the JD-R model. At the same time, it supports their renewal through the principles of COR theory. PBSP acts here as an integrating element that links the cognitive, emotional, and behavioral mechanisms described in the previous chapters and provides a comprehensive framework for supporting work–life balance in digital work.

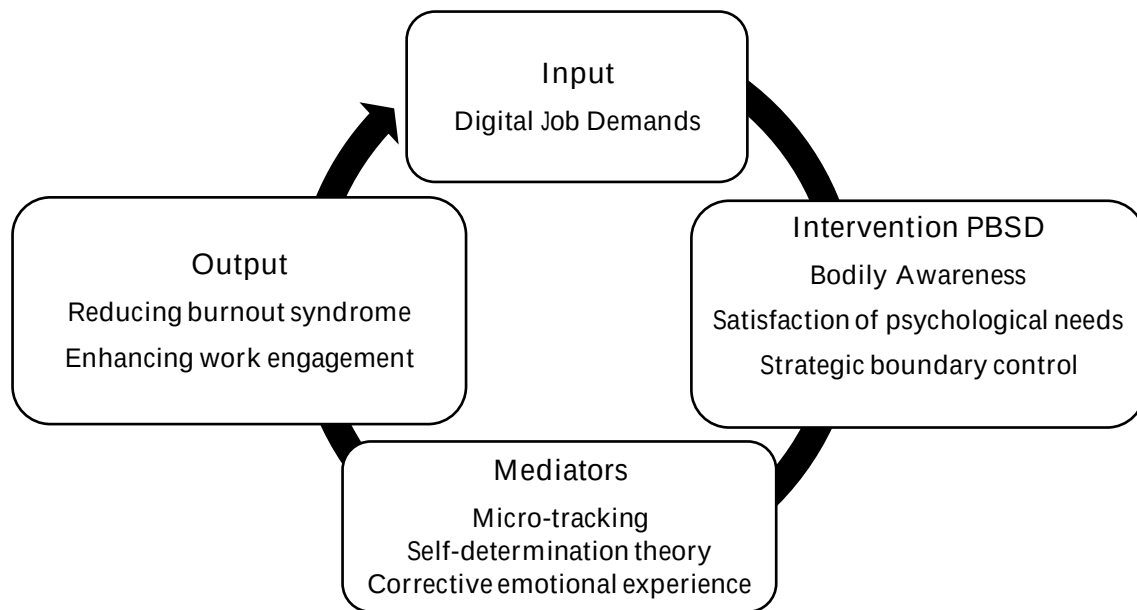


Figure 1. Integration of PBSP into the Work–Life Balance model in the digital age

The model (Fig. 1) captures four interconnected components. Input conditions include high job demands, continuous availability, and fragmentation of attention, which, in line with the JD-R model, are understood as key stressors requiring targeted intervention. These factors put pressure on managers' cognitive, emotional, and behavioral regulation and increase the risk of chronic exhaustion.

The intervention component involves incorporating PBSP, which promotes the development of bodily awareness, the satisfaction of basic psychological needs, and strategic control of the boundaries between work and private life. PBSP functions here as a mechanism for strengthening and restoring personal resources, thereby contributing to a reduction in emotional exhaustion and an increase in work motivation and engagement.

The effect of the intervention is mediated through mediators. The micro-tracking process develops body awareness and the ability to recognize signs of overload in a timely manner. Self-determination theory explains the satisfaction of the needs for autonomy, competence, and relatedness, which are key to sustainable motivation. Corrective emotional experience creates supportive conditions for restoring personal resources.

The output effects of this cyclical process include desirable psychological impacts, in particular a reduction in mental exhaustion and the risk of burnout, an increase in work engagement and motivation, a strengthening of regenerative capacity, and long-term sustainable work performance. The model depicts PBSP as part of a dynamic system in which

interventions influence managers' ability to cope with digital work demands and maintain a work–life balance retroactively.

6. Recommendations

Practical recommendations can be formulated for individual intervention and organizational practice based on the identified cognitive, emotional, and behavioral mechanisms affecting the work–life balance of managers in a digital work environment. The key starting point is shifting the focus from time management to the management of energy, attention, and psychological resources.

6.1. Recommendations for Managers and Executive Coaching

Interventions aimed at managers should focus on developing their ability to regulate their cognitive assessment of work demands, their emotional responses and their recovery-related behaviors.

Managers should be systematically trained in cognitive techniques that enable them to perceive high job demands as challenges rather than threats. According to the Job Demands-Resources (JD-R) model, this approach activates motivation, thereby reducing the risk of emotional exhaustion (Bakker & Demerouti, 2017; Lazarus & Folkman, 1984).

Executive coaching should emphasize the importance of active recovery as a prerequisite for long-term performance. It is crucial to establish clear digital boundaries, including designated times without work technology, and to encourage activities outside of work that facilitate psychological detachment. Research indicates that recovery processes are paradoxically most disrupted during periods of high stress, further exacerbating exhaustion (Sonnentag, 2018).

PBSP speaks of a 'messianic gene' that, under specific circumstances, can lead an individual to behave in an omnipotent and unlimited way (Sirinek, 2025). This is also related to feelings of guilt arising from the conflict between internalized norms of the 'ideal worker' and the needs of personal life. These feelings should be given special attention so that they can be recognized, processed, and connected with core vital forces (Sirinek, 2025).

6.2. Recommendations for Organisations and Personnel Policy

At an organizational level, it is necessary to go beyond formal flexibility and systematically establish a culture that supports healthy boundary management and resource renewal.

Organizational policies should increase managers' perceived boundary control. This can be achieved by introducing a 'right to disconnect', setting clear expectations regarding availability and providing support for effective delegation. These steps reduce pressure to be constantly connected and promote psychological detachment.

Organizations should regularly analyze job roles to ensure that high demands are balanced with adequate job resources. Emphasis should be placed on autonomy, social support and quality feedback, as these are key to activating the motivational process in the JD-R model.

Leadership development programs should educate leaders on the psychological costs of long-term work–life imbalance. Leaders play a key role in shaping implicit behavioral norms and should lead by example in managing boundaries, recovering and practicing self-care.

7. Discussion, Limits and Implications

The aim of this literature review was to examine research on the psychological mechanisms shaping managers' experiences of work–life balance in the digital work environment. The article proposes a conceptual framework that emphasizes the internal and subjective dimensions of work–life balance by integrating established theoretical approaches in work psychology, including the JD-R model, COR theory, the Transactional Model of Stress and Coping, with contemporary concepts, including Boundary theory and work rumination.

Integrating cognitive, emotional, and behavioral mechanisms provides valuable theoretical and practical insights. In particular, the incorporation of concepts from PBSP extends existing work–life balance models by addressing embodied and implicit processes that influence stress regulation, resource restoration, and boundary management beyond conscious cognitive strategies. The integrative model (Figure 1) describes WLB as a dynamic process and highlights the potential of PBSP-based interventions to strengthen personal resources and self-regulatory capacities of managers in digital environments.

This work has several limitations. Firstly, the review is based on a targeted selection of literature defined by specific thematic criteria and a limited time frame, which may have led to the exclusion of relevant but less frequently cited empirical studies. Secondly, the proposed model is conceptual in nature and requires further empirical validation of the assumed relationships between cognitive, emotional, and behavioral mechanisms. To date, no empirical studies have directly examined the effects of PBSP on managers' work–life balance in digital work contexts. Existing empirical evidence originates primarily from healthcare settings (Veiga et al., 2019; Zhang et al., 2024) and should therefore be interpreted cautiously due to differences in job demands and organizational conditions.

Despite these limitations, the proposed integrative model contributes to theory development by offering a coherent framework for understanding work–life balance in the digital age and provides a foundation for leadership development, executive coaching, and workplace well-being initiatives. By incorporating somatically oriented principles, the model supports the design of interventions aimed at enhancing boundary awareness, early detection of overload, and sustainable work performance among managers.

8. Conclusions

In the digital age, work–life balance is fundamentally influenced by managers' ability to manage the boundaries between work and non-work roles, and to satisfy basic psychological needs. This literature review demonstrates that work–life balance is a dynamic process influenced by cognitive evaluation, emotional regulation and behavioral boundary control.

The proposed integrative framework links established psychological models with the principles of Pesso-Boyden psychomotor therapy to provide a theoretically grounded

approach to preventing burnout and promoting sustainable work performance among managers. It emphasizes the importance of psychological distance, reducing rumination, and active recovery as key mechanisms for achieving long-term balance.

The framework also provides a basis for future empirical research, particularly in the form of studies examining the processes of resource depletion and restoration in digital work environments. From a practical perspective, the findings suggest a shift in organizational interventions from formal policies to developing managers' psychological competencies, which are essential for achieving a sustainable work–life balance.

Conflict of interest: none

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Energy Data Ecosystems Driving Sustainable Energy Mix Optimization in the EU: A 27-Country Assessment

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Abstract: The European Union's transition to climate neutrality requires not only renewable deployment but also institutional capacity to govern increasingly data-intensive electricity systems. While prior research emphasizes technological innovation, market design, and carbon pricing, limited attention has been paid to the strategic role of national energy data infrastructures. Drawing on the Resource-Based View and the Knowledge-Based View, this study conceptualizes energy data ecosystems as institutionalized public knowledge capabilities and examines their relationship with sustainable energy performance across the 27 EU Member States. To operationalize this perspective, the study develops and applies the Data-Centric Information Management Maturity Model, which evaluates national energy knowledge infrastructure along four dimensions: accuracy, timeliness, coverage, and accessibility. Using structured document analysis of Eurostat, ENTSO-E, and national regulatory sources, Member States are comparatively assessed and clustered into maturity tiers. The results reveal substantial heterogeneity in digital energy governance despite regulatory harmonization. Higher maturity scores consistently align with stronger renewable penetration and lower electricity-sector greenhouse gas intensity, supporting a structured capability performance relationship. By extending resource-based theory to national digital public infrastructure and introducing a measurable construct of institutional knowledge capability, this study advances strategic management scholarship and positions digital governance as a foundational pillar of sustainable energy transitions.

Keywords: energy data governance; renewable energy; Resource-Based View (RBV); Knowledge-Based View (KBV); digital public infrastructure

JEL Classification: Q48; O33; C43

1. Introduction

The European Union's commitment to climate neutrality by 2050 represents one of the most ambitious structural transformations in contemporary economic policy. Under the European Green Deal and REPowerEU framework, Member States must accelerate renewable deployment while strengthening market integration and energy security (European Commission, 2022). Although existing research emphasizes infrastructure

expansion, carbon pricing, and technological innovation, comparatively limited attention has been paid to the institutional maturity of national energy data systems that underpin renewable-heavy electricity markets. (Pahle et al., 2018; Sue Wing et al., 2020; Shahbaz et al., 2022),

Modern electricity systems are increasingly information-intensive and digitally coordinated (Goldfarb & Tucker, 2019; Nambisan et al., 2019). The integration of variable renewable sources such as wind and solar requires continuous monitoring, rapid coordination, and transparent market signaling (ENTSO-E, 2024; Ma et al., 2024; Santarius, T et al., 2021). Unlike fossil-based systems, renewable-heavy grids depend on reliable and timely data to balance supply and demand, manage cross-border flows, and mitigate volatility (ENTSO-E, 2024; Ma et al., 2024). In this context, energy data infrastructure is not merely administrative; it constitutes a core governance mechanism shaping system coordination and investment certainty.

Despite regulatory harmonization within the EU, Member States differ substantially in the maturity of their energy data ecosystems. These institutional differences align with broader research on digital transformation and sustainability governance (Pierli, G et al., 2023). Some countries operate advanced, interoperable platforms with real-time and machine-readable access, while others face delays, fragmentation, and limited accessibility (European Commission, 2024). These disparities raise a critical theoretical and empirical question: do differences in digital energy governance capacity influence renewable integration and carbon performance?

To address this question, this study draws on the Resource-Based View (RBV) and the Knowledge-Based View (KBV). The RBV posits that performance differences arise from heterogeneous resource endowments (Barney, 1991). Extending this logic to national systems, digital energy infrastructure can be conceptualized as a strategic public resource. The KBV further refines this argument by identifying knowledge as the most strategically significant resource in complex environments (Grant, 1996). Renewable-heavy electricity systems are inherently knowledge-intensive; their performance depends on the reliability, timeliness, comprehensiveness, and diffusion of energy-related information. National energy data ecosystems can therefore be conceptualized as institutionalized knowledge capabilities.

The study operationalizes this theoretical perspective through the Data-Centric Information Management Maturity Model (DCIM-MM), which evaluates national energy data systems across four dimensions: accuracy, timeliness, coverage, and accessibility. Applying the DCIM-MM to all 27 EU Member States provides one of the first structured cross-country assessments of digital energy governance maturity and examines its relationship with renewable share and greenhouse gas intensity. By integrating RBV and KBV with a national-level maturity operationalization, this study advances strategic management theory beyond the firm and introduces digital public infrastructure as a determinant of sustainability performance. It thus fills a theoretical and empirical gap at the intersection of energy policy and knowledge-based resource theory.

2. Theoretical Framework

This study conceptualizes national energy data ecosystems through the Resource-Based View (RBV) and the Knowledge-Based View (KBV) to explain cross-country variation in sustainable energy performance. The RBV argues that persistent performance differences arise from heterogeneous resource endowments (Barney, 1991). Resources generate advantage when they are valuable, rare, inimitable, and non-substitutable. This perspective builds on institutional economics emphasizing governance structures and transaction efficiency (Williamson, 1985). Although traditionally applied at the firm level, RBV logic extends to national systems. States differ in institutional capacity, regulatory design, and infrastructural sophistication, potentially producing divergent outcomes under similar policy regimes.

In renewable-heavy electricity systems, digital energy infrastructure constitutes a strategic public resource. Reducing information asymmetry and transaction costs is critical in platform-mediated and data-intensive environments (Cennamo & Santalo, 2013; van Dijck et al., 2018). Where digital infrastructures are interoperable, institutionally embedded, and difficult to replicate, they exhibit characteristics consistent with RBV. However, RBV does not specify which resources are most decisive in knowledge-intensive systems. The KBV refines this perspective by identifying knowledge as the central strategic resource (Grant, 1996).

Renewable-heavy electricity markets are inherently knowledge-intensive. System stability depends on continuous data generation, integration, and dissemination (Grant, 1996; Nambisan et al., 2019). Energy data ecosystems therefore function not merely as technical platforms but as institutionalized knowledge infrastructures. They perform four core functions: knowledge creation (data validation), knowledge integration (cross-sector aggregation), knowledge dissemination (open access and APIs), and knowledge application (market coordination and policy design). Performance differences emerge from variation in the quality of these capabilities. Countries with mature data ecosystems possess stronger institutional capacity to generate and diffuse energy knowledge, enhancing transparency, coordination, and adaptive capacity.

To operationalize this theoretical framework, the study employs the Data-Centric Information Management Maturity Model (DCIM-MM). The model evaluates national energy knowledge infrastructure across four dimensions: accuracy, timeliness, coverage, and accessibility (Fig. 1). These pillars represent reliability, responsiveness, comprehensiveness, and diffusion structural properties of institutionalized knowledge governance. Figure 2 illustrates the hierarchical pathway from resource heterogeneity (RBV) to knowledge capability (KBV), operationalized through the DCIM-MM and linked to renewable share and carbon intensity outcomes. The framework advances a structured capability performance relationship: mature knowledge infrastructures enhance coordination and transparency, thereby supporting renewable integration and emissions reduction. The model does not assume determinism but theorizes digital public infrastructure as a foundational knowledge capability shaping sustainability performance across national contexts.

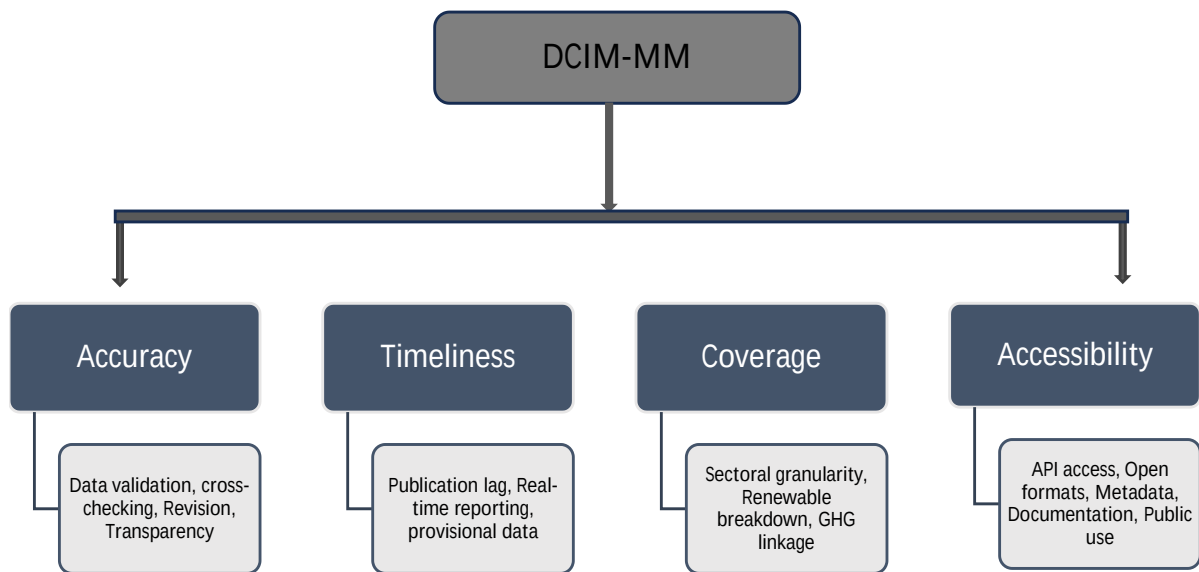


Figure 1. Structure of the DCIM-MM



Figure 2. Theoretical hierarchy and model structure

3. Methodology

3.1. Construct Development and Research Design

This study develops and applies the Data-Centric Information Management Maturity Model (DCIM-MM) as a structured operationalization of national-level knowledge capability. While prior maturity frameworks focus primarily on firm-level IT governance and digital transformation, the DCIM-MM extends maturity modeling to public, institutionalized digital infrastructure. This extension aligns with research on digital transformation strategy and public-sector capability development (Hess et al., 2016; Pierli, G et al., 2023), thereby building a cross-level bridge between strategic management theory and national governance systems.

The research adopts a qualitative comparative design based on structured document analysis across the 27 European Union Member States. The unit of analysis is the national energy data ecosystem defined as the institutional architecture governing the production, validation, integration, and dissemination of energy information. Consistent with the Knowledge-Based View (Grant, 1996), digital energy infrastructure is conceptualized as institutionalized knowledge capability rather than a technological artifact. The DCIM-MM captures graded variation across four theoretically derived pillars: accuracy, timeliness, coverage, and accessibility representing reliability, responsiveness, comprehensiveness, and diffusion within national knowledge systems.

3.2. Measurement Strategy, Validation, and Analytical Procedure

Each DCIM-MM pillar is assessed using a structured qualitative scoring rubric to ensure construct consistency across Member States. Indicators are drawn from publicly available institutional sources, including Eurostat energy statistics (Eurostat, 2024; 2025), the ENTSO-E Transparency Platform (ENTSO-E, 2024), national transmission system operator portals, National Energy and Climate Plans, and the European Commission Open Data Maturity Report (European Commission, 2024). Multi-source triangulation enhances internal validity and reduces single-source bias, consistent with best practices in data governance and transparency research.

Each pillar is scored on a standardized three-level maturity scale (low, moderate, high) based on documented evidence. The four pillars: accuracy, timeliness, coverage, and accessibility are weighted equally (25% each) to preserve theoretical neutrality and reflect the interdependence of core knowledge functions under the Knowledge-Based View. The aggregated composite index ranges from 0 to 100 and represents national energy knowledge capability within a harmonized EU regulatory environment. Uniform scoring criteria and consistent temporal reference points strengthen cross-country comparability.

Importantly, the DCIM-MM measures institutionalized knowledge governance capacity rather than technological sophistication alone. This distinction clarifies that the model captures capability maturity, not infrastructure presence. Although qualitative evaluation involves structured judgment, transparent criteria and documented decision rules enhance replicability. The composite scores are examined in relation to renewable energy share and electricity sector greenhouse gas intensity (see Table 1), providing a theoretically grounded proxy for assessing how public digital infrastructure shapes sustainability performance. A detailed replication protocol is provided in Supplementary Appendix A to ensure transparency and methodological robustness.

4. Results

The application of the Data-Centric Information Management Maturity Model (DCIM-MM) across the 27 EU Member States reveals substantial heterogeneity in national energy information management capabilities (Table 1). The composite scores reflect the institutional quality of energy data ecosystems as of early 2026, incorporating recent improvements in NECP reporting, TSO platform modernization, and API expansion. Despite regulatory harmonization within the Energy Union, digital maturity varies significantly, reinforcing the Resource-Based View: institutional convergence does not eliminate resource heterogeneity (Barney, 1991). This divergence aligns with broader evidence of uneven digitalization and transition pathways across Europe (Kochanek, 2021; Jonek-Kowalska, 2024).

Table 1. DCIM-MM scores and energy KPIs for 27 EU economies (Eurostat, 2025; EEA, 2024; National TSO/Market Operator Data)

Rank	Country	DCIM Score / IM Maturity	Cluster	Renewables Share (2023/24)	GHG Intensity (gCO ₂ e/kWh)	Key IM Strength	Key IM Gap
1	Denmark	98	High	79.70%	94	World-class API (Energi Data Service)	-
2	Sweden	97.2	High	88.10%	8	Real-time hydro/wind data integration	-
3	Finland	94.5	High	54.30%	40	Datahub centralized retail data	-
4	Netherlands	92.4	High	50.50%	263	High open data maturity, TenneT API	-
5	Estonia	91.5	High	41.00%	610	Estfeed API (Openness)	Carbon Legacy
6	Portugal	90	High	65.80%	119	REN DataHub visualisations & API	Sectoral efficiency data
7	Lithuania	88.7	High	31.90%	29	Real-time Flows	Domestic Gen
8	France	88	High	22.90%	50	RTE eCO ₂ mix app, nuclear transparency	Renewables granularity
9	Spain	87.5	High	59.70%	158	EsiOS API, real-time pricing data	Distributed generation data
10	Latvia	85.4	High	43.20%	67	Market Transparency	Interconnection
11	Germany	85	High	54.10%	329	SMARD platform coverage	Decentralized data aggregation
12	Luxembourg	84.1	High	11.70%	37	Leneda Platform (API)	Domestic RES
13	Austria	84	High	90.10%	85	APG transparency, hydro modeling	Complex federal reporting
14	Belgium	82.5	High	14.30%	145	Elia Open Data, offshore wind data	Heating/Cooling data gaps
15	Slovenia	78.6	Medium	25.10%	176	Open Data (OPSI)	Solar Granularity
16	Ireland	78	Medium	16.30%	260	SEAI "First Look" reports	Micro-generation visibility
17	Italy	75.5	Medium	20.10%	225	Terna transparency	API access barriers
18	Czechia	72.4	Medium	17.90%	440	OTE binary API transition	SME accessibility
19	Slovakia	70	Medium	24.90%	84	OKTE market data & EDC	Energy poverty data
20	Greece	68	Medium	51.20%	258	IPTO Analytics app improving	Historical data consistency

21	Hungary	65	Medium	24.10%	154	MEKH reports, regional integration	Public API availability
22	Croatia	62	Medium	58.00%	134	HOPS/CROPEX reporting	Weather-dependent forecasting
23	Romania	60.5	Low	25.30%	234	Transelectrica basic transparency	API usability (DAMAS)
24	Poland	58.3	Low	18.90%	614	PSE data available, CSIRE delayed	Significant reporting lags
25	Cyprus	55.2	Low	19.40%	585	-	Auto-Curtailment
26	Bulgaria	55	Low	22.10%	281	ESO operational data	Transparency, digitization
27	Malta	52.8	Low	13-17%	342	-	Data Granularity

It is important to distinguish digital maturity from structural energy endowment. For example, Estonia ranks among the top five in DCIM maturity due to advanced API accessibility and structured data governance, yet exhibits high carbon intensity reflecting legacy oil shale dependence. This case illustrates that institutionalized knowledge capability does not automatically eliminate historical fossil lock-in. Rather, digital maturity enhances transition capacity by improving coordination, transparency, and adaptive policy responsiveness. Similar structural effects are observable in Poland (coal dependence) and France (low carbon intensity linked to nuclear dominance). The DCIM-MM therefore captures governance capability, not energy resource structure.

Three capability tiers emerge. High-maturity systems (score ≥ 80) including Denmark, Sweden, Finland, Netherlands, Portugal, France, Spain, Germany, Austria, and Belgium operate interoperable, near real-time platforms with granular renewable reporting and structured validation. From a Knowledge-Based View perspective, these countries demonstrate advanced knowledge creation, integration, and diffusion capabilities. Many combine strong digital capacity with high renewable penetration and relatively low carbon intensity, suggesting a structured capability–performance alignment.

Medium-maturity countries (score 60–79) exhibit partial transparency and API functionality but fragmented knowledge diffusion. Low-maturity systems (score < 60) show reporting lags and limited machine-readability, often coinciding with higher fossil dependence and carbon intensity. While causality is not inferred, the clustering pattern supports the RBV–KBV proposition that institutionalized knowledge capability shapes sustainable energy performance. Beyond ranking differences, a structural pattern emerges. Figure 3 presents the distribution of DCIM scores across Member States.

High-maturity systems consistently exhibit higher renewable penetration, lower GHG intensity, and stronger crisis responsiveness. Digital transparency facilitates efficient renewable integration and adaptive policy responses (Pata, U., et al., 2022; IEA, 2023). Platforms such as Denmark’s Energi Data Service and Germany’s SMARD enabled timely coordination during shocks, whereas lower-maturity systems faced greater institutional friction and slower interventions (Dokupilová, 2024; IEA, 2022; Ruggiero et al., 2014). These

patterns illustrate how knowledge infrastructure conditions adaptive capacity within energy systems (Figure 4).

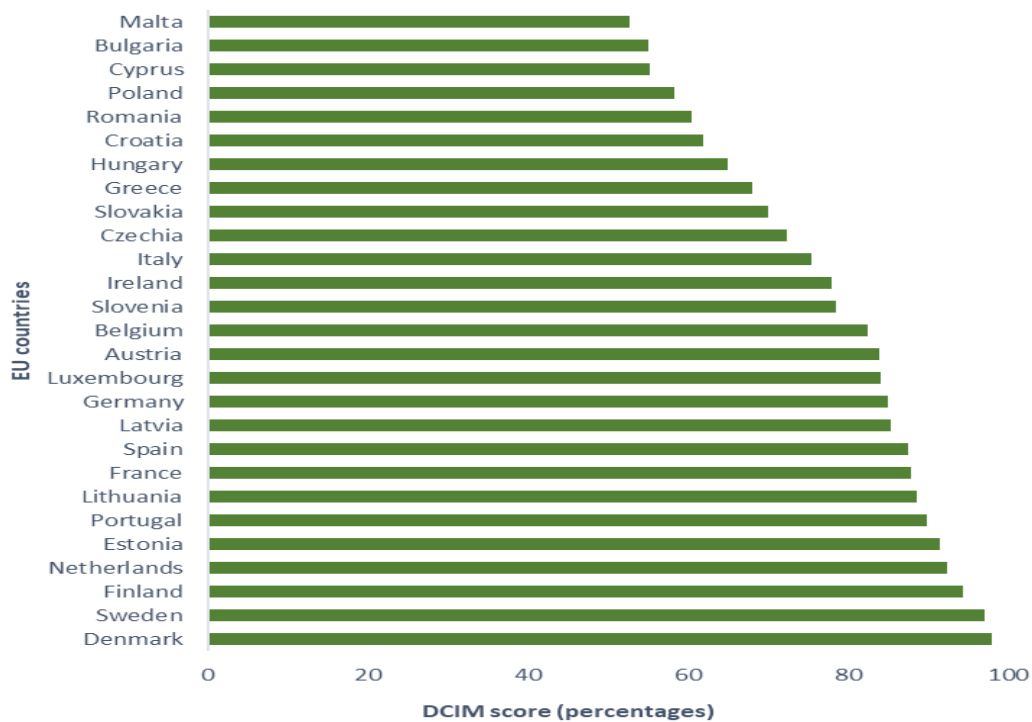


Figure 3. DCIM score (Index, 0–100)

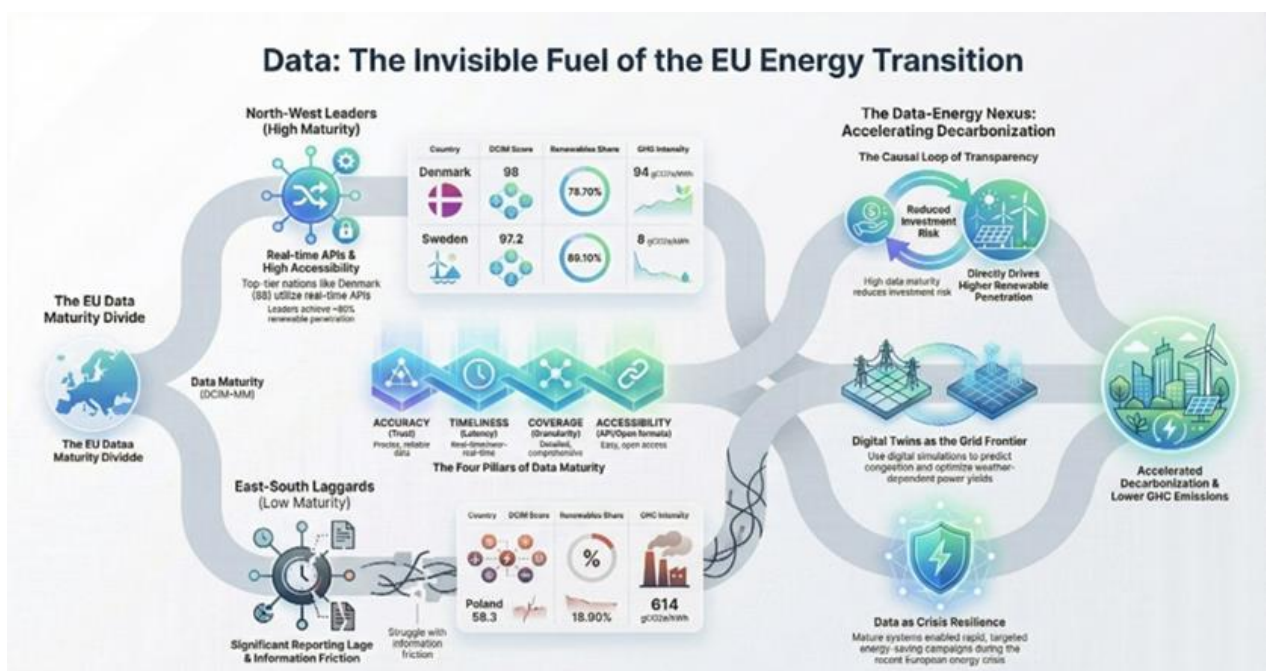


Figure 4. Data energy nexus.

This Data energy nexus loop (Fig 4) suggests that robust data governance acts as a strategic enabler of national energy transitions. The study does not claim deterministic causality but identifies a structured capability performance alignment consistent with RBV and KBV theory. Advanced data systems reduce information asymmetry, lower perceived investment risk, and facilitate renewable deployment. Greater renewable integration

improves grid flexibility and reduces carbon intensity, increasing demand for transparent, high-quality data.

Three conclusions emerge. First, digital energy governance maturity varies significantly across EU Member States despite regulatory harmonization. Second, high DCIM-MM scores reflect institutionalized knowledge infrastructures characterized by reliability, responsiveness, comprehensiveness, and diffusion capacity. Third, stronger knowledge capability systematically aligns with higher renewable penetration and lower emissions. Digital public infrastructure thus functions as a foundational strategic resource shaping sustainable energy performance.

5. Discussion

The findings reinforce the central proposition that national energy data ecosystems function as strategic knowledge capabilities shaping sustainable energy performance. Consistent with the Resource-Based View (Barney, 1991), substantial heterogeneity persists across EU Member States despite regulatory harmonization. Digital energy infrastructure is therefore not a uniform administrative feature but a heterogeneous strategic public resource embedded within institutional contexts. This extends RBV logic beyond the firm and aligns with research on digital platforms as coordination mechanisms in data-driven environments (Cennamo & Santalo, 2013; van Dijck et al., 2018).

Extending the Knowledge-Based View (Grant, 1996), the results show that performance differences relate not to the mere presence of digital systems but to their maturity as institutionalized knowledge infrastructures. Countries with high DCIM-MM scores demonstrate stronger reliability (accuracy), responsiveness (timeliness), comprehensiveness (coverage), and diffusion (accessibility). These properties enhance transparency, coordination, and regulatory responsiveness critical features in renewable-heavy electricity systems. The observed alignment between higher DCIM scores, stronger renewable penetration, and lower carbon intensity supports a structured capability performance relationship grounded in strategic resource theory rather than deterministic causality.

A central implication is the existence of a structural digital divide within the Energy Union. High-maturity systems benefit from lower uncertainty premiums, faster renewable integration, greater consumer empowerment, and stronger oversight. Lower-maturity systems face higher coordination costs, slower renewable scaling, and weaker transparency. This divide is institutional rather than purely technological and mirrors broader governance gaps identified in sustainability transition research (United Nations, 2023; World Economic Forum, 2024). Without interoperable standards and harmonized data architectures, cross-border electricity integration remains constrained. The Energy Union's success thus depends not only on physical interconnection but also on convergence in digital knowledge governance.

The study advances theory in three ways. First, it extends RBV to national digital public infrastructure as a strategic resource influencing sustainability outcomes. Second, it deepens KBV by framing energy data ecosystems as institutionalized public knowledge capabilities.

Third, through the DCIM-MM, it demonstrates how maturity models can operationalize cross-national capability heterogeneity in a structured manner.

Policy implications follow. Digital energy governance should be treated as strategic infrastructure. Priorities include standardized EU-wide APIs, harmonized metadata, interoperable reporting formats, and accelerated smart meter integration. Digital transparency and analytics enhance grid flexibility and optimization (Sleiti et al., 2022; Li et al., 2025). Embedding digital maturity benchmarks within EU funding mechanisms could accelerate convergence.

Limitations include the cross-sectional design, potential reverse causality, qualitative scoring subjectivity, and structural energy endowment differences (Newell et al., 1999; IEA, 2024). Future research should employ longitudinal designs, instrumental variables, and quantitative validation to further examine how institutionalized knowledge infrastructure shapes sustainable energy transitions.

6. Conclusions

This study set out to examine whether national energy data ecosystem maturity functions as a strategic knowledge capability influencing sustainable energy performance across the European Union. Grounded in the Resource-Based View and the Knowledge-Based View, the analysis conceptualized digital energy infrastructure not as a technical accessory, but as a strategic public resource embedded within institutional governance systems.

The findings demonstrate substantial heterogeneity in energy data maturity across EU Member States. Despite regulatory harmonization, digital knowledge infrastructures remain unevenly developed. Countries with higher DCIM-MM scores consistently exhibit stronger renewable energy penetration and lower electricity-sector greenhouse gas intensity. While structural energy endowments and policy design remain important determinants, the results suggest that knowledge infrastructure quality constitutes an independent and structurally relevant dimension of transition capacity.

From a Resource-Based View perspective, national digital energy systems represent heterogeneous strategic resources. From a Knowledge-Based View perspective, their maturity determines the reliability, responsiveness, breadth, and diffusion of institutional energy knowledge. The DCIM-MM operationalizes this theoretical construct and provides a structured empirical lens through which digital governance capacity can be evaluated. By bridging strategic management theory and energy policy analysis, this study advances understanding of how digital public infrastructure shapes sustainability outcomes. It moves beyond descriptive benchmarking by offering a theoretically grounded explanation of why differences in information management maturity matter.

The broader implication is clear: the energy transition is not solely a transformation of physical infrastructure, but also of institutional knowledge systems. Strengthening national energy data ecosystems enhances transparency, reduces uncertainty, and supports coordinated renewable integration. In this sense, digital knowledge governance constitutes a foundational pillar of Europe's climate neutrality strategy.

Future progress toward a fully integrated Energy Union will depend not only on grid interconnection and renewable capacity expansion, but also on convergence in digital maturity. Institutionalized knowledge capability is therefore not peripheral it is central to the long-term resilience and sustainability of European energy systems.

Acknowledgments: This work was supported by the internal project “SPEV 2026, University of Hradec Králové, Faculty of Informatics and Management, Czech Republic

Conflict of interest: none

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Appendix A

The Data-Centric Information Management Maturity Model (DCIM-MM) scores are calculated using a structured quantitative framework. The total score (ranging from 0 to 100) is the sum of four equally weighted pillars, each worth a maximum of 25 points. The calculation methodology follows this step-by-step process: Each country is evaluated against specific criteria within four pillars. Points are awarded based on the presence, quality, and performance of data attributes found in Eurostat datasets, ENTSO-E platforms, and national energy portals.

Pillar 1: Accuracy (Verification & Consistency) - Max 25 Points

- Series Completeness (10 pts): Calculated based on the continuity of historical data series (Eurostat *nrg_bal_s* and *nrg_ind_ren*) from 2005 to 2024.
 - Scoring: 20years Available = 10 pts. If a country has breaks in the time series, points are deducted proportionally.
- Cross-Validation (10 pts): Measures consistency between national aggregated data (e.g., TSO reports) and Eurostat figures.
 - Scoring: < 1% discrepancy = 10 pts; 1-5% discrepancy = 5 pts; > 5% discrepancy = 0 pts.
- Outlier Protocols (5 pts): Binary score (0 or 5) for the existence of public documentation regarding outlier detection and data correction methodologies.

Pillar 2: Timeliness (Decision Relevance) - Max 25 Points

- Data Availability (10 pts): Availability of definitive annual data for T-1 (previous year) and provisional data for the current year.
 - Scoring: 5 pts for T-1 definitive, 5 pts for current year provisional.
- Publication Lag (10 pts): Based on the latency of monthly reporting.
 - Scoring: Real-time/Day-ahead = 10 pts; Monthly (lag < 30 days) = 7 pts; Monthly (lag < 90 days) = 3 pts; Lag > 90 days = 0 pts.
- Provisional Flags (5 pts): Binary score (0 or 5) for the clear labeling of "provisional" vs. "final" data to prevent policy errors based on preliminary stats.

Pillar 3: Coverage (Holistic Assessment) - Max 25 Points

- Source Granularity (10 pts): Depth of renewable reporting.
 - Scoring: 2 pts for each granular category reported (e.g., Onshore Wind, Offshore Wind, Solar PV, Solar Thermal, Biogas). Max 10.
- Sectoral Breakdown (10 pts): Availability of consumption data across 4 key sectors (Industry, Transport, Households, Services).
 - Scoring: 2.5 pts per sector fully reported.
- Cross-Domain Linkages (5 pts): Integration of energy data with socio-economic indicators (e.g., energy poverty, prices).
 - Scoring: Partial integration = 2.5 pts; Full integration = 5 pts.

Pillar 4: Accessibility (Stakeholder Reach) - Max 25 Points

- Open Formats (10 pts): Availability of machine-readable files (CSV, JSON, XML).
 - Scoring: Non-proprietary formats = 10 pts; PDF/Static only = 0 pts.
- API Availability (10 pts): Functional public Application Programming Interface (API) for automated retrieval.
 - Scoring: Full RESTful API = 10 pts; Basic/Limited API = 5 pts; No API = 0 pts.
- Documentation (5 pts): Quality of English-language metadata and user guides.
 - Scoring: Comprehensive = 5 pts; Basic = 2.5 pts; None/Native only = 0 pts.

When Gaze Isn't Enough: A Systematic Review of Triangulated Eye-Tracking in Desktop E-Commerce

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Abstract: Desktop e-commerce research increasingly uses eye-tracking (ET), yet interpretation remains fragile when gaze is treated as a stand-alone indicator. This focused review integrates 24 ET-primary studies with explicit triangulation (ET plus ≥ 1 independent modality) and clarifies what eye-tracking can and cannot conclude in online shopping. Three consistent insights emerge. First, attention is strongly shaped by task intent and information architecture. Second, attention and behaviour often decouple: visual salience and recommender cues can attract gaze without reliably changing choices. Third, trust-relevant and sustainability cues more frequently show convergence between gaze allocation and subsequent judgments. At the same time, methodological mapping reveals uneven reporting of key ET parameters (sampling rate and data-quality handling), reducing comparability and cumulative inference. We argue that triangulation is essential for actionable UX conclusions and outline concrete priorities for future work: standardised ET reporting and explicit, multimodal workload measurement embedded in realistic shopping tasks.

Keywords: eye-tracking; triangulation; desktop e-commerce; online shopping; UX/usability; systematic review

JEL Classification: C91; M31; L81

1. Introduction

Eye-tracking (ET) provides granular evidence on visual attention during online shopping tasks, showing how users allocate gaze across product information, navigation elements, trust cues, and checkout interfaces. It complements conventional usability and experience measures by revealing attention patterns that are difficult to infer from self-report alone. ET studies in digital commerce vary in task realism, reporting completeness (e.g., device and sampling rate), and outcome operationalisation. They also differ in whether ET is paired with independent measures (e.g., questionnaires, interviews/think-aloud, psychophysiology, facial coding, or behavioural logs), which complicates evidence accumulation and comparability. We conducted a PRISMA-informed focused review with strict eligibility criteria requiring a desktop e-commerce website context, ET as the primary method, and triangulation—i.e., ET combined with at least one independent measure to strengthen interpretation beyond gaze alone. We report methodological mapping of included studies and a triangulation-informed thematic synthesis.

Recent syntheses have summarised eye-tracking evidence in (i) online shopping visual attention and interface factors (Li et al., 2024), (ii) eye-tracking-based usability/UX

evaluation across software systems (Santiago-Cruz et al., 2023; Novák et al., 2024), and (iii) design evaluation contexts where ET is increasingly combined with complementary metrics (Guo et al., 2024). Yet these reviews typically aggregate across platforms (desktop/mobile), contexts, and single-method ET designs. By restricting to desktop e-commerce tasks, requiring ET as the primary method, and enforcing explicit triangulation with ≥ 1 independent modality, our review provides a higher-validity synthesis of how attention relates to usability, trust cues, recommendation use, and user experience in online shopping.

Review questions. The thematic synthesis addressed four questions aligned with the reported themes:

We addressed four research questions: RQ1: How do task goals and information architecture shape attention allocation on e-commerce pages?; RQ2: How do trust and persuasion cues influence attention and downstream judgments/intentions?; RQ3: How do recommendation aids and decision supports affect attention and behavioural outcomes (e.g., choice/clicks)?; RQ4: How does triangulation improve inference about usability, affect, and decision processes beyond eye-tracking alone?

In addition, we provide a methodological mapping of study designs and reporting practices to contextualise the robustness of the triangulated evidence.

2. Methodology

This review follows PRISMA 2020 reporting principles (Page et al., 2021a/2021b). Methods and coding rules were defined a priori and recorded in an archived screening log.

2.1. Information Sources and Search Strategy

We searched Web of Science (WoS) as the sole source database (WoS-only backbone). Search documentation (full query strings and filters) was recorded by the authors and is available upon reasonable request. We adopted a WoS-only backbone to ensure a consistent indexing scope and a replicable single-export workflow for conference reporting.

The search was last executed on 6 January 2026. The WoS timespan covered 2015–2025. Note: Web of Science indexes Early Access/online-first items; records retrieved as Early Access within the search window and subsequently published with a 2025 year-of-record were included and treated as standard records in the PRISMA flow and eligibility assessment (counted by retrieval and full-text screening status).

Representative WoS query (Topic search):

```
TS=(((("eye track*" OR eyetrack* OR "gaze track*" OR "eye movement*" OR fixation* OR saccad* OR scanpath* OR "pupil dilat*" OR "pupil diameter" OR pupillometr*)) AND (("e-commerce" OR ecommerce OR "online shop*" OR "online shopping" OR "online retail*" OR "digital retail*" OR "online purchas*" OR "product page*" OR "product listing" OR "checkout" OR "shopping cart" OR "online marketplace")) AND (("user experience" OR UX OR usability OR "user satisfaction" OR "customer experience" OR "purchase intention" OR "recommendation intention" OR conversion OR "decision making"))))
```

2.2. Eligibility Criteria

We included studies only if (i) tasks were performed on desktop e-commerce websites (web store or product page), (ii) gaze-based eye-tracking was the primary method driving the main inferences, and (iii) ET was combined with at least one explicitly independent method (e.g., questionnaire/self-report, interview/think-aloud/retrospective think-aloud, psychophysiology, facial coding, or behavioural logs). We excluded live-streaming commerce, pure banner/ads environments, and non-shopping web contexts. Single forced-choice/customer choice outcomes alone were not treated as triangulation.

All included tasks were performed on desktop web pages (desktop/laptop display) within an e-commerce website context; studies using remote/webcam/ETG equipment were included only when the shopping interaction remained a desktop website task.

2.3. Selection Process

Records were screened at title/abstract level, followed by full-text retrieval. Non-retrieved reports were documented and were never counted as included. Full texts retrieved were assessed for eligibility, with full-text exclusion reasons coded and reported in the PRISMA flow diagram. Screening was conducted by a single reviewer (JP) at both title/abstract and full-text stages; no automation tools were used. Duplicates: no duplicate records were identified (WoS-only single export).

2.4. Data Charting and Coding

We charted sample, tasks/stimuli, ET device model, sampling rate (Hz), calibration reporting, and AOI (Areas of Interest) definition/use. We also coded ET data-quality handling (e.g., track loss criteria and exclusions) and triangulation modalities. For methodological mapping, items were coded as “reported” only when explicitly stated in text/tables; otherwise, we coded Not reported. Data charting and coding were performed by a single reviewer (JP) using a predefined codebook. Where reported, we coded ET metrics using consistent definitions (e.g., fixation count as the number of fixations within an AOI and fixation duration/time as the duration of fixations in milliseconds, ms, within an AOI). Time-based measures are reported in ms and sampling in Hz; pixel/luminance values are noted only when explicitly reported by primary studies.

2.5. Synthesis Approach

We performed descriptive methodological mapping and a triangulation-informed thematic synthesis across included studies.

2.6. Quality Appraisal

Methodological quality was appraised using the Mixed Methods Appraisal Tool (MMAT) version 2018 (Hong et al., 2018). Item-level judgments were recorded by the authors and are available upon reasonable request.

Materials availability: Full search strings, screening log, extraction sheets, and MMAT 2018 item-level appraisal matrix are archived by the authors and are available upon reasonable request.

Protocol and registration: This review was not registered and no publicly accessible a priori protocol was prepared.

Reporting bias and certainty assessment: We did not formally assess reporting bias or certainty of evidence (e.g., GRADE), given the descriptive mapping focus and the heterogeneity of designs and outcomes.

3. Results

3.1. Study Selection

A total of 124 records were screened, and 30 were excluded at title/abstract stage. Ninety-four full-text reports were sought for retrieval; 21 were not retrieved. Seventy-three reports were assessed for eligibility, and 49 were excluded at full-text stage (not desktop e-commerce website, n=22; not triangulation, n=16; eye-tracking not primary method, n=6; not e-commerce/online shopping context, n=3; not eye-tracking/gaze-based measurement, n=1; not UX/marketing outcome, n=1). Twenty-four studies were included in the review. The study selection process is summarised in Figure 1.

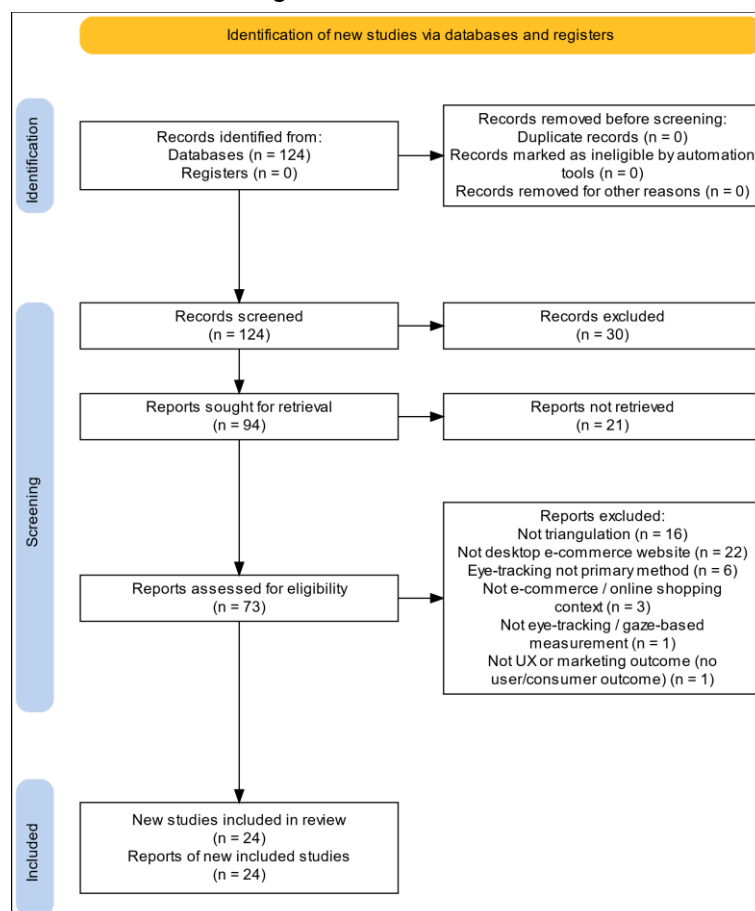


Figure 1. PRISMA flow diagram for the focused review (WoS-only backbone; included studies n=24).

Note: Flow diagram was generated using the PRISMA 2020 tool (Haddaway et al., 2022). The synthesis is reported in four themes corresponding to RQ1-RQ4.

3.2. Study Characteristics and Methodological Mapping

Table 1 summarises the included studies and their core methodological characteristics. Abbreviations: SR=self-report; BEH=behavioural measures/logs; PHYS=psychophysiology; QUAL=qualitative elicitation; NR=not reported.

Across the 24 included studies, reporting completeness varied by key methodological items. ET device model was explicitly reported in 23/24 (95.8%), while sampling rate (Hz) was reported in 18/24 (75.0%). Calibration procedures were described in 16/24 (66.7%). AOI use was reported in 21/24 (87.5%), and AOI definition/specification in 22/24 (91.7%). Handling of ET data quality (e.g., track loss criteria, exclusions, or preprocessing rules) was reported in 16/24 (66.7%). AOI use was coded as reported only when AOIs were explicitly defined in text/tables; papers showing only heatmaps without AOI definitions were coded as Not reported.

Triangulation modalities were heterogeneous and frequently combined (modalities were not mutually exclusive). Self-report measures were used in 23/24 (95.8%), behavioural logs/performance measures in 15/24 (62.5%), psychophysiology in 11/24 (45.8%), and qualitative elicitation (interview/think-aloud/RET) in 4/24 (16.7%). In terms of breadth, studies used 1 modality in 5/24 (20.8%), 2 modalities in 9/24 (37.5%), 3 modalities in 10/24 (41.7%).

Across the 24 included studies, participant sampling was predominantly convenience-based (often students or online panels), and reporting of participant characteristics and recruitment procedures was heterogeneous (Table 1). Primary outcome foci clustered around purchase/decision outcomes, UX/usability, trust/credibility and sustainability-related judgments, and recommendation/personalisation interfaces (Section 3.3). Quality appraisal was recorded as item-level MMAT judgments; consistent with MMAT guidance, we did not compute or interpret an overall MMAT score.

Table 1. Compact characteristics table for included studies (n=24).

Study	N	Device	Hz	Triangulation (modalities)	Outcome
Menzel (2022)	18	Gazepoint GP3 HD	150	SR+BEH+PHYS	Visual attention + Trust
Naeini (2023)	30	Tobii X2-30	30	SR+BEH+PHYS	Website usability / UX
Luan (2016)	ET=40; Survey=140	Tobii T120	120	SR+BEH	Online review search behavior / visual attention to review types
Guo (2015)	30	SMI infrared (Experiment Center 2)	Not reported	SR+BEH+PHYS	Emotional experience during online shopping
Chiang (2022)	80	Not reported	60	SR+BEH+PHYS	Age differences in visual attention
Najafabadiha (2025)	99	SMI iView RED 4	Not reported	SR	Decision/purchase
Ziemba (2017)	20	Not reported (eye-tracking device used with GazePoint software).	Not reported	SR+BEH+PHYS	UX/usability

Sulikowski (2022b)	30	Tobii Pro X3-120	120	SR+BEH+PHYS	Customer attention / UX: attention to recommendation area and product
Gorton (2024)	44	GazePoint (panel) on 22-inch monitor	60	SR+QUAL	Visual attention to marketplace “market signals” and purchase decision
Fu (2020)	141	SMI iView ETG type sensor	Not reported	PHYS	Online review search behaviour / decision-making
Deng (2021)	40	Tobii Pro X3-120	120	SR+BEH	Information acquisition
Wang (2019)	30	SMI RED500 (desktop)	50/60	SR+QUAL	Conformity / social proof effect in online shopping
Yang (2015)	108	EyeLink 1000 Desktop Mount (SR Research)	1000	SR	Purchase intention
AlSalem (2023)	10	RealEye v10	Not reported	SR+BEH	UX/usability
Koutroumpas (2025)	20	Gazepoint GP3 HD	60	SR	UX/engagement in recommender systems
Boardman (2023)	50	Tobii TX 300	300	SR+BEH+QUAL	Age-related differences in online fashion shopping behaviour and website
Weng (2019)	32	Not reported	Not reported	SR	Emotion
Sulikowski (2022a)	30	Tobii Pro X3	120	SR+BEH+PHYS	Attention / user perception / choice behavior
Lambillotte (2022)	58	Tobii X2-60 (Tobii Studio v3)	60	SR+BEH	Decision/purchase
Karmarkar (2021)	58	Tobii X2-60 (Tobii Studio v3)	60	SR+BEH	Decision/purchase
Shi (2017)	67 (of 76)	Tobii T60 (three devices)	60	SR+BEH+PHYS	Attention to recommendations
Chocarro (2022)	S1=58; S2=66	Study 1: EyeTribe Tracker	Study 1: 30; Study 2: 60.	SR+BEH+PHYS	Visual attention to product images vs name/price across shopping tasks and
Palcu (2017)	137	SMI RED 500	120	SR+PHYS	Visual attention + product evaluation / purchase intention
Boardman (2022)	52	Tobii TX300	300	SR+PHYS+QUAL	Attention, cognitive/affective responses and behavioural outcomes during

3.3. Triangulation-Focused Thematic Synthesis

We synthesised evidence across the focused cohort by grouping studies according to (i) where attention was directed on desktop e-commerce interfaces, (ii) which interface cues and decision supports were tested, and (iii) how triangulated modalities supported (or challenged) inferences from gaze behaviour. The synthesis is reported in four themes corresponding to RQ1–RQ4.

Across studies, gaze allocation was strongly shaped by task demands (browsing vs. searching; goal-directed vs. exploratory) and by the information architecture of product or listing pages. Product images typically captured attention early, but downstream attention

distribution varied across shopping stages and product categories. Attribute-oriented displays tended to promote cross-product comparisons and faster task completion in browsing contexts, whereas effects were weaker in explicit search tasks. Review-related information also showed differentiated attention patterns depending on the product type and the consumer's decision goal, suggesting that "what is fixated" is contingent on the consumer's information need rather than being purely stimulus-driven (Boardman & McCormick, 2022; Chocarro et al., 2022; Deng & Gu, 2021; Luan et al., 2016).

Several studies treated non-product elements as attention shapers and potential confounds. Marketplace cues such as price and photos were used as low-cost signals in low-involvement decision contexts, while higher-involvement choices relied more on credibility-relevant signals. Banner advertising with human faces was associated with greater attention to the banner area, and gaze direction was associated with both attention allocation and product judgements. Background features also modulated pupil-size-based indices of affective response, with stronger effects reported for experience-type products. Together, these findings reinforce that attention in e-commerce is jointly determined by interface structure, cue ecology, and goal state (Gorton et al., 2024; Palcu et al., 2017; Weng & Ye, 2019; Yang, 2015; Fu et al., 2020).

A smaller cluster of studies examined links between visual attention and trust- or persuasion-relevant constructs. Embedding regional cues in the interface was associated with greater visual attention and higher perceived regional presence, which was in turn related to trusting belief and intention. Social proof cues (e.g., high sales volumes) attracted longer fixations and were associated with stronger conformity tendencies, with qualitative accounts suggesting that such cues may act as decision heuristics. Sustainability-oriented interventions (e.g., environmental educational messages shown before browsing) were associated with greater attention to eco-friendly information and with shifts toward greener preferences, alongside reduced price sensitivity. In parallel, neuroscience-based work reported age-related differences in eye-movement patterns and complementary psychophysiological responses during sustainable-product browsing. Overall, these studies suggest that persuasive cues can operate via attentional capture and downstream interpretation, and that user characteristics and involvement may moderate observed associations (Menzel et al., 2022; Wang et al., 2019; Najafabadiha et al., 2025; Chiang et al., 2022; Gorton et al., 2024; Yang, 2015).

Decision-support elements-particularly recommendations, personalisation widgets, and visual highlighting-were frequently evaluated with triangulated designs. Recommendation presentation characteristics were associated with differences in gaze distribution and engagement: recommendation types differed in whether viewing was text-focused and predictable versus more distributed and exploratory, and blink-based indicators were interpreted as reflecting arousal or disengagement for low-relevance items. Source cues also mattered: recommendations attributed to consumer reviews attracted greater interest/attention than those attributed to expert reviews, whereas earlier presentation was not consistently associated with higher attention than later presentation. Visual highlighting showed a recurring dissociation between attention capture and choice: highly salient

animation could be associated with longer fixation time but lower selection likelihood, while lower-intensity highlighting (and aesthetic store design) tended to coincide with both higher attention and greater behavioural engagement in recommendation areas. (Koutroumpas et al., 2025; Shi et al., 2017; Sulikowski et al., 2022a; Sulikowski et al., 2022b).

Personalisation via display-only products showed another form of attention-outcome dissociation. Across experiments manipulating category congruence, mismatched display items reliably attracted more attention than matched items; however, matched displays were associated with higher purchase likelihood for the target product. In these studies, target fixation time often did not differ by condition, implying that purchase differences were not simply mediated by higher visual attention to the target AOI. This pattern suggests that some decision-support interventions may operate through interpretation or affective appraisal rather than through straightforward attentional amplification alone (Karmarkar et al., 2021; Lambillotte et al., 2022).

Triangulated measurement designs were used to strengthen inference about usability and affective experience, and to clarify when ET adds value beyond self-report. Several studies reported systematic associations between ET metrics (e.g., fixation- and saccade-based indicators, scan path characteristics, pupil size) and standard usability questionnaires, and indicated that user experience moderated visual search efficiency. Mixed-method evaluation frameworks combined expert heuristic review, usability testing, and ET to identify complementary classes of usability issues-ET being particularly useful for diagnosing inefficient attention paths and problematic element placement. Survey+ET approaches similarly produced website rankings that differed from survey-only rankings, supporting the incremental diagnostic value of gaze measures. (Naeini et al., 2023; AlSalem & AlShamari, 2023; Ziemba et al., 2017).

Cognitive load and mental workload were only indirectly addressed in this focused cohort, most often via proxy indicators (e.g., pupil size/dilation or blink activity) or via affective/effort-related self-report instruments rather than through standardised workload paradigms. This points to a research gap: future triangulated studies could more explicitly operationalise cognitive load (e.g., validated workload scales and/or complementary psychophysiology) and report ET parameters consistently to support cross-study comparability and mechanism-level interpretation (Naeini et al., 2023; Guo et al., 2015; Deng & Gu, 2021; Koutroumpas et al., 2025; Weng & Ye, 2019; Shi et al., 2017).

Affective responses were most convincingly characterised when subjective ratings were paired with ET and physiological measures. In a multimodal emotional-experience study, differences between websites were reflected primarily in subjective ratings and eye-movement indicators, whereas physiological responses differentiated shopping from rest but did not clearly discriminate between websites-highlighting both the potential and the limits of physiological convergence. Related work linked positive emotion and approach tendency to attention patterns under different task modes, and demonstrated that interface aesthetics/background features can influence pupil-size-based indices of emotional response. Finally, age-related differences in attention and behaviour were observed in fashion and sustainable shopping contexts, with qualitative data emphasising specific usability barriers

and design preferences relevant to inclusive desktop e-commerce. (Guo et al., 2015; Deng & Gu, 2021; Weng & Ye, 2019; Boardman & McCormick, 2022; Boardman & McCormick, 2023; Chiang et al., 2022).

4. Discussion

This focused review combines focused eligibility criteria (desktop e-commerce tasks, ET-primary designs, and explicit triangulation—ET plus ≥ 1 independent modality) with transparent PRISMA reporting and item-level quality appraisal. The methodological mapping highlights recurring reporting gaps (e.g., ET sampling rate) that constrain comparability, while the thematic synthesis shows how triangulated evidence links gaze behaviour to usability, affect, and consumer outcomes in desktop e-commerce.

Most studies combined ET with self-report (23/24) and behavioural measures (15/24). Psychophysiology (11/24) and qualitative elicitation (4/24) were less common. Most studies used multiple independent modalities (1: 5/24; 2: 9/24; 3: 10/24), which supports convergent interpretation; however, inference still depends on modality validity and reporting quality.

Implications for practice. The triangulated evidence suggests three design-relevant takeaways. First, match information architecture to shopping intent (search vs browse): support goal-directed search with scannable attributes and filters, and support browsing with clear visual hierarchy and curated comparisons. Second, treat trust/sustainability cues and recommendations as attention drivers, but validate impact with outcomes such as clicks, add-to-cart, or purchase intention (attention $\neq$ choice). Third, use disciplined triangulation and transparent ET reporting (self-report/behaviour/physiology/qualitative elicitation where feasible), including sampling rate (Hz), calibration, AOI definition, and data-quality handling.

Theoretical implications. The recurring attention–behaviour dissociation cautions against treating gaze as a direct proxy for preference or choice. Trust- and sustainability-related cues more often aligned attention with subsequent judgments, consistent with credibility and signaling mechanisms. Overall, triangulation supports stronger mechanism-level inference by separating what users look at from what they decide.

5. Limitations

This focused review used a WoS-only search backbone and therefore may not capture all eligible studies indexed exclusively in other databases. We did not conduct a meta-analysis because study designs, tasks, and outcomes were highly heterogeneous; the intended contribution was methodological mapping and thematic synthesis. In addition, 21 reports were not retrieved and were not counted as included; this constrains completeness and may introduce availability bias and related reporting bias. We applied a strict triangulation definition (ET plus at least one explicitly described independent method), excluding studies where 'triangulation' was operationalised only as single forced-choice/choice labels; this improves construct clarity but narrows scope. At the same time, many included studies collected ET and self-report within the same session, which may be susceptible to demand characteristics and common-method bias; future work should strengthen independence by

incorporating objective behavioural traces (click/log data), temporally separated measures, or multi-sensor designs. Finally, more standardised reporting of ET hardware, sampling rates, calibration, AOI specification, and data-quality handling would improve comparability. Screening and data charting/extraction were performed by a single reviewer, which may increase selection and extraction bias; mitigation included a predefined codebook and an archived screening log.

Future research. None of the included triangulated desktop e-commerce studies directly operationalised cognitive load or mental workload as a primary outcome. This omission aligns with broader eye-tracking usability/UX reviews that call for richer outcome constructs beyond attention metrics and more systematic integration of complementary measures (Santiago-Cruz et al., 2023; Novák et al., 2024; Guo et al., 2024). A pragmatic minimum package for workload-oriented triangulation in shopping tasks could include: (i) a validated workload scale (e.g., NASA-TLX) administered at task level; (ii) an ET/physio proxy sensitive to cognitive effort (e.g., pupil dynamics and blink metrics, with luminance controlled) alongside optional EDA/GSR for arousal; and (iii) an explicit workload manipulation (e.g., time pressure, information density/complexity, or multitasking) embedded in a standardised shopping task. In reporting and interpretation, studies should distinguish cognitive effort (information processing demands) from affective arousal/valence, which can influence pupil and EDA signals. Recent ergonomics work in online shopping has begun to connect webpage complexity and shopping motivation to workload using eye-tracking (Chen, 2025), but multi-modal triangulation remains rare. Standardised reporting of ET parameters (sampling rate, calibration and data-quality handling) and shared analysis conventions would further support cross-study comparability and stronger inference.

6. Conclusions

We synthesised 24 triangulated, ET-primary studies in desktop e-commerce, mapping methodological reporting and distilling four themes on attention, trust cues, recommendations, and usability. Persistent reporting gaps (e.g., sampling rate, calibration, data-quality handling) limit comparability; future work should standardise reporting and explicitly operationalise cognitive workload.

Conflict of interest: none

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The Impact of Visual Attributes on User Engagement in B2B Social Media

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Abstract: This study examines the impact of specific visual attributes on user engagement within the professional social network LinkedIn, focusing on the B2B automotive sector. While B2B marketing increasingly relies on content distribution, empirical evidence regarding granular visual execution remains fragmented. The research analyzes a dataset of 319 posts from major Tier-1 automotive suppliers, collected between June and November 2025. Using a quantitative observational design, four visual dimensions were coded: photography type, presence of people, text overlay, and branding intensity. Non-parametric statistical analysis (Kruskal-Wallis and Mann-Whitney U tests) revealed that "clean" photography and images without text overlays significantly outperform hybrid visual formats containing graphical elements or headlines. Contrary to trends on other social platforms, the presence of human faces and high brand prominence did not yield a statistically significant increase in reactions. The findings suggest that professional audiences exhibit "banner blindness" toward ad-like visual signals. Consequently, B2B marketers are advised to prioritize visual authenticity and minimize text-heavy graphics to enhance user engagement.

Keywords: LinkedIn; B2B marketing; user engagement; visual attributes; automotive industry

JEL Classification: M31; M37; L62

1. Introduction and Literature Review

In recent years, the professional social network LinkedIn has established itself as a key channel for B2B communication, employer branding, and building trust in industrial sectors. Unlike entertainment-oriented platforms, the dominant context here is professional identity, reputation, and business relationships. Consequently, the audience evaluates content through the lens of competence, relevance, and credibility. Within B2B marketing, there has been a long-term shift from "push" advertising to a "pull" approach—creating and distributing content that is practically useful to the audience, thereby fostering relationships and trust (Holliman & Rowley, 2014; Järvinen & Taiminen, 2016).

In this logic, LinkedIn becomes an environment where individual posts compete for limited user attention in a rapidly changing feed. The success of content shifts from merely conveying the correct message to the ability to capture attention and provoke interaction

(reactions, comments, shares). Research in the B2B context indicates that engagement is not just a superficial metric; it correlates with relationship building and perceived content value. For instance, Sundström et al. (2021) suggest that action-oriented messages may generate higher engagement than purely product-oriented or abstract value framing. However, the visual component of posts acts as the primary filter. Users typically process the visual signal first—photography, graphics, composition—before paying attention to the text.

A critical challenge in this domain is the phenomenon of "banner blindness." Benway (1998) empirically demonstrated that users often overlook salient, colorful elements if they perceive them as "ads" rather than useful information. This mechanism is highly relevant to social feeds: if a visual carries "ad-like" signals (e.g., heavy text overlay, artificial composition), it may be subconsciously filtered out as less trustworthy. Conversely, while studies on platforms like Instagram suggest that human faces increase engagement (Bakhshi et al., 2014), the effect in a professional B2B context remains ambiguous.

Despite the growing body of research on B2B social media strategies, empirical evidence specifically focusing on the granularity of visual attributes—such as the type of photography, presence of text in images, or branding intensity—remains fragmented. Existing studies often address general content strategies rather than specific visual execution (Sundström et al., 2021) or focus on the source of the message (Balaji et al., 2023).

The aim of this paper is to identify which specific visual elements of LinkedIn posts are associated with statistically significant differences in user engagement, specifically measured by the number of Reactions. The study analyzes a dataset of 319 posts from the automotive industry, focusing on four visual dimensions: Photography Code (visual type), People Code (presence of people), Text Code (text in image), and Brand Code (branding visibility). The research addresses the following questions: Does the level of reactions differ significantly based on the type of visual used, the presence of people, the inclusion of text in the image, or the intensity of branding? By answering these questions using robust non-parametric statistical methods, this study provides practical implications for optimizing B2B visual communication to avoid "ad-like" signals and maximize authentic engagement.

2. Methodology

The research employs a quantitative observational design based on the analysis of published posts on the professional network LinkedIn. The unit of analysis is a single LinkedIn post. To ensure compliance with LinkedIn's Terms of Service regarding automated data scraping, data collection was conducted manually. The observational period spans six months, from June 2025 to November 2025. The dataset consists of $N = 319$ posts collected from the seven largest Tier-1 automotive suppliers in the European Union. These companies were selected based on revenue rankings for the year 2024, as reported by the automotive consulting firm Berrylls (Top 100 Archive, 2026). For each post, engagement metrics (Reactions, Comments, Shares) were collected, along with a set of manually coded visual attributes. The primary dependent variable for this study is the number of Reactions, as it represents the most immediate and low-cost form of user feedback, suitable for capturing the "first impression" effect of the visual content.

2.1. Operationalization of Variables

The independent variables represent visual attributes categorized into four dimensions, coded on a scale of 0–2:

- Photography Code: 0 = clean photography; 1 = photo with graphics/overlay; 2 = artificial graphics/collage.
- People Code: 0 = no people; 1 = people in background/partial; 2 = specific recognizable people.
- Text in Image Code: 0 = clean image (no text); 1 = headline only; 2 = message/detailed info.
- Brand Code: 0 = no branding; 1 = weak branding; 2 = strong branding.

2.2. Statistical Analysis and Hypotheses Testing

The statistical analysis was performed using Python (libraries pandas, SciPy, matplotlib). First, the assumption of normality for the dependent variable (Reactions) was tested using the Shapiro-Wilk test (Shapiro & Wilk, 1965). The test results indicated a significant deviation from normality ($W = 0.694, p < 0.001$), confirming the "heavy-tail" distribution typical for social media engagement metrics. Consequently, non-parametric methods were selected for hypothesis testing.

To answer the research questions regarding the differences in reactions across visual categories, the Kruskal-Wallis H test was employed as a non-parametric alternative to one-way ANOVA (Kruskal & Wallis, 1952). The effect size for the omnibus test was estimated using epsilon-squared (ϵ^2).

Where the omnibus test indicated statistically significant differences, post-hoc pairwise comparisons were conducted using the Mann-Whitney U test (Mann & Whitney, 1947). To control for the family-wise error rate in multiple comparisons, the Bonferroni correction was applied (Bonferroni, 1936). The effect size for pairwise differences was reported using the rank-biserial correlation coefficient $r = Z/\sqrt{N}$. Finally, Spearman's rank correlation coefficient (ρ) was used to explore relationships between visual variables and among different engagement metrics (Spearman, 1904). The significance level was set at $\alpha = 0.05$.

3. Results

This section presents the results of the inferential analysis examining the differences in user engagement (Reactions) across four visual dimensions: Photography, People, Text in Image, and Brand. Due to the non-normal distribution of the dependent variable, non-parametric tests were applied.

3.1. Visual Attributes Based on Omnibus Testing

First, the Kruskal-Wallis H test was conducted to determine if there are statistically significant differences in the median number of reactions between categories for each visual attribute. The results are summarized in Table 1.

Table 1. Results of Kruskal-Wallis H test for reactions ($df = 2$)

Factor	H-statistic	p-value	ϵ^2 (Effect Size)	Conclusion
Photography Code	21.588	< .001	0.062	Significant
People Code	1.602	.449	~0.000	Not significant
Text in Image Code	17.042	< .001	0.048	Significant
Brand Code	3.880	.144	0.006	Not significant

Note: Significance level $\alpha = 0.05$.

The analysis revealed statistically significant differences for Photography Code ($p < .001$) and Text in Image Code ($p < .001$). In contrast, neither the presence of people nor the intensity of branding showed a significant effect on the number of reactions in this dataset.

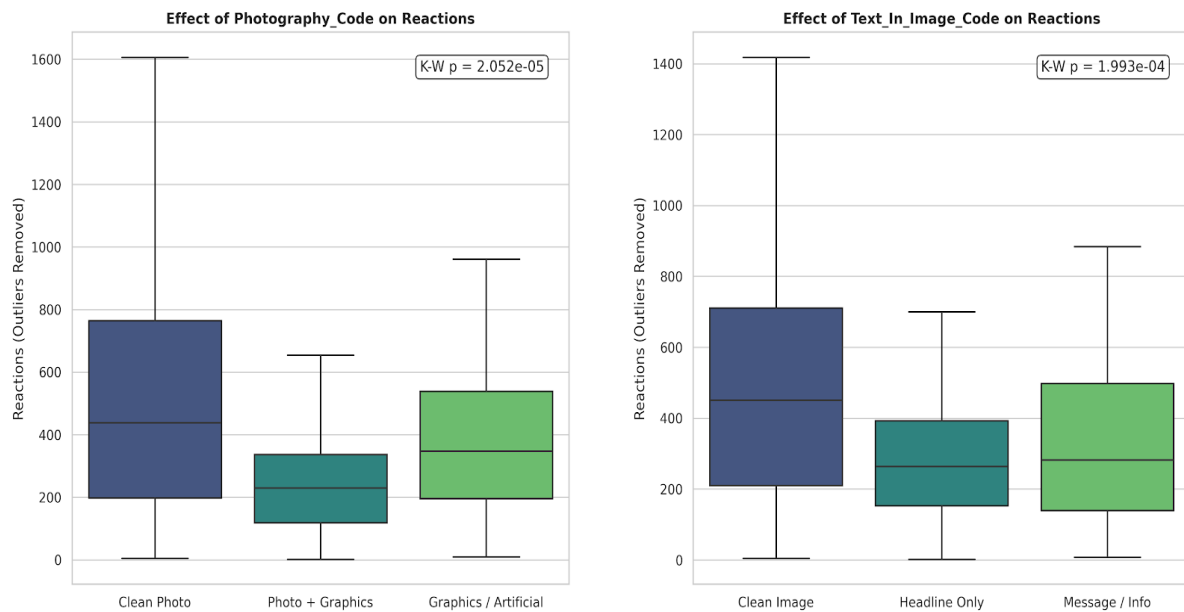


Figure 1. Boxplots showing the distribution of Reactions across categories of Photography Code (left) and Text in Image Code (right).

3.2. Post-hoc Pairwise Comparisons

For the factors that showed significant results in the omnibus test, post-hoc pairwise comparisons were performed using the Mann-Whitney U test with Bonferroni correction for multiple comparisons ($p_{adj} < .017$).

For Photography Code, the "Clean Photo" category (Median = 438) significantly outperformed the "Photo + Graphics" category (Median = 229.5), with a medium effect size ($r = 0.289$). The difference between "Clean Photo" and "Graphics/Artificial" was not statistically significant.

For Text in Image Code, posts with a "Clean Image" (no text overlay) achieved significantly higher engagement (Median = 451) compared to both "Headline Only" (Median = 264) and "Message/Info" (Median = 282). No significant difference was found between the two text-heavy categories.

Table 2. Selected Post-hoc Mann-Whitney U test results (Bonferroni adjusted)

Comparison (Group A vs. Group B)	Median A	Median B	padj	Comparison (Group A vs. Group B)
Photography: Clean Photo vs. Photo + Graphics	438	229.5	< .001	0.289
Photography: Clean Photo vs. Graphics/Artificial	438	347.5	.755	0.072
Text: Clean Image vs. Headline Only	451	264	.002	0.213
Text: Clean Image vs. Message/Info	451	282	.006	0.192

3.3. Relationships Among Variables

Spearman's rank correlation analysis was used to explore the relationships between visual attributes and engagement metrics. A correlation heatmap is presented in Figure 2.

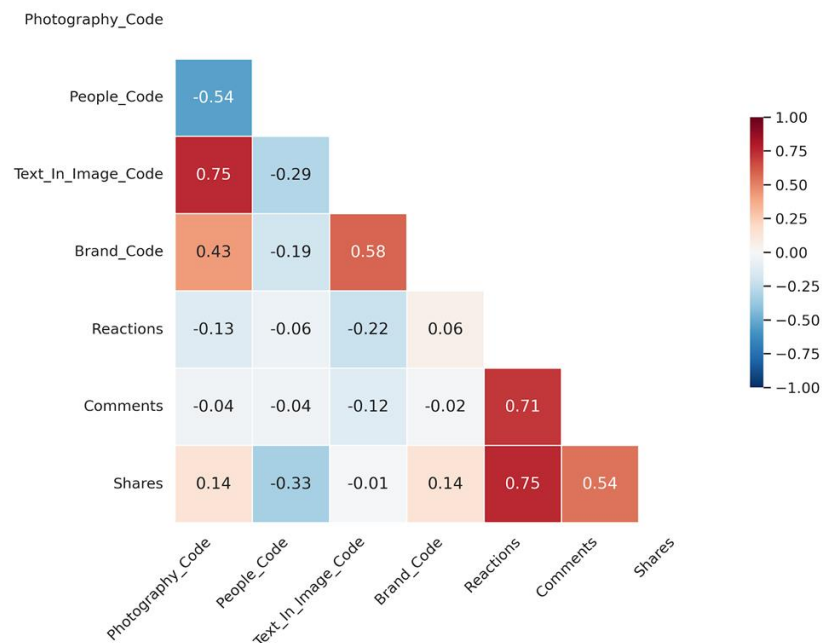


Figure 2. Spearman correlation matrix of visual codes and engagement metrics (Reactions, Comments, Shares).

The analysis identified significant correlations between visual attributes, suggesting that they often appear in clusters. For instance, Photography Code is strongly correlated with Text in Image Code ($\rho = 0.748, p < .001$), indicating that artificial or graphic-heavy visuals are more likely to contain text. Regarding engagement metrics, Reactions are strongly positively correlated with Comments ($\rho = 0.710$) and Shares ($\rho = 0.751$). Interestingly, while the People Code did not significantly affect Reactions, it showed a negative correlation with Shares ($\rho = -0.332, p < .001$), suggesting that posts featuring specific people might be shared less frequently.

4. Discussion

The primary objective of this study was to determine how specific visual attributes influence user engagement on LinkedIn in a B2B context. The results indicate that

"cleanliness" and the absence of "ad-like" features are significant drivers of reactions, while the presence of people or branding intensity plays a less decisive role than often assumed.

4.1. Authenticity Over Artificiality and Banner Blindness

The analysis revealed a significant preference for "Clean Photos" over "Photo + Graphics" hybrid formats. This finding aligns with the theory of source credibility in B2B marketing; visual forms that appear organic are perceived as more authentic, whereas heavy graphical overlays may signal "marketing fabrication" (Balaji et al., 2023). Similarly, the negative impact of text overlays on reactions supports the "banner blindness" phenomenon described by Benway (1998). Users in a professional feed likely filter out content that visually resembles advertisements or flyers (high text density, artificial composition) to focus on information they perceive as relevant (Cho & Cheon, 2004). The "binary penalization" observed—where any text overlay significantly reduced performance compared to clean images—suggests that the mere presence of text acts as a heuristic cue for ad avoidance.

4.2. The Ambiguous Role of Human Elements and Branding

Contrary to findings on social platforms like Instagram, where faces typically drive higher engagement (Bakhshi et al., 2014), this study found no significant difference in reactions based on the People Code. This discrepancy highlights the specific nature of the professional B2B context, where the relevance of the message may outweigh the emotional appeal of a human face. Furthermore, a negative correlation was observed between the presence of specific people and the number of Shares ($\rho = -0.33$), suggesting that while "human" posts are well-received, they are viewed as internal or personal content that users are less inclined to share with their own professional network. The lack of significant impact from the Brand Code implies that branding acts as a hygiene factor rather than a driver of engagement in the automotive B2B sector. Moreover, high brand prominence can sometimes trigger ad avoidance mechanisms if the content is perceived as purely promotional (Xiao et al., 2024).

4.3. Limitations

The study has several limitations.

First, the dataset is restricted to the automotive Tier-1 industry ($N = 319$) and spans a six-month observational period (June–November 2025). This limited timeframe may exclude seasonal trends or specific industry events typical of the full annual cycle, potentially affecting the temporal generalizability of the results.

Second, the analysis relies on absolute interaction counts (Reactions) without normalizing for Reach or Impressions, which were unavailable. Similarly, the study does not control for the varying follower base sizes of the included companies, which naturally biases absolute engagement numbers towards larger accounts. Consequently, it is impossible to strictly separate the effect of "better creative" from "algorithmic distribution" or brand popularity.

Furthermore, the manual coding of visual attributes was performed by a single researcher. While a standardized codebook was utilized, the absence of multiple coders prevents the assessment of Inter-coder Reliability (ICR). Future research should incorporate multiple independent coders to validate these visual constructs and mitigate potential subjective bias.

Finally, the univariate non-parametric approach does not account for the interaction effects between variables, nor does it consider the influence of textual captions (copywriting quality, length, hashtags), which act as a significant confounding variable in driving user engagement.

5. Conclusions

This paper empirically examined the impact of visual attributes on LinkedIn user engagement. The findings challenge the common practice of using heavily designed, text-rich visuals in B2B communication. The statistical analysis confirmed that "Clean Photography" and "Clean Images" (without text overlays) significantly outperform hybrid formats and visuals containing headlines or detailed information. Conversely, the presence of people and strong branding did not yield a statistically significant increase in Reactions.

5.1. Managerial Implications

Based on these results, B2B marketers should:

- Minimize text in images: Move headlines and detailed information to the post caption to avoid triggering banner blindness.
- Prioritize visual authenticity: Avoid "hybrid" formats (photos with graphical overlays) that resemble flyers. Use high-quality, authentic photography instead.
- Use human elements strategically: Recognize that while photos of people may build community, they are less likely to be shared virally compared to content focused on products or industry insights.

Future research should incorporate exposure metrics (Reach/Impressions) to calculate engagement rates and employ multivariate regression models to isolate the specific effects of overlapping visual attributes.

Conflict of interest: none

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Optimization of Production Costs and Revenues for the Selected Confectionery Product

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Abstract: This article aims to demonstrate the usefulness of quantitative methods in production management, but also to point out the practical benefits that linear programming can bring in finding effective decisions in the specific conditions of a manufacturing company. Based on a detailed description of the production process in a selected company, mathematical models are developed to identify the optimal distribution of resources and determine effective production outputs. These models account for constraints such as production capacity, time availability, and raw material consumption. The primary goal is to find a solution that maximizes net revenue. The results indicate that the current pricing strategy is unsustainable, as production costs exceed revenues in the baseline scenario, necessitating a strategic adjustment of sales prices.

Keywords: quantitative methods; linear programming; production management; mathematical model; optimisation

JEL Classification: D81; C61; M11

1. Introduction

In an environment of increasing competition and dynamic market conditions, emphasis is placed on effective management of business processes, especially in the production sphere. Companies that want to survive in the long term must focus on continuous improvement of productivity, cost reduction and quality of production. A key tool that is increasingly being used in this direction is the optimization of the production process. (Cadkova, 2025).

Manufacturing process optimization involves the systematic analysis and adjustment of manufacturing systems with the aim of improving efficiency, reducing operational costs, and increasing overall output. This is typically achieved by identifying critical stages within the production process, eliminating non-value-adding activities, and implementing measures that enhance productivity (Slack, Brandon-Jones, & Johnston, 2022).

In practice, manufacturing process optimization is frequently supported by quantitative approaches, including material flow analysis, lean manufacturing principles, and the adoption of advanced production management information systems (Heizer, Render, & Munson, 2020). Lean manufacturing emphasizes waste reduction through methods such as

Just-in-Time (JIT), which limits excess inventory levels and improves material flow throughout the organization (Womack & Jones, 2003).

An alternative approach is the theory of constraints, which focuses on identifying and addressing the primary bottlenecks within a production system. This methodology is particularly effective in environments where production capacities across individual processes are uneven and where maintaining the continuity of the entire production chain is essential (Goldratt & Cox, 2016).

One widely used method for production process optimization is linear programming. This technique enables the modeling of production systems using systems of equations and inequalities, allowing key performance indicators—such as profit or production volume—to be maximized while respecting constraints related to raw material availability, machine capacity, or storage limitations (Bazaraa, Jarvis, & Sherali, 2010). In practical applications, linear programming is commonly employed for production planning optimization, waste minimization, and the efficient allocation of manufacturing resources (Winston, 2004).

Linear programming as an operations research tool has been very popular in recent years and is used in many scientific articles in various scientific fields, from computer science (Olivieri, Mangini & Fanti, 2026) and (Khezrimotlagh, 2026), through economics (Moatsos, de Zwart, 2025) or (Djeumou Fomeni, 2026) to energy (Wu, Li, 2026).

2. Methodology

Economic formulation focuses on the practical application and interpretation of the model in the context of economic problems. Objectives, such as maximizing profit or minimizing costs, are identified, and constraints based on real economic conditions, such as available resources, production capacity, or demand, are defined. The mathematical formulation of linear programming is the process of converting a real problem into a mathematical form, which allows its analysis and solution using mathematical methods. The first step in creating a mathematical model is to determine the decision variables. These variables represent the quantities or levels of various activities or resources that are to be optimized. Another key part is defining an objective function that expresses the optimization goal - for example, maximizing profit or minimizing costs. This function is written as a linear combination of the decision variables with corresponding coefficients that represent the benefits or costs of the individual variables. The formulation of the limiting conditions is another essential step. These constraints can include the availability of raw materials, production capacity, labor, and other factors. They are expressed using equations or inequalities that reflect resource constraints or other requirements that must be met.

The simplex method is one of the most commonly used algorithms for solving linear programming problems. This method was developed by George Dantzig and its principle is to search a finite number of basic solutions in order to find the optimal result (Dantzig and Thapa, 2003). The method is widely used in areas such as production, logistics or finance, where the emphasis is on efficient use of resources and cost minimization.

The mathematical function Solver is intended as a key tool for finding the optimal solution within a given mathematical model. This function is used primarily in optimization problems, where it is necessary to maximize or minimize a given target parameter while meeting all defined constraints.

3. Application

The aim of the application part of the contribution is to optimize the costs and revenues of a selected company for the production of the chosen confectionery. Company XYZ is manufacturing confectionery and for reasons of privacy, neither its exact name nor the exact composition of the product is given. More details about the production can be found in the thesis (Cadkova, 2025).

A questionnaire was created to obtain input data on the production of the chosen confectionery. This questionnaire was subsequently distributed to the company XYZ that specializes in the production of these products. The results of the questionnaire provide an overview of various aspects of production, distribution and costs associated with this product. Additional production data were provided by the company based on questions asked regarding a specific issue.

3.1. Basic Data for Building Mathematical Models

Based on the input data obtained from the questionnaire survey, the key parameters required for building of the mathematical models are summarized here. This data is used to define the input variables, constraints and optimization criteria that will be used in the design of the model. Due to the company's request, the attachments regarding the exact recipe and the amount of raw materials needed were hidden.

The cost of raw materials for the production of one piece of confectionery is carefully calculated. The cost of a waffle ingredience is 0.64 CZK, tube filling 2.42 CZK and tube packaging 5.32 CZK. All mentioned prices are with excluding VAT. The availability of raw materials is ensured by monthly deliveries, which include 5800 kg of flour, 4000 kg of sugar, 3200 kg of milk, 10500 kg of fat, 300 kg of egg yolks, 40 kg of flavoring and 2000 kg of starch. There are 2 shifts per day and the workforce consists of 53 employees working a 7.5-hour shift, of which 40 are production workers and the rest are warehouse workers. Working hours are from 6:00 to 14:00 and from 14:00 to 22:00, without restrictions, with the possibility of maintenance during operation or on Saturdays. The company's daily production capacity is 74000 waffles, 50000 rolled tubes, 60000 filled tubes and 56000 packages. The time required for one piece of confectionery is 1 minute per waffle, 50 seconds for rolling and 20 seconds to 1 minute for filling.

4. Models and Results

4.1 Revenue Maximization Model with Production Linkage (Model 1)

The first model is designed to maximize production yields while maintaining continuity (waffles, rolling, filling, and packaging). The price per package of

confectionery is 6.9 CZK, and each package contains two pieces of confectionery. The time required is calculated in seconds as a ratio of the length of the shift and production capacity. The economic model is summarized in Table 1 below, and the mathematical model follows in formula (1).

Table 1. Economical model 1

Production	Time Consumption (in seconds)	Production capacity (in pieces)
x ₁ - waffles	0.73	74,000
x ₂ - rolling	0.90	60,000
x ₃ - filling	1.08	50,000
x ₄ - packaging	0.90	56,000
Time availability	54,000	
Price per package	6.90 CZK	

objective function:

$$f(x): 6.9x_4 \rightarrow \max \quad (1)$$

subject to:

time availability	$0.73x_1 + 0.9x_2 + 1.08x_3 + 0.9x_4$	$\leq 54,000$
production capacity – waffles	x_1	$\leq 74,000$
production capacity – rolling	x_2	$\leq 60,000$
production capacity – filling	x_3	$\leq 50,000$
production capacity – packaging	x_4	$\leq 56,000$
production linkage – rolling	$x_1 - x_2$	≥ 0
production linkage – filling	$x_2 - x_3$	≥ 0
production linkage – packaging	$x_3 - 2x_4$	≥ 0
non-negativity condition	$x_1, \dots, x_4$	≥ 0
integer condition	$x_1, \dots, x_4$	$\in \mathbb{Z}$

We convert the model to canonical form and enter it into the Solver. The output and settings of the solver are shown in the following figures.

	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	f(x)	
	0	0	0	0	0	0	0	0	0	0	0	0	0	
	0	0	0	6.9	0	0	0	0	0	0	0	0	0	54,000
	0.73	0.90	1.08	0.90	1	0	0	0	0	0	0	0	0	
	1	0	0	0	0	1	0	0	0	0	0	0	0	74,000
	0	1	0	0	0	0	1	0	0	0	0	0	0	60,000
	0	0	1	0	0	0	0	1	0	0	0	0	0	50,000
	0	0	0	1	0	0	0	0	1	0	0	0	0	56,000
	1	-1	0	0	0	0	0	0	0	-1	0	0	0	0
	0	1	-1	0	0	0	0	0	0	0	-1	0	0	0
	0	0	1	-2	0	0	0	0	0	0	0	-1	0	0
Solution														
objective function														
constrains														

Figure 1. Canonical form

	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	f(x)	
	17,088	17,088	17,088	8,544	1.92	56,912	42,912	32,912	47,456	0	0	0		
	0	0	0	6,9	0	0	0	0	0	0	0	0	58,953.6	
	0,73	0,9	1,08	0,9	1	0	0	0	0	0	0	0	54,000	54,000
Solution	1	0	0	0	0	1	0	0	0	0	0	0	74,000	74,000
objective	0	1	0	0	0	0	1	0	0	0	0	0	60,000	60,000
function	0	0	1	0	0	0	0	1	0	0	0	0	50,000	50,000
constrains	0	0	0	1	0	0	0	0	1	0	0	0	56,000	56,000
	1	-1	0	0	0	0	0	0	0	-1	0	0	0	0
	0	1	-1	0	0	0	0	0	0	0	-1	0	0	0
	0	0	1	-2	0	0	0	0	0	0	0	-1	0	0

Figure 2. Solver settings

We obtain the following optimal solution:

$$x_{opt} = (17088; 17088; 17088; 8544; 1.92; 56912; 42912; 32912; 47456; 0; 0; 0) \quad (2)$$

with corresponding objective function:

$$f(x_{opt}) = 5853.6 \text{ CZK} \quad (3)$$

Economical interpretation of solution (model 1)

To achieve the maximum revenue of 58,953.6 CZK per day, 8,544 packages of confectionery must be produced. Production capacity is mainly limited by the available time; the remaining time is less than 2 seconds in the entire production day. Individual production lines have sufficient capacity ranging from 33,000 to 57,000 seconds. Production continuity is ensured; all waffles are rolled, then filled, and finally packaged in pairs. This implies a 99.9% utilization of the defined 54,000-second production window.

4.2 Revenue Maximization Model with Production Linkage and Ingredients Capacity (Model 2)

The second model maximizing revenue is an extension of the previous model 1. We add constraints related to the storage capacity of ingredients needed to produce the chosen confectionery. When calculating daily capacities, 22 working days in a month were considered. Table 2 summarizes the quantities of ingredients for one waffle and one filling, including the daily available quantity in stock.

Table 2. Confectionery ingredients and their daily capacities

Production	Flour (in kg)	Sugar (in kg)	Milk (in kg)	Fat (in kg)	Egg yolk (in kg)	Flavouring (in kg)	Starch (in kg)
waffle	0.005	0.0002	0.0004	0.00	0.0002	0.00	0.00
filling	0.00	0.0042	0.0016	0.08	0.00	0.0002	0.0011
Daily capacity	263.64	181.82	145.45	477.27	13.64	1.82	90.91

Resulting mathematical model follows in formula (4):

objective function:

$$f(x): 6.9x_4 \rightarrow \max \quad (4)$$

subject to:

$$\begin{aligned}
 \text{time availability} & 0.73x_1 + 0.9x_2 + 1.08x_3 + 0.9x_4 & \leq 54,000 \\
 \text{production capacity} & x_1 & \leq 74,000 \\
 & x_2 & \leq 60,000 \\
 & x_3 & \leq 50,000 \\
 & x_4 & \leq 56,000 \\
 \text{production linkage} & x_1 - x_2 & \geq 0 \\
 & x_2 - x_3 & \geq 0 \\
 & x_3 - 2x_4 & \geq 0 \\
 \text{storage capacity - flour} & 0.005x_1 & \leq 263.64 \\
 \text{storage capacity - sugar} & 0.0002x_1 + 0.0042x_3 & \leq 181.82 \\
 \text{storage capacity - milk} & 0.0004x_1 + 0.0016x_3 & \leq 145.45 \\
 \text{storage capacity - fat} & 0.08x_3 & \leq 477.27 \\
 \text{storage capacity - egg yolk} & 0.0002x_1 & \leq 13.64 \\
 \text{storage capacity - flavouring} & 0.0002x_3 & \leq 1.82 \\
 \text{storage capacity - starch} & 0.0011x_3 & \leq 90.91 \\
 \text{non-negativity condition} & x_1, \dots, x_4 & \geq 0 \\
 \text{integer condition} & x_1, \dots, x_4 & \in \mathbb{Z}
 \end{aligned}$$

We convert the model to canonical form and enter it into the Solver, the output can be seen in the following image.

	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12
	27,528	27,528	5,965	2,982	3.36	46,472	32,472	44,035	53,018	0	21,563	1
	0	0	0	6.9	0	0	0	0	0	0	0	0
	0.73	0.9	1.08	0.9	1	0	0	0	0	0	0	0
	1	0	0	0	0	1	0	0	0	0	0	0
	0	1	0	0	0	0	1	0	0	0	0	0
	0	0	1	0	0	0	0	1	0	0	0	0
Solution	0	0	0	1	0	0	0	0	1	0	0	0
objective	1	-1	0	0	0	0	0	0	0	-1	0	0
function	0	1	-1	0	0	0	0	0	0	0	-1	0
constrains:	0	0	1	-2	0	0	0	0	0	0	0	-1
	0.005	0	0	0	0	0	0	0	0	0	0	0
	0.0002	0	0.0042	0	0	0	0	0	0	0	0	0
	0.0004	0	0.0016	0	0	0	0	0	0	0	0	0
	0	0	0.08	0	0	0	0	0	0	0	0	0
	0.0002	0	0	0	0	0	0	0	0	0	0	0
	0	0	0.0002	0	0	0	0	0	0	0	0	0
	0	0	0.0011	0	0	0	0	0	0	0	0	0

x13	x14	x15	x16	x17	x18	x19	f(x)	
126	151.2614	124.8948	0.07	8.1344	0.627	84.3485		
0	0	0	0	0	0	0	20,575.8	
0	0	0	0	0	0	0	54,000	54,000
0	0	0	0	0	0	0	74,000	74,000
0	0	0	0	0	0	0	60,000	60,000
0	0	0	0	0	0	0	50,000	50,000
0	0	0	0	0	0	0	56,000	56,000
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	1.1102E-16	0
1	0	0	0	0	0	0	263.64	263.64
0	1	0	0	0	0	0	181.82	181.82
0	0	1	0	0	0	0	145.45	145.45
0	0	0	1	0	0	0	477.27	477.27
0	0	0	0	1	0	0	13.64	13.64
0	0	0	0	0	1	0	1.82	1.82
0	0	0	0	0	0	1	90.91	90.91

Figure 3. Solver settings

We obtain the following optimal solution:

$$x_{opt} = (27528; 27528; 5965; 2982; 3.4; 46472; 32472; 44035; 53018; 0; 21563; 1; 126; 151; 125; 0.07; 8.13; 0.627; 84.35) \quad (5)$$

with corresponding objective function:

$$f(x_{opt}) = 20575.8 \text{ CZK} \quad (6)$$

Economical interpretation of solution (model 2)

Instead of 8,544 packages sold based on model 1, only 2,982 were produced when ingredients capacities were added. This reduced the revenue to 20,575.8CZK. The main reason is the insufficient capacity of fat, which remains in stock after production is 0.07 kg. If we were to double its stock, we would run out of stock of flavoring. To achieve the daily maximum production limited by time capacity, it would be necessary to have at least 226.5kg of sugar, 159.1kg of milk, 1,367.2kg of fat, 4.1kg of flavouring and 103.2kg of starch in stock to produce 8544 tube packages (i.e. 17088 pieces of tubes).

4.3. Cost Minimization Model with Production Linkage (Model 3)

Finally, let us design the model by minimizing the production costs of the selected confectionery. The basic constraints are again the available time and production continuity. In addition, the minimum production quantity must be considered; without this condition, the model would suggest not producing anything, resulting in zero costs. The minimum production value is set at 8,544 packages of confectionery, which results from model (1)

maximizing revenue. to ensure comparability with the revenue maximization model. From the questionnaire, we know the costs of the semi-finished products, but we must convert them into individual costs. We can subtract the waffles and filling from the packaging to get the packaging costs, and we can subtract the cost of the waffles from the filling to get the filling costs. There is no cost of tube rolling as only production time is required and no ingrediencies are involved. The economic model is summarized in Table 3 below, and the mathematical model follows in formula (7).

Table 3. Economical model 3

Production	Time Consumption (in seconds)	Production cost (in CZK)
x_1 - waffles	0.73	0.64
x_2 - rolling	0.90	0
x_3 - filling	1.08	1.79
x_4 - packaging	0.90	2.26
Time availability	54,000	
Minimal amount	8,544 (pc)	

objective function:

$$f(x): 0.64x_1 + 1.79x_3 + 2.26x_4 \rightarrow \min \quad (7)$$

subject to:

time availability	$0.73x_1 + 0.9x_2 + 1.08x_3 + 0.9x_4$	≤ 54000
production linkage – rolling	$x_1 - x_2$	≥ 0
production linkage – filling	$x_2 - x_3$	≥ 0
production linkage – packaging	$x_3 - 2x_4$	≥ 0
minimal production	x_4	≥ 8544
non-negativity condition	$x_1, \dots, x_4$	≥ 0
integer condition	$x_1, \dots, x_4$	$\in \mathbb{Z}$

We convert the model to canonical form and enter it into the Solver, the output can be seen in the following image.

	x1	x2	x3	x4	x5	x6	x7	x8	x9	f(x)
	0	0	0	0	0	0	0	0	0	
	0.64	0	1.79	2.26	0	0	0	0	0	0
	0.73	0.9	1.08	0.9	1	0	0	0	0	54,000
	1	-1	0	0	0	-1	0	0	0	0
	0	1	-1	0	0	0	-1	0	0	0
	0	0	1	-2	0	0	0	-1	0	0
	0	0	0	1	0	0	0	0	-1	8,544

Figure 4. Canonical form

	x1	x2	x3	x4	x5	x6	x7	x8	x9	f(x)	
	17,088	17,088	17,088	8,544	1.92	0	0	0	0		
	0.64	0	1.79	2.26	0	0	0	0	0	60,833.28	
	0.73	0.9	1.08	0.9	1	0	0	0	0	54,000	54,000
Solution objective	1	-1	0	0	0	-1	0	0	0	0	0
function constrains:	0	1	-1	0	0	0	-1	0	0	0	0
	0	0	1	-2	0	0	0	-1	0	0	0
	0	0	0	1	0	0	0	0	-1	8,544	8,544

Figure 5. Solver settings

We obtain the following optimal solution:

$$x_{opt} = (17088; 17088; 17088; 8544; 1.92; 0; 0; 0; 0) \text{ CZK} \quad (8)$$

with corresponding objective function:

$$f(x_{opt}) = 60833.3 \text{ CZK} \quad (9)$$

Economical interpretation of solution (model 2)

Producing at least 8544 packages of confectionery leads to the minimal daily cost of 60833,28CZK. Production capacity is mainly limited by the required production amount and available time; the remaining time is less than 2 seconds in the entire production day. Production continuity is ensured; all waffles are rolled, then filled, and finally packaged in pairs.

5. Discussion

The outputs of models (1) and (3) do not differ in terms of production volume and time consumption. However, there is a significant difference in their objective function values. The maximum daily profit is 58,953.6 CZK, and the minimum daily costs for the same production are 60,833.28 CZK. With the current sales price set at 6.9 CZK per package, there is a daily loss of 1,879.68 CZK. These findings align with the principles of Heizer, Render, and Munson (2020), who emphasize that operational efficiency is not merely about volume, but about the balance between sustainability and cost management. The production process set up is inefficient and unprofitable. We recommend that Company XYZ should increase the sales price to at least 7.12 CZK to balance costs and revenues. If Company XYZ wants to generate at least a 15 percent profit, the minimum selling price would need to be set at CZK 8.19 CZK per one package of confectionery.

6. Conclusion

Based on the three developed models, the following conclusions and recommendations are proposed:

- Pricing Strategy Realignment: The most significant finding is that at the current selling price of 6.90 CZK per package, the company generates a daily loss of approximately 1,880

CZK. The break-even price was identified at 7.12 CZK. To achieve a sustainable profit margin of 15%, the company must increase the selling price to at least 8.19 CZK per package.

- Supply Chain Optimization: Model 2 demonstrated that raw material constraints, specifically fat (shortening) reserves, significantly limit the potential revenue. The current stock levels allow for only 35% of the total production capacity to be utilized. It is recommended to renegotiate delivery frequencies or increase storage capacity for key ingredients to prevent production idling.
- Resource Allocation: The models show a near-perfect utilization of the 54,000-second production shift. However, such high utilization leaves no room for unexpected machine downtime or maintenance. A strategic buffer of at least 5-10% in time capacity should be integrated into future planning to increase operational resilience.

In conclusion, the use of quantitative optimization methods allowed the identification of "invisible" losses caused by an incorrectly set price-to-cost ratio. By implementing the proposed price adjustment and addressing material bottlenecks, Company XYZ can transform its production from a loss-making operation into a highly efficient and profitable business.

Acknowledgments: This contribution has been supported by the institutional support of the University of Pardubice, Czech Republic. We thank Karolína Čádková for her help.

Conflict of interest: none

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Precision Viticulture in Central Europe: A Comparative Analysis of Technological Adoption in the Czech Republic and Austria

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Abstract: Precision viticulture (PV), a subfield of precision agriculture, has become increasingly relevant in Central Europe as wine producers face mounting environmental, economic, and technological challenges. This article presents a comparative analysis of PV technology adoption in the Czech Republic and Austria, drawing upon secondary data and a qualitative, multi-dimensional framework. The study evaluates adoption across seven key areas—including satellite imaging, drone use, soil and microclimate sensors, and variable rate applications—while integrating economic indicators such as investment costs, operational savings, return on investment (ROI), and subsidy intensity. Findings indicate that Austria leads in PV adoption due to coherent institutional support, stronger financial incentives, and effective integration of research and practice. The Czech Republic, while showing accelerating uptake, continues to face structural barriers related to farm fragmentation, limited advisory capacity, and less targeted funding instruments. This indicates that structural scale alone is insufficient without institutional and advisory coordination. The article also considers tax implications, including VAT and excise duties, highlighting their influence on the economic attractiveness of PV technologies. A 5–10-year prognosis suggests that sustained investment, improved training systems, and climate-driven pressures could substantially increase PV adoption in Czech vineyards.

Keywords: precision viticulture; technological challenges; agricultural policy; Czech Republic; Austria

JEL Classification: Q12; Q18; H25

1. Introduction

Precision agriculture (PA) has emerged over the past decades as a core paradigm for improving the economic and environmental performance of farming systems through targeted input use, spatially differentiated management, and data-driven decision-making (Zhang et al., 2002; Gebbers & Adamchuk, 2010). Within this framework, precision viticulture (PV) represents a specialised application to vineyard systems, addressing inherent spatial and temporal variability (Matese & Di Gennaro, 2015).

The relevance of PV has intensified as European wine regions experience increasing climate variability, droughts, and disease pressure. Technologies such as satellite remote

sensing, UAVs, soil and microclimate sensors, and decision support systems enable vineyard managers to respond effectively to these challenges (Reynolds, 2021; Tardaguila et al., 2021; Santesteban, 2018).

The Czech Republic and Austria provide a comparative context. Both countries share similar agro-climatic conditions and viticultural traditions yet differ markedly in the pace and depth of digital technology adoption. Austria has positioned itself as a frontrunner in sustainable and digitally supported viticulture, supported by stable rural development programmes and close cooperation between research institutions and practitioners (Smart Rural 21, 2023).

Viticulture contributes significantly to rural employment, regional branding, and tourism (Anderson and Pinilla, 2018; Santini et al., 2013). Wine is often perceived by many consumers as a natural and sustainable product. However, there are several environmental and socio-economic challenges which the wine industry has to overcome in order to do justice to this assessment. The ongoing global warming with its negative effects on cultivation emphasize the need for a rapid transformation towards more sustainability (Wagner et al., 2023). In addressing the trade-offs between the various pillars of sustainability, wine producers should be able to prioritize investments that bolster environmental sustainability without compromising their economic viability. Ideally, such investments should generate synergies that enhance economic sustainability by providing additional revenue streams for producers (Padilla et al., 2022). Although precise national statistics on precision viticulture (PV) adoption are not systematically collected, available sectoral analyses and expert reports indicate a clear difference between the two countries. In Austria, an estimated 35–45% of vineyards use at least one PV-related technology (e.g., remote sensing, UAV monitoring, or decision support systems), whereas in the Czech Republic adoption is lower, approximately 15–25%. This disparity reflects differences in advisory systems, institutional continuity, and historical pathways of technological innovation in viticulture.

2. Methodology

This study uses a qualitative comparative research design based on secondary data analysis from peer-reviewed journals, EU and national policy documents, agricultural chambers, funding agencies, and platforms such as Smart Rural 21.

Research Question:

How do institutional support, policy frameworks, advisory services, and fiscal mechanisms influence the adoption and economic feasibility of precision viticulture technologies in Austria compared to the Czech Republic?

To address this question, the study employs a qualitative comparative approach based on secondary data analysis. Data sources include peer-reviewed journal articles, government and EU reports, white papers from agricultural technology providers, and online repositories such as Smart Rural 21. The analysis focuses on seven dimensions of PV technology adoption:

- Satellite imagery and remote sensing,
- Use of drones (UAVs),
- Soil and microclimate sensors,
- Variable rate application (VRA),
- Meteorological data systems,
- Policy support and funding mechanisms,
- Training and extension services.

A SWOT framework and trend extrapolation are used to interpret the findings and provide a 5–10-year outlook for PV adoption, integrating economic and fiscal considerations. This approach allows for a comprehensive, context-sensitive comparison of technology adoption patterns without relying on formal statistical testing, while linking insights to policy and economic implications.

Analytical methods combine descriptive comparison, SWOT-based interpretation, trend extrapolation, and integration of economic indicators including investment costs, operational savings, subsidy intensity, and ROI (Pierpaoli et al., 2013; Landwirtschaftskammer Österreich, 2024; SZIF, 2024). Adoption dynamics are interpreted using diffusion theory (Lowenberg-DeBoer & Erickson, 2019). The analysis also draws upon recent research on drivers and barriers of precision agriculture adoption in Central European farming systems, particularly studies examining structural and behavioural determinants of technology uptake in the Czech context. (Žáková Kroupová et al., 2026).

Methodological note on economic and adoption indicators

The economic figures presented in the cost–benefit and ROI table are based on a scenario model developed for a hypothetical 10-hectare vineyard. These values are not farm-survey averages but model-based estimations combining (i) investment cost ranges reported in precision viticulture literature and industry sources, (ii) subsidy intensity levels from national and EU rural development frameworks, and (iii) performance effect intervals (yield gains, input savings, quality improvements) commonly reported in PV impact studies. The purpose of these figures is illustrative and comparative, showing the order of magnitude and structural differences between national contexts rather than statistically representative outcomes.

Structural characteristics of vineyard ownership and management

A crucial factor influencing precision viticulture adoption lies in the distinction between land ownership fragmentation and operational farm structure. These two dimensions are often conflated but have different implications for technological uptake.

In the Czech Republic, although vineyard ownership is fragmented, operational management is highly concentrated. According to national vineyard register statistics, agricultural enterprises cultivating vineyard areas exceeding 30 hectares manage more than half of the total national vineyard area (Central Institute for Supervising and Testing in Agriculture, 2024).

This results in a relatively consolidated operational structure, enabling economies of scale, higher capital availability, and better access to mechanization and digital technologies. Such structural conditions create a potentially favourable environment for investment in PV technologies. While vineyard ownership is fragmented in both countries, the Czech Republic exhibits higher operational concentration. However, this indicates that structural scale alone is insufficient without institutional and advisory coordination. Austria displays greater alignment between ownership and management at smaller scales.

Austria, in contrast, is characterized by a predominance of small and medium-sized family-operated vineyards, where ownership and management are closely linked. Although this structure supports strong local knowledge networks and cooperative systems, individual producers often operate on a smaller scale, which may limit investment capacity and increase dependence on collective advisory services and subsidy mechanisms.

Therefore, while Austria currently demonstrates higher PV adoption, the Czech structural model contains latent potential for rapid technological diffusion through large operational units, provided institutional and advisory barriers are addressed.

3. Results

Austrian vineyards—particularly in Wachau and Burgenland—widely employ satellite imagery, UAV monitoring, and soil sensors to manage variability and optimise inputs (Smart Rural 21, 2023). These technologies are embedded within integrated decision support systems developed in collaboration with universities and advisory bodies. In the Czech Republic, PV adoption is more fragmented, with UAVs and remote sensing in experimental settings or larger producers. Smaller vineyards face financial constraints, limited technical support, and lower awareness of PV benefits.

3.1. Comparative Adoption of Precision Viticulture Technologies

The following Table 1 provides a comparative overview of the adoption of key precision viticulture technologies and institutional support mechanisms in Austria and the Czech Republic. It highlights substantial differences in the extent of technological implementation, access to advisory and training services, and the strength of policy and funding frameworks. Overall, the comparison illustrates Austria's more advanced and integrated precision viticulture ecosystem, while the Czech Republic remains at an earlier and more fragmented stage of adoption. Adoption levels are expressed as qualitative intensity categories derived from structured synthesis of secondary sources rather than measured adoption rates. Classification reflects convergence across policy documents, sector reports, and academic studies.

Training and knowledge transfer also differ. Austria has well-established vocational and extension systems; Czech advisory services are still developing.

Table 1. Comparative adoption of precision viticulture technologies

Technology / Practice	Austria	Czech Republic
Satellite Imagery & Remote Sensing	Widely adopted in larger vineyards; commonly used for canopy mapping, zoning, and vigour assessment.	Limited use; primarily within research projects or by large-scale producers.
Drones (UAVs)	Regularly used for aerial monitoring, stress detection, and disease assessment.	Growing interest: adoption remains largely experimental.
Soil & Microclimate Sensors	Commonly integrated into vineyard management systems; applied to optimize irrigation and fertilization.	Used selectively, mainly in pilot projects or academic research settings.
Variable Rate Application (VRA)	Applied in combination with soil mapping and decision support tools; supported by EU and national subsidies.	Rare; limited adoption due to high costs and insufficient technical support.
Yield Monitoring Systems	Present in some mechanized vineyards; frequently linked to GPS-based harvesting systems.	Limited availability: yield estimation is predominantly manual.
Decision Support Systems (DSS)	Widely available and increasingly used; often integrated with mobile applications.	Few commercial solutions available; adoption constrained by digital infrastructure.
GIS-based Vineyard Zoning	Advanced implementation in premium wine regions (e.g., Wachau); widely used for spatial management.	Emerging interest: GIS tools used mainly for academic or experimental purposes.
Training & Extension Services	Well-established; provided by viticultural schools, cooperatives, and advisory bodies.	Fragmented and limited; advisory services remain under development.
Government Policy & Funding	Strong support through rural development programs and innovation-oriented grants.	Moderate support: funding is available but not specifically targeted at PV technologies.
Collaboration with Research Institutions	Close cooperation with universities (e.g., BOKU Vienna); field-testing and applied research encouraged.	Active academic research; weaker transfer to commercial vineyard practice.

3.2. Economic Assessment and Adoption Dynamics

Table 2 presents a comparative analysis of the estimated return on investment (ROI) for a medium-sized (10 ha) vineyard implementing precision viticulture (PV) technologies in the Czech Republic and Austria.

Table 2. Comparative ROI analysis (10 ha vineyard)

Indicator	Austria	Czech Republic
Initial Investment	€ 90,000	€ 85,000
Annual operational savings	€ 14,000	€ 12,000
Increase in average yield	+ 10%	+8%
Increase in premium grape share	+18%	+15%
Estimated ROI period	5.8 years	6.5 years
Average subsidy intensity	~ 50%	~ 40%

Note: Values represent model-based scenario estimations for a medium-sized vineyard and serve illustrative comparative purposes. They are not empirical sample averages.

The indicators summarize capital expenditures, operational savings, yield improvements, and subsidy intensity, providing a clear overview of the economic feasibility of PV adoption in both contexts. This comparison highlights the influence of national policy support and market conditions on the financial attractiveness of precision technologies.

Differences shown in Table 2 are shaped by three interacting factors: (1) structural farm characteristics, (2) institutional and advisory systems, and (3) financial support mechanisms. Austria's higher intensity of PV adoption reflects stable advisory networks, integration between research institutions and practice, and targeted rural development schemes. Conversely, the Czech Republic combines favourable operational farm size with weaker institutional coordination and less specialized support for digital technologies. This configuration explains why structural capacity alone does not automatically translate into higher adoption rates.

The data suggest that while both countries demonstrate positive economic outcomes from PV adoption, Austrian vineyards benefit from slightly higher operational savings, larger increases in yield and premium grape share, and shorter ROI periods, reflecting stronger subsidy coverage and more established technological ecosystems. In the Czech context, ROI remains favourable, but adoption may be constrained by lower subsidy intensity and limited access to advisory support. These results underscore the importance of tailored financial instruments and institutional support to accelerate the adoption of precision viticulture in regions with smaller or fragmented vineyard holdings.

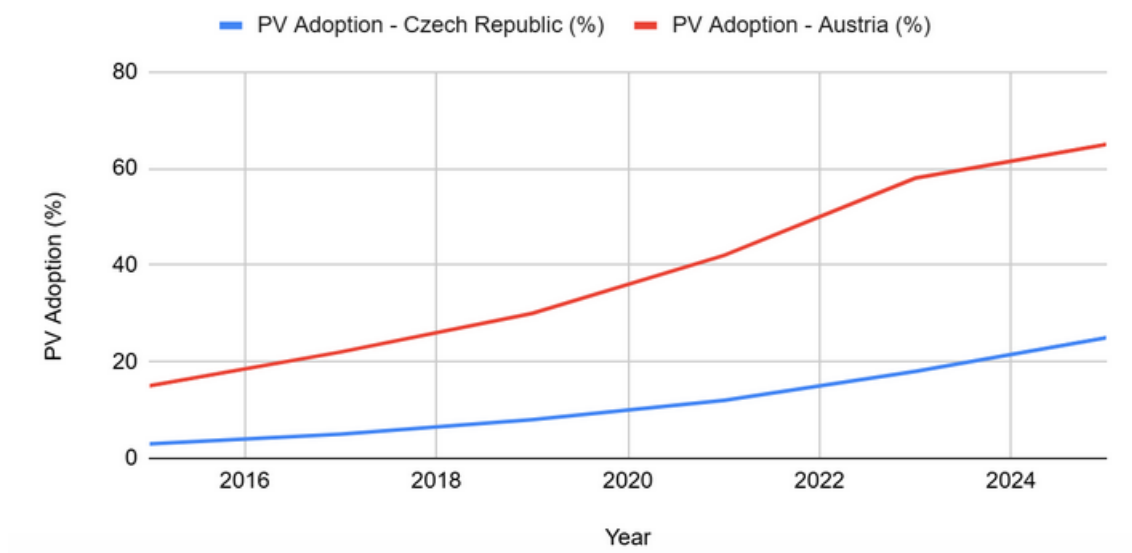


Figure 1. Conceptual illustration of relative precision viticulture adoption trends in Austria and the Czech Republic (2015–2025).

Figure 1 provides a conceptual illustration of the relative adoption trajectories of precision viticulture (PV) technologies in Austria and the Czech Republic between 2015 and 2025. Adoption rates represent vineyards using at least two core PV technologies, data are synthesized from Smart Rural 21 (2023) and recent literature. The figure does not represent a statistical time series. Instead, it visualizes the direction and relative dynamics of adoption derived from qualitative synthesis of sector reports, policy documents, and

academic literature. The graphical representation is intended to support the comparative interpretation presented in the text by illustrating Austria's earlier and steeper adoption pathway in contrast to the Czech Republic's later but gradually accelerating uptake. It reflects differences in institutional support, advisory systems, and policy continuity discussed in Sections 2 and 3.

The figure serves an explanatory and heuristic purpose rather than providing measured quantitative adoption rates. Graphical trend illustrations are used in a conceptual manner to visualise comparative adoption dynamics and should not be interpreted as statistically measured time-series data.

3.3. Taxation and Fiscal Considerations

The adoption of precision viticulture (PV) technologies is closely linked to taxation and fiscal policy, as changes in vineyard productivity, grape quality, and wine output directly affect taxable income and overall profitability. Understanding these interactions is essential for assessing the true economic feasibility of PV investments.

Table 3. Comparative overview of taxation and fiscal implications for precision viticulture adoption in Austria and the Czech Republic

	Austria	Czech Republic
Value Added Tax (VAT)	Austria applies a standard 20% VAT on wine sales, although certain local initiatives and small-scale producers may benefit from reduced rates for specific products or regional programs.	The standard VAT rate is 21%, with a reduced rate of 15% applied to selected food products. Wine generally falls under the standard rate, though small-scale producers may access exemptions or simplified VAT schemes.
Excise / Alcohol Tax	Wine is generally exempt from excise duties, with taxes applied primarily to fortified wines or products exceeding standard alcohol content thresholds.	Wine with alcohol content below 15% ABV is exempt from excise duties, whereas fortified or higher-alcohol wines are taxed according to national regulations.
Implications for PV adoption	The use of PV technologies often results in higher yields and improved grape quality, which can increase taxable turnover. However, Austria's well-structured subsidy schemes and investment incentives, particularly under rural development programs, mitigate these fiscal effects. In practice, subsidies can offset a substantial portion of VAT liabilities and initial investment costs, improving net profitability for vineyards adopting PV technologies. Additionally, precision monitoring allows producers to target quality-enhancing interventions selectively, optimizing both tax efficiency and economic returns.	Implementation of PV technologies can lead to higher yields and an increase in premium-quality wine production, directly affecting VAT obligations. While eligible subsidies from the European Union and national programs partially offset these fiscal burdens, the Czech system currently provides less targeted support than Austria. Consequently, vineyards must carefully plan for potential VAT increases associated with productivity gains. PV-driven yield optimization can help align production with tax planning, for example by enabling strategic allocation of grapes to premium products with favorable market pricing, which can improve after-tax returns.

3.4. Comparative Insights

- Both countries demonstrate that PV adoption has a dual effect: while it increases revenue potential through higher yields and improved wine quality, it simultaneously raises taxable turnover and potential fiscal liabilities.
- Austria's system of targeted subsidies, in combination with stable rural development incentives, provides more predictable mitigation of fiscal impacts, effectively lowering financial risk for adopters.
- In the Czech Republic, fiscal planning is more critical, as subsidies are less directly linked to PV investment, requiring careful assessment of potential VAT liabilities when scaling production or introducing premium product lines.

3.5. Strategic Recommendations for Vineyards

- Incorporate PV-driven yield forecasts into tax planning and cash flow projections.
- Align PV interventions with subsidy eligibility criteria to maximize fiscal offsets.
- Consider product segmentation (standard vs. premium wine) to optimize VAT exposure.
- Maintain detailed records of PV-enabled improvements to support claims for investment grants and future tax deductions.

Taxation and fiscal policies play a critical role in determining the net economic benefit of PV technologies. While PV adoption enhances operational efficiency and quality outcomes, vineyard managers must account for potential VAT and excise impacts. Austria's stronger fiscal and subsidy framework facilitates smoother adoption, whereas in the Czech Republic, targeted fiscal planning and strategic use of subsidies are essential to ensure that increased production and quality translate into tangible, after-tax profitability.

Data synthesized from Austrian Ministry of Finance (2024); Ministry of Finance of the Czech Rep. (2024); SZIF (2024)

4. Discussion

The comparative analysis highlights several important insights. Austria demonstrates not only higher PV adoption but also a more integrated ecosystem encompassing research institutions, advisory services, and rural development funding. This coherence allows Austrian winegrowers to leverage PV technologies more effectively, achieving both operational efficiency and quality improvements.

In contrast, the Czech Republic, despite recent progress, faces structural challenges that hinder rapid adoption. Fragmented vineyard ownership, limited access to technical support, and lower levels of subsidy intensity reduce the immediate economic feasibility for many small and medium-sized producers. However, pilot projects and academic collaborations indicate growing awareness and interest.

The integration of taxation considerations further nuances the economic analysis. While PV can improve yields and increase premium grape share, it also increases taxable turnover. Effective fiscal planning and targeted subsidies are therefore critical to ensure that PV adoption translates into net economic benefits. In Austria, higher subsidy intensity and

institutional support help offset VAT liabilities, while in the Czech Republic, ongoing EU co-financing and national support programs provide partial mitigation but remain less targeted.

The adoption curves suggest that PV uptake in the Czech Republic is accelerating, particularly in South Moravia, but still lags Austrian regions. Policy interventions focused on training, advisory support, and integration with digital platforms can catalyse further adoption. The findings of Žáková Kroupová et al. (2026) underscore the need for targeted policy measures. Additionally, climate change and labour shortages are likely to increase the attractiveness of precision technologies across both countries. Currently, remote, and proximal monitoring technologies and variable-rate machinery are applied on a broad basis, while robotics reported in this review are in an experimental stage. (Matese & Di Gennaro, 2015). Looking ahead, climate change pressures, labour shortages, and market demand for quality and traceability are likely to further strengthen the economic rationale for PV adoption across both countries, consistent with recent international evidence (Martínez-Falcó et al., 2024).

Overall, the findings underscore the need for a multifaceted approach to PV adoption that combines technological investment, fiscal planning, policy support, and human capital development. A 5–10-year outlook indicates that, with sustained EU co-financing and targeted national measures, Czech vineyards could achieve a 30–50% increase in PV adoption, narrowing the gap with Austrian counterparts. These insights have implications not only for economic efficiency but also for long-term sustainability, resilience to climate change, and competitive positioning in European and global wine markets (Martínez-Falcó et al. 2024).

5. Conclusions

This article has examined the adoption of precision viticulture (PV) technologies in Central Europe through a comparative analysis of the Czech Republic and Austria, integrating technological, economic, institutional, and fiscal perspectives. The findings confirm substantial differences in adoption dynamics between the two countries, reflecting broader disparities in policy coherence, institutional support, and economic incentives.

Austria emerges as a mature adopter of PV technologies, supported by a well-integrated ecosystem that combines research institutions, advisory services, and targeted rural development funding. This alignment enables winegrowers to translate technological investments into tangible gains in operational efficiency, grape quality, and long-term competitiveness. The Austrian case illustrates how coordinated policy frameworks can reduce adoption risk, shorten return-on-investment periods, and facilitate diffusion beyond early adopters.

In contrast, the Czech Republic remains at an earlier stage of the adoption curve. Structural factors—such as fragmented vineyard ownership, limited advisory capacity, and lower subsidy intensity—continue to constrain the economic feasibility of PV investments for small and medium-sized producers. Nevertheless, indicators from pilot projects and academic collaborations indicate increasing awareness and a gradual shift toward digital

vineyard management, particularly in South Moravia. Adoption trajectories suggest that the Czech viticulture sector is entering an acceleration phase, albeit from a lower baseline.

A key contribution of this study lies in the explicit integration of taxation considerations into the economic assessment of PV adoption. While precision technologies enhance yields and increase the share of premium grapes, they also raise taxable turnover and VAT liabilities. The results highlight the importance of aligning innovation support with fiscal policy to ensure that productivity gains translate into net economic benefits at the farm level. Austria's higher subsidy coverage partially offsets fiscal burdens, whereas Czech support schemes, though improving, remain less targeted and thus less effective in accelerating adoption.

From a technological perspective, the analysis confirms that remote and proximal sensing technologies, decision support systems, and variable-rate applications are currently the most widely implemented PV tools, while advanced robotics remain experimental (Matese & Di Gennaro, 2015).

Overall, the study underscores that precision viticulture adoption is not merely a technological decision, but a multifaceted economic process shaped by policy design, fiscal conditions, institutional capacity, and human capital development. Given the presence of large operational vineyard enterprises, the Czech Republic may experience faster PV diffusion once institutional and advisory barriers are reduced. Structural readiness in terms of farm scale may allow more rapid technological scaling than in systems dominated by very small holdings.

Conflict of interest: none

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Governance From the Perspective of University Staff Management: A Conceptual Model—A Theoretical Approach

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Abstract: Research on meso-level university governance has expanded rapidly, yet remains fragmented. Existing studies typically focus on participation models, academic staff wellbeing, and quality evaluation and institutional performance metrics. The literature indicates a lack of an integrative approach at the meso level, where governance structures directly shape working conditions, workload, and the organisational climate. Prior work rarely examines how managerial models and metric-driven logics affect academic staff wellbeing, job satisfaction, and work–life balance (Levecque et al., 2017; Kinman & Wray, 2020). At the same time, emerging organisational maturity models tend to overlook the human factor as a core element of universities' missions. In response, this article argues for developing an integrated tool for evaluating universities that would capture the relationships between governance, working conditions, and the performance of academic staff as the institution's key stakeholder. Such a tool could serve a diagnostic function and support responsible, sustainable governance of higher education.

Keywords: university governance; academic work; human resource management in higher education

JEL Classification: M1; M10

1. Introduction

Over recent decades, higher education institutions worldwide have faced mounting demands: massification of education, competition for funding, expectations regarding research and teaching quality, and greater accountability to stakeholders. These shifts have moved higher education from an elite model toward mass participation, necessitating new governance solutions. The traditional collegial model, centred on autonomous academic bodies, has become less effective amid growing organisational complexity and competitiveness. Consequently, hybrid arrangements that combine collegiality with managerial governance have gained prominence, enabling faster and more flexible decision-making (Shattock, 2014, 2019).

In response, governance—understood as the constellation of actors, institutions, rules, and processes that coordinate university activity—has become critical to effective management (Paradeise et al., 2009; Bleiklie & Kogan, 2007). Well-functioning governance mechanisms allow universities to adapt to changing external and internal conditions while maintaining accountability and operational capacity, particularly in human resource

management. Contemporary universities require more precise management of resources—finance, infrastructure, and personnel—to reduce goal conflicts arising from their multi-mission character (Amaral et al., 2003). Rising demands for transparency and efficiency, together with accountability pressures, also require robust governance structures that help prevent dysfunctions such as staff overload and the erosion of trust (Brunsson & Sahlin-Andersson, 2000).

Moreover, demographic changes in the academic workforce—such as ageing staff and increasing international mobility—call for modern, strategic personnel policies whose effectiveness depends on governance quality. Research shows that a lack of coherent decision-making structures hampers career management, balancing teaching and research workloads, and attracting talent (Enders & de Weert, 2009). Governance therefore becomes a key element in ensuring the stability and quality of academic staff and, in turn, universities' teaching and research outcomes (Shattock, 2019).

Despite the growing body of research on university governance, the field remains fragmented—especially at the meso level, where governance structures shape working conditions and the organisational climate. Studies seldom examine how specific governance models and leadership quality affect academic staff wellbeing, professional autonomy, and work–life balance (Levecque et al., 2017; Kinman & Wray, 2020). To address this gap, the article proposes developing an integrated tool for evaluating university performance that analyses the institution from the perspective of its key stakeholder—academic staff—incorporating their professional experiences and perceptions of organisational justice.

2. University Governance in the Literature

In higher education research, university governance is typically analysed across three interrelated levels: macro, meso, and micro. The macro level covers the systemic relationship between the state and higher education (steering models, regulations, agencies, and policy instruments). The meso level concerns the university as an organisation with its own decision-making structures, strategies, governing bodies, and rules of resource allocation. The micro level refers to organisational units (faculties, departments) and individual actors (staff, students, leaders) and their organisational practices (Reale, 2014; Bleiklie & Kogan, 2007; Paradeise et al., 2009). This three-level perspective integrates analyses of public policy with institutional solutions and the everyday functioning of academic communities (Reale, 2014), and helps explain how system-level decisions translate into internal university processes.

Contemporary scholarship clearly emphasises that governance is a key factor shaping universities' capacity to fulfil their missions, adapt to changing conditions, and manage resources effectively. Transformations of the academic environment—massification, internationalisation, pressure on research and teaching quality, competition for funding, and rising public accountability requirements—have increased organisational complexity and exposed the limitations of classic collegial models (Bleiklie & Kogan, 2007; Paradeise et al., 2009). In this context, governance—understood as a set of mechanisms, structures, and

processes of steering, coordination, and control—assumes central importance for organisational stability and institutional performance.

The importance of governance is confirmed by comparative research, including studies indexed in Scopus and Web of Science, which show that the organisation of authority and decision-making is among the strongest predictors of scientific, teaching, and organisational outcomes (Shattock, 2019; Dobbins & Knill, 2014). Governance is often described as a university's "architecture of possibilities": it provides a framework for strategic planning, defines rules of participation, establishes accountability relations and resource-allocation conditions, and shapes the balance between academic autonomy and public responsibility (Reale, 2013). From a normative perspective, governance grounded in transparency, participation, and accountability fosters trust both within the institution and in relations with external stakeholders (students, the state, funders, and economic partners).

Governance is also significant due to its direct practical implications for university management. Empirical research indicates that universities with stable, coherent, and professional governance mechanisms achieve better results in educational service quality and human resource management (Atanaw et al., 2025). Transparent decision-making rules enhance staff engagement, reduce organisational conflict, and enable more consistent personnel policies—including workforce development planning, optimisation of teaching and research workloads, and the creation of conditions conducive to research (Fumasoli et al., 2015). Governance also matters for quality assurance processes: not only as a set of formal structures but also as an institutional practice that shapes organisational culture, information flows, and the coherence of internal assessment systems (Seyfried & Pohlenz, 2018). Accordingly, governance is increasingly treated as a factor conditioning the effectiveness of organisational change and mitigating the unintended costs of reforms (e.g., growing bureaucratisation or declining internal trust).

Recent systematic reviews further show that governance gains new relevance in the context of twenty-first-century challenges such as digitalisation, risk management, sustainability, and the growing importance of institutional reputation (Oliveira et al., 2022; Raza et al., 2024). Universities with more mature and modern governance mechanisms appear better able to learn organisationally, respond rapidly to crises (e.g., the COVID-19 pandemic), and maintain institutional resilience amid dynamic environmental change. Governance thus ceases to be merely descriptive and becomes a strategic determinant of universities' long-term development, quality maintenance, and delivery of their social mission.

In sum, the international literature confirms that university governance is of fundamental importance both for higher education research and for the practice of managing academic institutions. Its growing salience reflects environmental pressures as well as the need to use resources effectively and to build an organisational culture grounded in transparency, responsibility, and participation. Strong governance enhances universities' capacity to make sound decisions, implement strategies, and maintain balance across multiple goals; it also creates conditions conducive to academic staff development, teaching innovation, research excellence, and institutional stability.

3. Academic Staff as a Key Stakeholder of University Governance

Research on university governance increasingly focuses on academic staff—not only as performers of teaching and research tasks but also as active stakeholders whose experiences and views reflect how governance structures operate. The literature discussed here clusters around three parallel streams: (1) participation models and shared governance, (2) academic staff wellbeing, and (3) quality evaluation, metrics, and institutional assessment systems.

3.1. *Shared Governance*

A growing body of work examines how higher education institutions implement shared governance models that involve academic staff in decision-making on strategy, internal policy, educational quality, and resource allocation. Reviews highlight considerable diversity in definitions, concepts, and practices, indicating increasing interest in how governance structures respond to demands for inclusiveness and collegiality (Honu, 2018; Birnbaum, 2004; Kezar & Eckel, 2004). Synthesis studies suggest that shared governance remains an ambiguous organisational category whose implementation depends on institutional traditions, leadership models, and the strength of academic bodies (Shah, 2014; Minor, 2004). Empirical evidence shows that, in many universities, formal participation does not translate into real influence over decision processes—especially in strategic and financial domains (Honu, 2018; De Boer & File, 2009; Lapworth, 2004). Staff are often marginalised in key managerial processes, which is also supported by comparative studies of participatory governance pointing to “symbolic representation” of employees in university governing bodies (Jungblut, 2017; Gayle et al., 2003).

One of the most recent systematic reviews, covering 48 empirical studies (Raza et al., 2024), identifies five main analytical axes of shared governance research: (1) actors involved in decision-making, (2) roles of academic leaders, (3) values and norms underpinning co-governance, (4) decision-making procedures, and (5) organisational models of shared governance. This indicates growing maturity and structuring of the research field. Consistent with other studies, governance appears to be evolving toward hybrid forms that combine managerialism with traditional collegiality, often generating tensions between administration and academic staff (Bleiklie & Kogan, 2007; Deem, 2007; Bolden et al., 2009). The literature stresses that the effectiveness of shared governance depends heavily on the quality of staff–leader relations, levels of trust, transparency of communication, and genuine opportunities to influence decisions (Tierney, 2006; Ramsden, 1998). Taken together, these findings suggest that academic staff participation is a core element of governance, yet its effectiveness is strongly contingent on the organisational and cultural context of the university.

A substantial body of research—especially bibliometric work—analyses relationships between university governance and the delivery of core missions: teaching, research, and the so-called third mission (engagement with external partners and knowledge transfer). In a review perspective, Rodríguez-Castro et al. (2021) propose a functional framework that identifies key institutional “functions and capabilities” and shows that governance—understood as decision-making structures, resource allocation, and steering mechanisms—is

crucial for maintaining balance between educational, research, and societal roles (Rodríguez-Castro et al., 2021). Similarly, comparative analyses by Huisman and Mampaey (2018) underline that governance affects the organisation of academic work, the dynamics of research teams, and universities' capacity to adapt to systemic change. This approach—linking institutional policy, management, and assessment systems—implies that academic staff, as the primary executors of the mission, are integral to governance analysis because the effectiveness of management systems is directly reflected in the quality of research and teaching (Fumasoli et al., 2015). The literature also includes a growing number of studies on institutional maturity models that conceptualise the university as an organisation evolving in its structures, processes, and institutional culture. Szydło (2024), in a bibliometric analysis of Web of Science and Scopus publications, shows that interest in maturity models increased sharply after 2010 and that one of the most frequently cited maturity factors is the stability and quality of governance. Teeroovengadum (2020) similarly argues that governance is a foundation of institutional quality and of universities' capacity to implement development-oriented strategies.

3.2. Academic Staff Wellbeing

Over the last two decades, the literature has shown a marked increase in interest in academic staff wellbeing and in the relationship between wellbeing and governance structures in higher education. These studies assume that governance—understood as a system of rules, procedures, decision structures, and leadership models—directly shapes academic working conditions and thereby determines wellbeing, work–life balance, and job satisfaction (Shin & Jung, 2014; Levecque et al., 2017).

A first stream of research focuses on academics' psychological wellbeing (mental health, wellbeing) as a function of organisational conditions. In seminal work, Levecque et al. (2017), studying doctoral candidates in Belgian universities, found that more than one-third reported clinically relevant depressive symptoms; key predictors included publication pressure, role ambiguity, interpersonal conflict, and lack of supervisory support—factors closely linked to local governance arrangements. Similar results were obtained in larger-scale UK studies, which showed that perceptions of organisational justice, transparency of promotion decisions, and the quality of relations with supervisors correlate with academic staff wellbeing more strongly than individual-level factors (Kinman & Wray, 2020; Guthrie et al., 2017). A growing body of systematic evidence also confirms that governance and organisational culture are decisive for employees' mental health (Hughes et al., 2020).

A second line of work examines work–life balance and its links to institutional policies and management practices. Bibliometric and comparative research (e.g., Siem, 2025) indicates that academia is among the most demanding professional environments, and that the intensifying “measure and publish” culture—driven by evaluation policies—reduces the capacity to maintain balance between professional and private life (Kyvik & Aksnes, 2015). Gender-studies-informed scholarship (e.g., Sallee, 2012; O'Meara et al., 2019) highlights that governance policies can reinforce inequalities in workload, particularly for women and for staff in lower-ranking positions who are more frequently drawn into organisational and

teaching tasks at the expense of research. These studies suggest that universities employing more participatory and transparent governance models report higher staff satisfaction with working conditions and better opportunities to sustain work–life balance.

Research also addresses the effects of performance pressure and metric logic on staff wellbeing. Evaluation systems based on publication point schemes, bibliometric indicators (e.g., the h-index), journal rankings, and unit-level performance-based assessments strongly shape academics' working environments, as documented in numerous WoS/Scopus-based analyses (Hicks et al., 2015; Aagaard, 2015; Moher et al., 2020). This work shows that metrics can increase workload, shorten research time horizons, intensify publication races, and restrict professional autonomy—which, combined with inadequate support structures, directly elevates stress and burnout (Shin & Jung, 2014; Guthrie et al., 2017). The phenomenon is sometimes described as an “academisation of organisational pressure,” whereby governance—through evaluation regulation—creates a high-demand environment with substantial physical and emotional costs.

A related stream examines academic leadership as a mediator between governance and wellbeing. Studies by Bolden et al. (2009) and Ramsden (1998) show that management style, communication transparency, and the quality of staff–leader relations substantially affect employees' sense of security. Douglas (2025), in a qualitative analysis of UK universities, argues that staff wellbeing is interpreted primarily in organisational terms—as a function of policy clarity, support, and predictability—rather than solely as the outcome of individual coping strategies.

3.3. Quality Evaluation, Metrics, and Institutional Assessment Systems

A review of the literature indicates that interest has grown in recent years in the relationship between governance systems and quality evaluation practices, organisational maturity models, and institutional performance assessment in higher education. Governance—understood as a system of rules, decision-making structures, procedures, and coordination mechanisms—is treated as a key determinant of how quality and control processes operate within universities (Paradeise et al., 2009; Shattock, 2019).

A first prominent strand concerns the links between governance and quality evaluation systems. Many studies show that rising accountability and efficiency pressures have led to the institutionalisation of diverse assessment mechanisms—including accreditation, audits, benchmarking, and national systems of performance-based evaluation of units (Stensaker & Harvey, 2011). Quality evaluation functions both as a control instrument and as a mechanism for strategic steering, which is particularly evident in New Public Management-based systems emphasising measurable results and process standardisation (Ferlie et al., 2008). From a governance perspective, the literature suggests that appropriate decision structures and process transparency are prerequisites for effective implementation of quality policies; their absence tends to produce superficial bureaucratisation and academic staff resistance (Huisman et al., 2007).

A second developing strand focuses on institutional maturity models used to assess universities' organisational development. Szydło (2024) reports a dynamic rise in interest in

maturity models after 2010, reflecting the need to understand the stages of organisational development in which universities are located and how governance affects their adaptive capacity. These models classify universities by the advancement of managerial, quality, and digital processes and assess organisational and strategic coherence. Schneider and Sadowski (2022) similarly show that institutional maturity correlates with operational effectiveness, the quality of strategic decision-making, and organisational resilience.

A third key strand relates to performance metrics, which over the last two decades have become an integral component of higher education governance. Hicks et al. (2015), in articulating the Leiden Manifesto, caution against excessive metricisation of science and argue for responsible use of bibliometric indicators. The literature repeatedly notes that indicator-based systems—publication evaluations, unit-level assessments, and university rankings—serve as instruments of organisational control and shape strategic behaviours of institutions and their employees (Aagaard, 2015; Moher et al., 2020). Kyvik and Aksnes (2015) show that evaluation-driven publication pressure significantly alters academics' research strategies, indicating that governance performs both regulatory and culture-forming functions.

A fourth strand, related to the above, examines the relationship between governance and institutional development. The literature suggests that universities operating under more collegial and participatory governance models cope better with implementing quality systems and assessment tools, whereas universities dominated by managerial models more often use evaluation as a control instrument (Bleiklie & Kogan, 2007). Studies also confirm that the way metrics and assessment models are used functions both as an indicator of organisational development and as a strategic planning tool, influencing mission, development priorities, the organisation of staff work, and stakeholder relations (Shattock, 2019; Pinheiro et al., 2015).

A synthesis of the available literature shows that, despite intensive development of governance research, several areas remain underexplored. As noted above, existing work concentrates primarily on three parallel streams: (1) participation models and shared governance, (2) academic staff wellbeing, and (3) quality evaluation, metrics, and institutional assessment systems. Each area is well represented; however, there is a substantial gap in integrating them, particularly at the meso level of institutional governance structures. Although many studies address shared governance and academic staff roles in decision-making, most do not examine how governance models directly affect staff wellbeing and professional functioning. Wellbeing research focuses on workload, publication pressure, or employment conditions, but rarely links these phenomena to institutional power structures, leadership quality, or degrees of participation (Levecque et al., 2017; Kinman & Wray, 2020). Thus, empirical accounts connecting governance → management practices → wellbeing remain scarce. Second, research on metrics and institutional evaluation tends to focus on consequences for scientific productivity, publication behaviour, and institutional strategies (Aagaard, 2015; Hicks et al., 2015), but pays less attention to impacts on the quality of academic work, work–life balance, or job satisfaction. As a result, explanatory models are

still lacking regarding how metric logic—as an element of governance—shapes staff wellbeing and organisational climate.

The author also notes that while institutional maturity models are developing (Szydło, 2024), they primarily analyse managerial and organisational processes without fully incorporating the human factor—especially the perspective of academic staff as the main executors of universities' missions. Research linking governance maturity to staff wellbeing, workload, and work quality remains limited.

Existing studies often analyse governance at the macro level (state policies) or the micro level (individual experiences), whereas the meso level—the everyday functioning of institutional governance structures—is comparatively under-described. Yet it is precisely at the meso level that the practical consequences of policies emerge: workload, accountability, metric culture, and leadership support.

There is therefore a need to propose an integrated tool for evaluating university performance that would analyse institutional functioning from the perspective of its key stakeholder—academic staff. Current assessment models—whether focused on teaching quality, research performance, or organisational maturity—provide fragmentary information and do not capture the systemic interdependencies between governance structures, working conditions, and employees' wellbeing and performance. The literature emphasises that institutional quality is inseparable from the conditions under which staff operate, as they carry the core educational and scientific mission (Fumasoli et al., 2015; Huisman & Mampaey, 2018). Meanwhile, dominant evaluation tools in higher education focus on organisational, bibliometric, or financial metrics, largely neglecting employees' professional experiences, perceived workload, organisational justice, and the quality of relations with leadership (Shin & Jung, 2014; Levecque et al., 2017).

Implementing an integrated evaluation tool—combining governance, academic staff wellbeing, metric culture, professional autonomy, working conditions, leadership quality, and organisational effectiveness—would enable comprehensive, multidimensional monitoring of university functioning. The literature highlights a gap precisely in this area: the absence of an instrument that analyses universities not only as organisational structures but also as workplaces and developmental environments for the most important stakeholder group, whose condition directly affects educational and research quality (Kinman & Wray, 2020; Hughes et al., 2020). Such a tool would also help identify latent governance dysfunctions, better align personnel policies, and, consequently, improve overall university performance in line with principles of responsible and sustainable management.

4. Proposed Conceptual Model

Figure 1 presents a proposed conceptual model of meso-level governance and its influence on the management of academic staff.

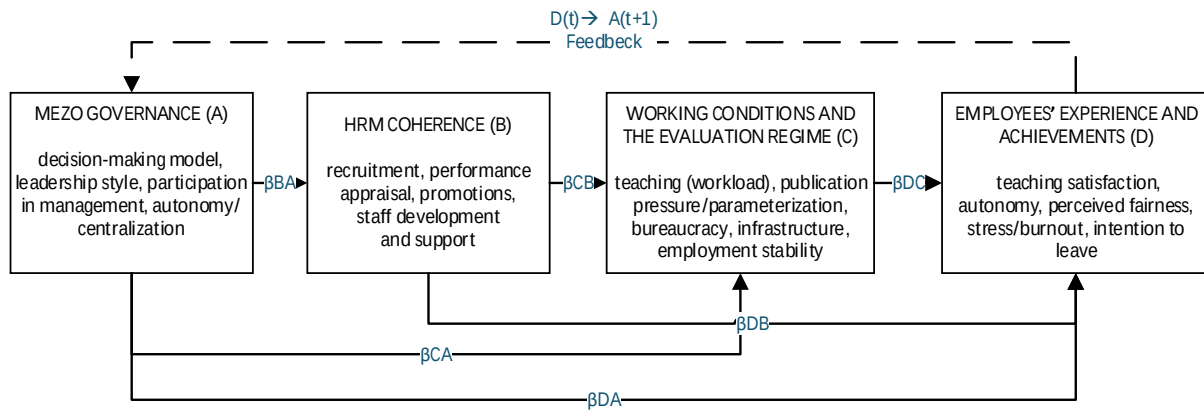


Figure 1. Relational conceptual model of academic work (blocks A–D)

The proposed conceptual model depicts the university as a complex system in which governance structures, personnel policy, organisational culture, and staff experiences form a dynamically connected configuration of mutually interacting elements. The framework is grounded in a relational perspective, which assumes that institutional effectiveness, the quality of academic work, and staff wellbeing do not result from single solutions but from interactions across the meso-organisational and micro levels. The model captures subtle—often not immediately visible—linkages between formal structures and everyday academic practices, highlighting the multidimensional nature of contemporary universities.

At the centre of the model is Block A, covering meso-level university governance. It is at this level that the institutional framework for the remaining processes is shaped. Governance constructs the architecture of authority, determines the degree of centralisation, the scope of unit autonomy, and the relationships between administration, academic authorities, and academic staff. The adopted steering mode sets directions and boundaries. Its significance lies in influencing both formal procedures and informal mechanisms that regulate day-to-day institutional functioning.

Within this block, the governance model plays a particularly important role, as it determines decision-making processes and the level of collegiality and organisational stability. It directly affects the extent to which staff can co-shape their working environment and the institution's capacity to create conditions supportive of research and teaching autonomy. Leadership style serves as a bridge between formal structures and individual experiences: it influences how decisions are communicated, interpersonal relation patterns, and the practical interpretation of university strategy. It can foster dialogue and trust—or, conversely, reinforce a hierarchical and control-oriented organisation. Staff participation, which is central to shared governance, is another key element: it provides opportunities to influence institutional decisions, strengthens perceptions of organisational justice, and reduces tensions between administrative and academic roles. The block is completed by organisational autonomy, which determines the university's ability to shape HR policies, research priorities, and curricula, and thus to balance external pressures with the institution's internal mission.

Built on these institutional foundations is Block B, which concerns the human resource management (HRM) system. In the model, HRM is not treated as a merely technical set of procedures but as a carrier of values and a mechanism shaping academic norms. Recruitment, evaluation, promotion, remuneration, and professional development systems reflect strategic priorities, and their implementation affects trust, perceptions of fairness, and staff motivation. HRM is therefore one of the main channels through which governance influences daily staff experience. At the same time, HR practices shape organisational culture by rewarding particular behaviours, promoting specific forms of research and teaching activity, and affecting relationship structures and collaboration. HRM thus has both regulatory and culture-forming functions.

Block C focuses on the immediate work environment, which most strongly determines academic staff's everyday experience. It encompasses the material, organisational, and procedural conditions of work that generate stress, satisfaction, overload, burnout, or effectiveness.

A key component is teaching workload: its intensity, diversity, and scheduling influence opportunities for research, recovery, and balancing responsibilities. Another element is publication pressure and performance-based assessment, which define the framework for evaluating scientific output. At its centre lies a point-based logic, journal lists, and publication expectations that shape the hierarchy of academic activities.

A important dimension of Block C is bureaucratisation of work, including reporting, accountability documentation, and administrative tasks shifted onto academic staff. High levels of bureaucratisation often reduce research efficiency. Access to research infrastructure is also crucial, as it determines the capacity to conduct internationally competitive research. Finally, employment stability affects perceived security, career planning, and the motivation of early-career researchers.

Block C serves as an environmental transmission channel through which governance and HRM exert influence. Its quality directly determines staff wellbeing.

These processes are reflected in Block D, which encompasses individuals' experiences and wellbeing. In the relational model, this level is treated as the most sensitive indicator of the university's overall functioning. Staff wellbeing results from perceived autonomy, fairness, workload, organisational security, and fit between institutional expectations and professional values. How staff perceive their situation shapes engagement, creativity, willingness to initiate actions, and intent to remain in the organisation. At the same time, individual experiences feed back into higher levels of the model: satisfied and motivated staff more readily participate in participatory processes, strengthen a culture of trust, and contribute to governance stabilisation. In this way, Block D is not only an outcome but also an active element of the relational system.

Overall, the model portrays the university as a structure in which institution-level decisions, HR practices, organisational climate and culture, and staff wellbeing constitute mutually conditioning components of a single system. Central to this approach is relationality: the processes are not analysed in isolation but as parts of a dynamic network of feedback loops. This perspective helps explain variation in university functioning in Poland

and internationally, underscores the importance of institutional relationship quality, and opens space for designing more adequate management interventions that reflect the complexity of the academic environment.

To increase analytical precision, the proposed framework can be expressed as a simple path model (structural equation model, SEM) that mirrors the relationships shown in Figure 1. Let A denote the quality of meso-level governance (e.g., decision-making arrangements, leadership style, participation, autonomy), B the coherence of the HRM system (recruitment, appraisal, promotion, development), C working conditions and the evaluation regime (teaching load, publication pressure, bureaucratization, research infrastructure, employment stability), and D employees' experiences and well-being (satisfaction, perceived organizational justice, autonomy, stress/burnout). The relationships between blocks can then be represented by three equations:

$$B = \beta_{BA} \cdot A + \varepsilon_B \quad (1)$$

$$C = \beta_{CB} \cdot B + \beta_{CA} \cdot A + \varepsilon_C \quad (2)$$

$$D = \beta_{DA} \cdot A + \beta_{DB} \cdot B + \beta_{DC} \cdot C + \varepsilon_D \quad (3)$$

This formulation implies that governance shapes HRM, HRM structures the work environment, and the work environment co-determines well-being. At the same time, “shortcut” effects may be incorporated (e.g., a direct path $A \rightarrow D$) if they are supported empirically. A key advantage of this formalization is that it separates direct effects (e.g., governance on well-being) from indirect effects (e.g., governance $\rightarrow$ HRM $\rightarrow$ working conditions $\rightarrow$ well-being). Practically, this enables estimation of whether staff well-being depends primarily on the governance model itself or rather on how governance is translated into HR policies and the concrete conditions under which academic work is performed.

Because the model also assumes feedback mechanisms (well-being influences participation, governance quality, and the implementation of HRM), these relationships can be most clearly captured in a dynamic, time-indexed form, for example: $A(t+1) = \phi_A \cdot A(t) + \gamma_{AD} \cdot D(t) + \eta_A$ (analogously for B and C). Such a specification strengthens the scholarly status of the concept by indicating clear pathways for empirical testing (e.g., cross-institutional comparisons, panel designs, or SEM-based estimation) while preserving the multidimensional relationships depicted in the figure.

A review of contemporary literature indexed in Scopus suggests that the proposed model is innovative, although its novelty lies primarily in integrating previously separate research approaches. The dominant JD–R (job demands–resources) perspective in studies of academic work focuses on relationships between demands and resources and their effects on stress, burnout, and wellbeing, without systematically incorporating the role of governance and formal institutional policies (Bakker & Demerouti, 2017; Boya et al., 2022). Research on teaching workload management, in turn, typically approaches it from the perspective of organisational efficiency and labour distribution (Szelągowska-Rudzka, 2018) and does not integrate it with evaluation regimes or employees' psychosocial experience.

A parallel stream on evaluation regimes and research performance-based assessment emphasises increasing indicator pressure, the influence of ranking systems, and publish-or-perish logics that distort scientific priorities and shape organisational culture (De Rijcke et al., 2016; Moed, 2017). However, this literature rarely links evaluation mechanisms with HRM practices or governance styles, limiting the ability to capture their systemic consequences for academic work. Conversely, HRM research in higher education increasingly addresses relationships between HR practices and employee engagement and wellbeing, but typically omits working conditions as a distinct analytical level (Przytula et al., 2025; Yin & Frenkel, 2020).

Against this background, the proposed model offers an original relational framework that connects four levels: governance (Block A), HRM (Block B), working conditions and the evaluation regime (Block C), and individual wellbeing (Block D). Particularly innovative is the delineation of Block C as the work environment, integrating teaching workloads, bureaucratisation, employment stability, infrastructure access, and publication pressure into a single coherent analytical category. In the literature these elements usually appear in a dispersed form, assigned to different research strands and rarely treated as systemically interconnected components of everyday academic work.

The model thus provides substantial added value by enabling analysis of academic work as a configuration of interacting structures, practices, and environmental conditions rather than the outcome of single factors. It thereby offers a fuller explanation of variation in wellbeing and work outcomes among universities operating under similar legal and policy environments. The model's innovation lies in creating a holistic theoretical framework that coherently integrates previously fragmented research areas in higher education studies.

5. Conclusions

The aim of this study was to propose a relational conceptual model explaining the conditions of academic work by linking four levels of university functioning: meso-level governance (Block A), the human resource management system (Block B), working conditions and the evaluation regime (Block C), and employees' experiences and wellbeing (Block D). The author's intention was to develop an analytical framework that clarifies how institutional rules, HR practices, and the work environment translate into academic staff's everyday functioning and why staff experiences may differ even within the same higher education system. In the context of dynamic changes in university management—rising evaluation pressure, intensification of research and teaching work, and progressive bureaucratisation—this perspective is relevant both theoretically and practically.

The model's relevance also stems from a research gap: existing studies of academic work remain dispersed across analyses of the psychosocial consequences of publication pressure, governance research, and selected HRM issues. Integrative approaches that capture interdependencies and feedback loops are still scarce. The proposed model addresses this problem by treating the work environment (Block C) as an autonomous yet pivotal analytical level that mediates between HRM practices and employee wellbeing.

A strength of the concept is its holistic and relational character: academic work is not presented as a consequence of individual procedures but as the result of a configuration of structural, organisational, and psychosocial factors. The model is anchored in the realities of contemporary higher education (metricisation, increasing workloads, bureaucratisation) and enables these phenomena to be operationalised. Its flexibility is also an advantage—it can be used in quantitative and qualitative research as well as in comparative analyses.

A limitation of the model is its complexity, which may hinder unambiguous operationalisation of the blocks and the measurement of relationships, particularly within Block C, which requires precise indicators. Moreover, the framework does not explicitly include macro-structural factors (public policy, global competition for talent, digitalisation) that may substantially shape university functioning and should be incorporated in further developments of the model.

The model opens promising avenues for further research, including empirical testing of relationships between blocks, institutional and international comparisons, long-term analyses of the effects of changes in evaluation and governance, and expansion of the framework to the macro level. Overall, it represents a step toward a more systemic understanding of academic work and may support more informed and sustainable design of HR policies and university governance strategies.

Conflict of interest: none

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Online Accommodation Intermediaries in Global Tourism: A Quantitative Comparative Analysis of Six Major Platforms

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Abstract: Digital platforms have fundamentally transformed the distribution of tourism services and are increasingly shaping the structure of global accommodation markets. Therefore, this study examines the market structure, financial performance and strategic profiles of six major travel platforms: Booking Holdings, Airbnb, Trip.com Group, Expedia Group, Tripadvisor, and MakeMyTrip. Drawing on secondary data from annual reports for the period 2017-2024, the study applies the Herfindahl-Hirschman Index and CR3 to assess market concentration, a phased Compound Annual Growth Rate analysis across three structurally distinct periods, and a descriptive cluster analysis based on four dimensions of financial and strategic profile. $HHI = 2,724.6$ confirms the oligopolistic character of the upper market segment (H1), with the three largest platforms controlling 83% total sample revenue. The phased growth rate analysis shows that the pandemic shock (2019-2021) was significantly deeper for platforms dependent on international travel, while recovery dynamics (2021-2024) favour platforms operating in emerging markets. The cluster analysis identifies three strategic profiles: high-margin global leaders, mid-scale platforms, and regional specialists. The key differentiator of financial performance is the combination of business model and geographic diversification, not platform size alone.

Keywords: online travel agencies; HHI; market concentration; CAGR; platform economics

JEL Classification: L13; L83

1. Introduction

The digital revolution has transformed the way tourism products are distributed and sold. Online accommodation intermediaries (OTAs) have become an indispensable part of the global travel ecosystem, with hotel reservations representing the second largest source of revenue from online sales channels, after air transport (Pinto & Castro, 2019).

OTAs operate as two-sided markets (Rochet & Tirole, 2003), connecting accommodation providers with travellers through network externalities on both sides of the platform. Hein et al. (2020) show that digital platforms with stronger network effects naturally converge towards higher market concentration, which this study empirically verifies in the context of the OTA industry.

Existing research focuses predominantly on a single platform or limited geographic comparisons (Talwar et al., 2020a, 2020b). A systematic comparative analysis encompassing all six dominant publicly traded platforms (BKNG, ABNB, TCOM, EXPE, MMYT, TRIP) in terms of market structure, financial performance, and strategic profile is lacking. This study addresses that gap.

Based on the analytical framework, three hypotheses are formulated:

H1: The global OTA platform market exhibits a high degree of concentration in 2024 ($HHI > 2,500$), indicating an oligopolistic market structure.

H2: The pandemic shock (2019-2021) had a significantly deeper impact on platforms focused on international travel than on platforms with a predominance of domestic markets.

H3: Platforms operating primarily in emerging markets (India, China) exhibit a higher recovery CAGR (2021-2024) than platforms focused on developed markets.

2. Methodology

The study employs a comparative case design (Yin, 2018) combining quantitative and qualitative methods. The primary data source is secondary financial data from annual reports and SEC/EDGAR filings for the period 2019-2024. The six companies analysed were selected on the basis of the following criteria: a digital OTA or travel platform listed on a public market (NYSE, Nasdaq, HKEX, or SGX), with an accommodation segment share of at least 30% of revenue or a strategic priority in this segment, availability of annual reports for a minimum of five years (2019-2024), presence on at least three continents or a dominant position in a regional market, and a market capitalisation above USD 1 billion as of 1 January 2025.

Based on these criteria, six companies were included: Booking Holdings (BKNG), Airbnb (ABNB), Trip.com Group (TCOM), Expedia Group (EXPE), Tripadvisor (TRIP), and MakeMyTrip (MMYT). Currencies were converted to USD using the average exchange rate for the relevant fiscal year. MMYT's fiscal year ends 31 March; FY2024 (April 2023 to March 2024, revenue USD 782 million) was used for the market concentration analysis.

2.1. Herfindahl-Hirschman Index and CR3

The HHI is defined as the sum of the squared percentage market shares of all observed entities (Rhoades, 1993):

$$HHI = \sum_{i=1}^n s_i^2 \quad (i = 1, 2, \dots, n) \quad (1)$$

where s_i is the percentage market share of the i -th firm expressed in percentage points (a 40% share enters as 40, not 0.40). The HHI value ranges from $10,000/n$ to 10,000. According to U.S. Department of Justice (2010) guidelines, markets with $HHI < 1,500$ are unconcentrated, 1,500-2,500 are moderately concentrated, and $HHI > 2,500$ are highly concentrated. The cumulative share of the three largest players (CR3) is defined as $CR3 = s_1 + s_2 + s_3$.

Methodological limitation: the HHI is calculated on a sample of six publicly traded platforms, not on the entire OTA market (which includes thousands of regional and niche OTAs). The result therefore characterises the oligopolistic upper tier of the market.

2.2. CAGR Analysis

To capture revenue growth dynamics across three structurally distinct phases, the CAGR (Compound Annual Growth Rate) was calculated for each company:

$$CAGR = (Revenue_{end} / Revenue_{start})^{(1/n)} - 1 \quad (2)$$

The analytical phases are defined as three adjacent time periods with shared endpoints: (1) 2017 to 2019 as the pre-pandemic baseline of organic growth; (2) 2019 to 2021 capturing the cumulative impact of the COVID-19 pandemic including the second wave; (3) 2021 to 2024 as the recovery period.

2.3. Cluster Analysis, Porter's Five Forces, and PEST Analysis

The descriptive cluster analysis classifies the six platforms on the basis of four dimensions: 2024 revenue (USD), net margin (%), ROIC (%), and the share of the primary market in total revenue (%). The qualitative analysis of industry structure follows Porter's (2008) five forces model, where the intensity of each force is assessed on a Low-Medium-High scale based on evidence from annual reports. The macro-environment of the industry is assessed through a PEST analysis covering the political, economic, social, and technological factors relevant to the OTA industry in 2024.

3. Results

3.1. Market Concentration Analysis

The market concentration analysis is based on the revenues of the six observed platforms for 2024. Total sample revenues amount to USD 58.45 billion. Table 1 presents the complete HHI calculation.

Table 1. HHI Calculation, 2024.

Company	Ticker	Revenue 2024 (USD bn)	Market share s_i (%)	s_i^2 (HHI points)
Booking Holdings	BKNG	23.74	40.6	1,648.4
Expedia Group	EXPE	13.69	23.4	547.6
Airbnb	ABNB	11.10	19.0	361.0
Trip.com Group	TCOM	7.30	12.5	156.3
Tripadvisor	TRIP	1.84	3.1	9.6
MakeMyTrip	MMYT	0.78	1.3	1.7
TOTAL / HHI		58.45	100.0	2,724.6

HHI = 2,724.6 clearly exceeds the 2,500-point threshold under the U.S. DOJ (2010) methodology, thereby confirming H1 of a highly concentrated, oligopolistic market. CR3 = 83.0%. The market leader BKNG alone controls 40.6% of total sample revenue. This result is consistent with the predictions of two-sided market theory (Rochet & Tirole, 2003): platforms with strong network effects naturally converge towards a concentrated market structure.

3.2. CAGR Analysis

Table 2 captures revenue CAGR across three analytically distinct periods. The pre-pandemic CAGR is calculated from revenues for 2017 and 2019 as the organic growth baseline. The pandemic CAGR covers the years 2019-2021 and captures the cumulative impact of the pandemic including the second wave. The recovery CAGR is calculated for the period 2021-2024. Data are drawn exclusively from annual reports (Form 10-K/20-F) filed through the SEC EDGAR system, where each company's results overview provides comparable historical revenues for prior years.

Table 2. Revenue CAGR by time phase

Company	Pre-pand. CAGR 2017→2019 (%)	Pand. CAGR 2019→2021 (%)	Recovery CAGR 2021→2024 (%)	Intl. share (%)
BKNG	+13.2	-14.7	+29.4	>85 (global)
EXPE	+8.4	-15.6	+16.8	~39
ABNB ¹	N/A (IPO 2020)	N/A	+22.8	~69
TCOM	+20.1	-34.0	+33.2	~78
TRIP	+4.8	-24.0	+26.7	~75
MMYT ²	+14.6	-38.3	+74.8	<10

Note: ¹ABNB: listed December 2020, pandemic CAGR not available. ²MMYT: fiscal year ends 31 March; FY2022→FY2025 used for recovery phase.

The results support H2 and H3. During the pandemic period 2019-2021, the deepest cumulative decline was recorded by platforms focused on Asian markets: MMYT (-38.3% CAGR), TCOM (-34.0%), and TRIP (-24.0%). BKNG and EXPE reported a comparable contraction (-14.7% and -15.6% CAGR respectively). Airbnb does not have comparable data (IPO December 2020), however its 2021 annual report documents a revenue decline from approximately USD 4.8 billion in 2019 to USD 6.0 billion in 2021, indicating recovery already during the pandemic period driven by a shift in demand towards domestic and rural destinations.

In the recovery period 2021-2024, H3 holds: MMYT (+74.8% CAGR) and TCOM (+33.2%) significantly outpace the recovery tempo of platforms focused on developed markets (EXPE +16.8%, BKNG +29.4%). TCOM recorded strong recovery despite the delayed reopening of the Chinese market to international flights (April 2023), after which a sharp surge in pent-up demand followed.

3.3. Cluster Analysis

Based on the combination of revenue, net margin, ROIC, and geographic concentration, the six platforms can be assigned to three strategic clusters.

Cluster C1 comprises platforms that converted market dominance into high margins and strong cash flows. The shared feature is an agency or quasi-agency model and global reach. Cluster C2 includes platforms with a more complex structure. EXPE faces high interest costs from debt financing; TCOM records a high net margin owing to tax preferences for Chinese tech companies, but the operating margin (26.6%) better reflects true profitability. Cluster C3 represents platforms in a phase of transformation or expansion: Tripadvisor is reshaping its

business model, while MakeMyTrip is capitalising on the structural growth of the Indian market.

Table 3. Strategic clusters of OTA platforms

Cluster	Platforms	Key characteristics	Net margin 2024	ROIC 2024
C1: High-margin global leaders	BKNG, ABNB	Global reach, agency or hybrid model, highest free cash flow, strong brand	> 23%	> 23%
C2: Mid-scale platforms	EXPE, TCOM1	Mid-sized revenue, hybrid model, mixed geography, lower margins or impact of non-operating income	9-32%*	15-18%
C3: Regional specialists	TRIP, MMYT	Low revenue, niche or regional strategy, low or unstable margin, high recovery CAGR	0.3-9.7%	5-12%

Note: ¹TCOM 32% includes significant non-operating income and a tax benefit.

3.4. Porter's Five Forces Analysis

The industry structure of the OTA market is assessed using Porter's five forces model (Porter, 2008). The intensity of each force is evaluated on the basis of evidence from annual reports and reflects the situation as of 2024.

Table 4. Assessment of Porter's five forces

Porter's force	Intensity	Key evidence
Rivalry among existing competitors	VERY HIGH	Massive performance marketing expenditure (SEM, affiliate); price wars and discounts; loyalty programmes as a differentiator (Genius, One Key)
Threat of new entrants	MEDIUM	Low technological barrier, but high capital intensity of marketing; main threat from tech giants (Google Travel)
Bargaining power of customers	HIGH	Zero switching costs; price transparency; multi-homing (simultaneous comparison across multiple platforms)
Bargaining power of suppliers	MEDIUM-HIGH	Large hotel chains strengthening direct channels; dependence on GDS systems and cloud infrastructure
Threat of substitutes	HIGH	Direct bookings on hotel websites; metasearch (Google Hotels); emerging AI travel assistants

The overall assessment confirms that the OTA industry operates in a structurally demanding environment. Four of the five forces act with high or very high intensity. This finding explains the sample's average net margin of 15.0% and median of 11.4%, which is significantly lower than in industries with a more favourable structural position.

3.5. Financial Indicators and Business Models

Table 5 summarises the key financial and operational indicators for all six platforms for 2024. Financial data were obtained from company annual reports (Airbnb, 2025; Booking Holdings, 2025; Expedia Group, Inc., 2025; MakeMyTrip Limited, 2025; Tripadvisor, Inc., 2025; Trip.com Group Limited, 2025).

Table 5. Comparison of key financial and operational indicators, 2024

Indicator	BKNG	EXPE	ABNB	TCOM	TRIP	MMYT
Revenue (USD bn)	23.74	13.69	11.10	7.30	1.84	0.78
Operating margin (%)	31.8	9.6	23.0	26.6	5.0	12.3
Net margin (%)	24.8	9.0	23.9	32.0	0.3	9.7
ROIC (%)	56.2	17.7	23.8	~15	~5	~12
Gross bookings (USD bn)	~165	110.9	81.8	N/A	N/A	7.95
Business model	Agency + Merchant	Merchant + Agency	Agency (fee)	Agency	CPC + Comm.	Commission
Accommodation share of revenue (%)	~89	~80	~95	~40	~32	~46

Booking Holdings dominates across all absolute metrics and achieves the highest ROIC (56.2%) as a result of the combination of a hybrid model, global reach, and a long-growing share of direct bookings through the Genius programme (Booking Holdings, 2025). Airbnb stands out for the combination of a high net margin (23.9%) and strong free cash flow; collecting service fees at the time of booking rather than at the time of the stay structurally gives it the strongest FCF in the sample (Airbnb, 2025). Trip.com Group reports an anomalously high net margin (32%) owing to non-operating income from financial investments and the application of a reduced tax rate for tech companies in China. Looking at the operating margin (26.6%), it is the second most profitable player in the sample (Trip.com Group, 2025). Tripadvisor, with a net margin of 0.3%, is valued by the market as a platform in restructuring.

3.6. Macro-environment (PEST)

The following macro-environment analysis assesses four factors affecting the OTA industry in 2024. Regulation of short-term rentals (STR) tightened significantly in 2024. The EU Council adopted a regulation in March 2024 on harmonised registration requirements for hosts (OECD, 2024) and at the city level London applies a 90-day rule (Greater London Authority, 2025), Prague is proposing a statutory limit of 60 days (Horníčková, 2025), and Budapest is planning a complete ban in one district from 2026 (Budapest Invest, 2024). Regulatory pressure is also expanding into the area of competition law. Booking.com received a record fine of EUR 413.2 million from the Spanish competition authority for abuse of dominant position and enforcement of price parity (Kahánek, 2024), and the European Commission blocked the acquisition of Etraveli Group (Booking Holdings, 2025).

Economically, the industry remains in a growth phase. The global OTA market reached a value of USD 253.2 billion in 2024 and expected growth to 2034 is approximately USD 533.7 billion (Global Market Insights, 2025).

On the demand side, Generation Z and millennials are reshaping the way people travel and purchase. They prefer personalisation, mobile access, and authentic experiences over standardised hotel stays (Quinby, 2024), which is pushing platforms to transition from a purely distributive model towards guiding the entire travel experience.

Technologically, generative AI has become the central strategic trend. Platforms are investing in AI planners, dynamic pricing, and customer support automation (Papandreou, 2024), with Trip.com investing USD 1.8 billion in research and development in 2024, demonstrating that technological differentiation is becoming a key instrument of competitive rivalry.

4. Discussion

The empirically measured value of $HHI = 2,724.6$ and $CR3 = 83\%$ confirm H1 and are consistent with the predictions of two-sided market theory (Rochet & Tirole, 2003). Three platforms control 83% of sample revenue, with BKNG alone holding 40.6%. This result reflects the mechanism described by Hein et al. (2020): network externalities lead to natural tendencies towards oligopolisation, as a larger platform attracts more providers and customers, thereby further reinforcing its position.

The CAGR analysis confirms H2 and H3. During the pandemic period 2019-2021, the strongest impact was on platforms focused on Asian markets, specifically MMYT (-38.3% CAGR) and TCOM (-34.0%). Recovery dynamics 2021-2024 are markedly asymmetric, with MMYT (+74.8%) and TCOM (+33.2%) significantly outpacing the recovery tempo of developed markets such as EXPE (+16.8%). This asymmetry has implications for strategic planning, as diversification into emerging markets may strengthen overall portfolio resilience.

The results have three practical consequences for strategic decision-making. First, the future development of OTAs will be shaped by the tension between technological consolidation, where AI deepens differentiation, and regulatory pressure in the form of DMA and antitrust proceedings. Second, platforms that remain purely distributive intermediaries face growing pressure from AI planners and metasearch tools, and the industry is therefore moving towards integrated travel platforms of the Connected Trip type. Third, insufficient adaptation to the STR regulatory framework may lead to financial penalties and reputational damage.

The HHI is calculated on a sample of six platforms; the actual concentration of the entire OTA market (including thousands of smaller players) is significantly lower. The cluster analysis is a descriptive typology at $n = 6$; statistical validation would require a substantially larger dataset. Fiscal years are not identical (MMYT: April-March), which limits the precision of cross-company comparison.

5. Conclusions

This study provides the first systematic, quantitatively grounded analysis of market concentration and strategic profiles of the six major publicly traded OTA platforms using data for the period 2017-2024. $HHI = 2,724.6$ unambiguously confirms the oligopolistic character of the upper market segment (H1), $CR3 = 83\%$. The phased CAGR analysis confirms H2 and H3: the pandemic shock (2019-2021) was most severe for platforms dependent on international travel, and recovery (2021-2024) is significantly faster in emerging markets.

The key differentiator of financial performance in the OTA industry is the combination of market position and business model, not absolute size. Platforms with an agency model collecting fees prior to the stay achieve structurally stronger free cash flow independently of their market share.

The future development of the market will be shaped by two opposing forces. Technological transformation in the form of generative AI and the Connected Trip concept deepens differentiation and raises entry barriers, while regulatory pressure in the form of DMA, antitrust proceedings, and STR regulation seeks to preserve competitive dynamics. Platforms that can effectively balance investment in technology with adaptation to the regulatory environment will be better positioned to maintain competitiveness in a growing oligopoly.

Acknowledgments: The work was supported by the internal project “SPEV – Management Challenges in the Context of Digital Transformation”, 2025, University of Hradec Králové, Faculty of Informatics and Management, Czech Republic.

Conflict of interest: none

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Comparing Housing Affordability in the European Union

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Abstract: This paper presents an alternative approach to the comparative analysis of housing affordability in European Union countries, utilizing linear regression on logarithmically transformed data. Methodologically, it builds on the model proposed by Kratochvíl and Havlíček (2024), who critically questioned the validity of per capita indicators in international comparisons. Traditional ratio-based indicators often distort reality by systematically overestimating values for small countries and underestimating them for countries with large populations, particularly when no direct proportional relationship exists between the observed variables and population size. The proposed regression approach enables the identification of residuals as indicators of deviations from the expected price trend based on population size. By comparing these residuals with conventional indicators, we provide evidence that regression-based models can serve as a more robust and equitable tool for assessing housing affordability, thereby supporting more informed public policymaking in the housing sector.

Keywords: housing affordability; log–log regression; residual analysis; per capita bias

JEL Classification: C21; R31; O18

1. Introduction

Housing affordability has become a key economic and social issue across the Member States of the European Union in recent years (Kikerec, 2024; Matějková & Tichá, 2025). It is typically assessed using ratio-based indicators, such as the share of housing expenditures relative to income or the housing cost overburden rate, often defined as spending more than 40% of disposable income on housing (European Construction Sector Observatory, 2019; Eurostat, 2022). While these approaches provide a certain degree of practical guidance (Bogdon & Can, 2003; Stone, 2006), they remain limited, as they fail to adequately account for structural differences between countries, such as population size, demographic density, or the level of urbanization (Licchetta, Dias Martins & Vašíček, 2025; Kikerec, 2024).

Kratochvíl and Havlíček (2024) demonstrated that ratio-based (per capita) indicators systematically bias results: small countries tend to be overestimated, while large countries are underestimated, whenever there is no direct proportional relationship between the observed variable and population size. This critique has proven relevant not only for GDP, mortality rates, or CO₂ emissions, but the same principle also applies to housing prices and income ratios.

In assessments of housing affordability, standardized indicators such as the housing cost overburden rate—defined as the share of households spending more than 40% of their disposable income on housing—are frequently used. This indicator is officially employed by institutions such as Eurostat and the OECD (European Construction Sector Observatory, 2019), but its simplicity entails substantial limitations. For instance, it does not account for the uneven distribution of income across population groups and may therefore conceal the actual difficulties faced by low-income households within average values (Kikerec, 2024). Another drawback is that the indicator operates as a simple ratio (costs/income), making it prone to distortions like those affecting other per capita measures. Countries differ in their tax structures, levels of social transfers, market prices of real estate, and cultural models of homeownership, all of which affect data comparability. For this reason, some authors recommend more sophisticated tools, such as multidimensional models or quantile regressions, which better capture the differentiated impacts of housing prices across socioeconomic strata (Fairbrother, 2014; Chung et al., 2019). These methods enable the analysis of affordability not only on average, but also at the level of poorer households, for whom the problem of housing affordability is often most acute.

Therefore, we propose applying linear regression on a log–log scale (Kratochvíl & Havlíček, 2024) to purge price indicators of the effect of population size. The model residuals (i.e., deviations from the expected price trend) then serve as a more robust measure of housing affordability, free from the inherent limitations of ratio-based indices. This regression-based approach enables the identification of countries that face genuinely higher or lower housing cost burdens relative to their economic and demographic profiles.

2. Methodology

The analysis is based on a combination of harmonized macroeconomic and demographic data obtained primarily from Eurostat databases (2024a, 2025) and the Organisation for Economic Co-operation and Development (OECD, 2024), with data from national statistical offices of individual EU Member States used where necessary. For each country, the following variables were collected:

- Total population (as of 1 January of the respective year).
- Median market price of a dwelling (in euros), with imputed values used in cases of missing data based on prices per square meter and a typical dwelling size.
- Median net annual income of a household or an individual, depending on data availability and methodological comparability.

The datasets were further adjusted for logarithmic transformation and cross-country harmonization. Following the methodology proposed by Kratochvíl and Havlíček (2024), a log–linear regression model is employed to analyze the relationship between population size and median dwelling prices across EU Member States.

In the literature and official statistics, housing affordability is most often assessed using ratio-based indicators, including in particular:

- PIR – Price-to-Income Ratio
- The ratio between the average property price and the annual median household income. Used, for example, by the World Bank and the OECD. Lower values indicate higher housing affordability (OECD, 2024a; IMF, 2025).
- HCM – Housing Cost Overburden Rate
- The share of the population spending more than 40% of their income on housing-related costs (including energy). A standard Eurostat indicator. A higher share indicates lower housing affordability (Eurostat, 2024a; OECD, 2024b).
- MIR – Mortgage-to-Income Ratio
- The ratio between monthly mortgage payments and monthly household income. Accounts not only for housing prices but also for interest rates and loan maturity (OECD, 2024a).
- Rent-to-Income Ratio
- The ratio between rent and income (monthly or annual). Used primarily in analyses of rental housing markets (OECD, 2024a).

Although these indices are intuitive and easy to compute, they suffer from inherent limitations: as ratio-based measures, they ignore the effects of population size, demographic density, and market structures. Therefore, we propose a regression-based approach inspired by Kratochvíl and Havlíček (2024), which addresses these distortions through a log–log model and residual analysis.

3. Results

The results of the analysis show that the traditional Price-to-Income Ratio (PIR) exhibits high variability and pronounced sensitivity to extreme values, particularly in countries with very low-income levels (e.g., Bulgaria and Romania) and in countries with exceptionally high housing prices (e.g., Luxembourg and the Netherlands). These extremes tend to affect relative cross-country comparisons significantly. In contrast, the residual values derived from the log–linear regression model display considerably greater stability, as the influence of extreme observations is substantially reduced.

Countries in Central and Eastern Europe—specifically Czechia, Slovakia, Hungary, Poland, and Croatia—exhibit PIR values well above the general trend line. This pattern points to the presence of structural factors, most notably rapid housing price growth in recent years, a persistently limited supply of new housing, tightening financing conditions, and a strong preference for owner-occupied housing. The regression residuals, however, suggest that the broader relationship between housing prices and income levels can explain part of these differences.

By contrast, countries such as Denmark, Bulgaria, and Italy record low residual values, indicating that housing prices in these countries are broadly in line with, or slightly below, the levels expected given household income. This finding suggests that high or low PIR values do not necessarily reflect the true extent of housing cost burden. Still, it may instead result from methodological limitations inherent in ratio-based indicators.

Overall, the results confirm that the regression-based approach, which relies on the logarithmic transformation of variables, mitigates distortions arising from extreme values and small-sample effects, thereby providing a more stable and methodologically consistent framework for international comparisons of housing affordability.

The quantitative results indicate substantial differences in dispersion between the PIR index and the regression-based residuals. While PIR values range from 3.093 to 13.305, regression residuals vary only between -0.262 and 0.300 , demonstrating markedly lower variability across countries. This narrower interval suggests that the regression approach effectively controls for income differences and reduces cross-country distortions. Overall, the empirical comparison confirms the greater statistical stability of the residual-based indicator.

3.1. Detailed Results of the Analysis

The results of the log-linear regression analysis of the relationship between prices of newly built dwellings and household incomes in European Union countries allow for a systematic comparison with the traditional Price-to-Income Ratio (PIR). The analysis assesses differences in the explanatory power of both approaches in evaluating housing affordability.

In the selected model, the dependent variable was the average price of a newly built 70 m² apartment (in EUR), while the independent variable was the average annual gross household income (in EUR). By applying a log-log linear regression, we examined whether housing prices correspond to income levels across individual countries, that is, whether a proportional relationship exists between these two variables.

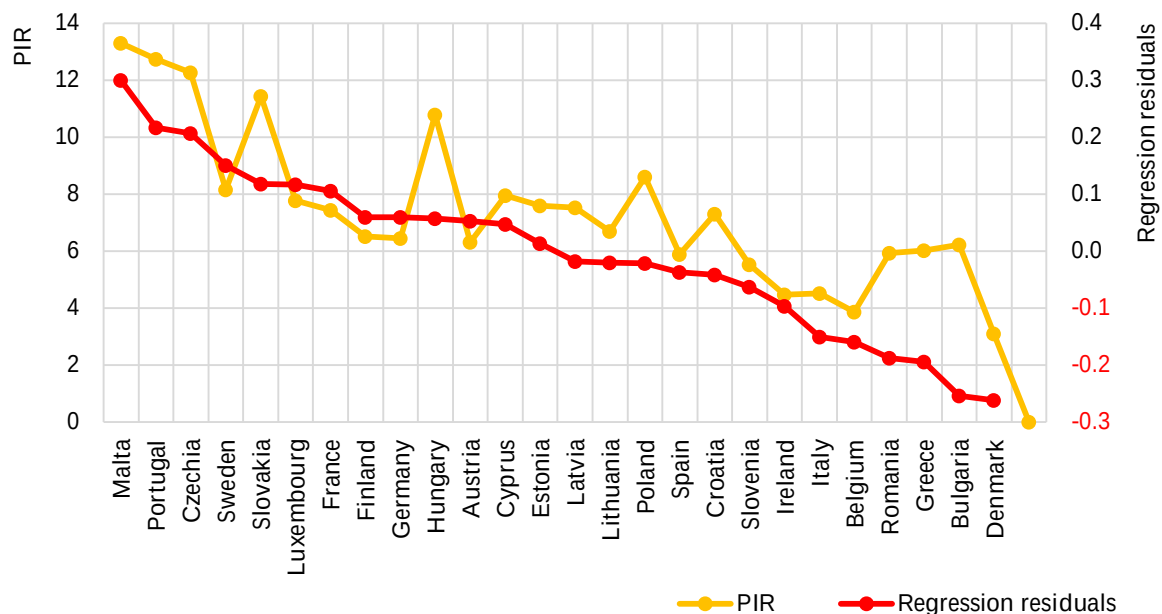


Figure 1. Graphical comparison of the two examined metrics

The figure contrasts two alternative metrics used to evaluate housing affordability across EU Member States.

- The yellow line (Price-to-Income Ratio, PIR) represents a conventional indicator that measures the number of average annual incomes required to purchase a dwelling of a given size.
- The red line (representing residuals from the log–linear regression model) indicates the deviation of observed dwelling prices from values implied by national income levels, showing whether prices exceed or fall below expectations.

The analysis demonstrates that the PIR is characterized by substantial dispersion and marked sensitivity to extreme observations. This is particularly evident in countries with very low-income levels, such as Bulgaria and Romania, as well as in countries with exceptionally high housing prices, including Luxembourg and the Netherlands, where relative comparisons are disproportionately affected. In contrast, residuals obtained from the log–linear regression framework exhibit considerably lower volatility, as the impact of extreme values is attenuated mainly, resulting in a smoother and more stable pattern.

Several Central and Eastern European countries—namely Czechia, Slovakia, Hungary, Poland, and Croatia—record PIR values that significantly exceed the prevailing trend. This outcome points to a combination of structural factors, including rapid increases in housing prices, persistently constrained housing supply, tightening credit conditions, and a strong cultural preference for owner-occupied housing. At the same time, the regression residuals indicate that part of these deviations can be attributed to the underlying income–price relationship rather than to affordability distortions alone.

Conversely, Denmark, Bulgaria, and Italy are associated with relatively low residual values, suggesting that housing prices in these countries broadly correspond to, or remain slightly below, levels predicted by household income. This finding highlights that elevated or depressed PIR values do not necessarily reflect the actual housing cost burden. It may instead be influenced by methodological shortcomings inherent in ratio-based measures.

Taken together, the results indicate that the regression-based approach, employing logarithmic transformations, reduces biases associated with extreme values and limited sample sizes. Consequently, it offers a more robust and internally consistent framework for cross-national comparisons of housing affordability.

As a result, these countries exhibit a significant divergence between PIR values and regression-based predictions since the simple price-to-income ratio fails to capture all relevant structural factors. In contrast, the regression model partially stabilizes these effects through its underlying trend function.

The traditional PIR index is limited by its sensitivity to absolute income and price levels and may overstate affordability problems in wealthier countries while understating them in poorer ones. Residual analysis based on the log–log model mitigates this shortcoming, enabling a more equitable assessment of housing affordability across countries.

The map illustrates the residual values from the log–linear regression between the average price of a newly built dwelling and average annual income. The blue color scale represents deviations from the trend-based prediction:

- Light blue: prices below the predicted level.
- Medium blue: prices in line with the trend.
- Dark blue: prices above the expected level.

This visualization facilitates a rapid spatial overview of differences in housing affordability across the European Union.

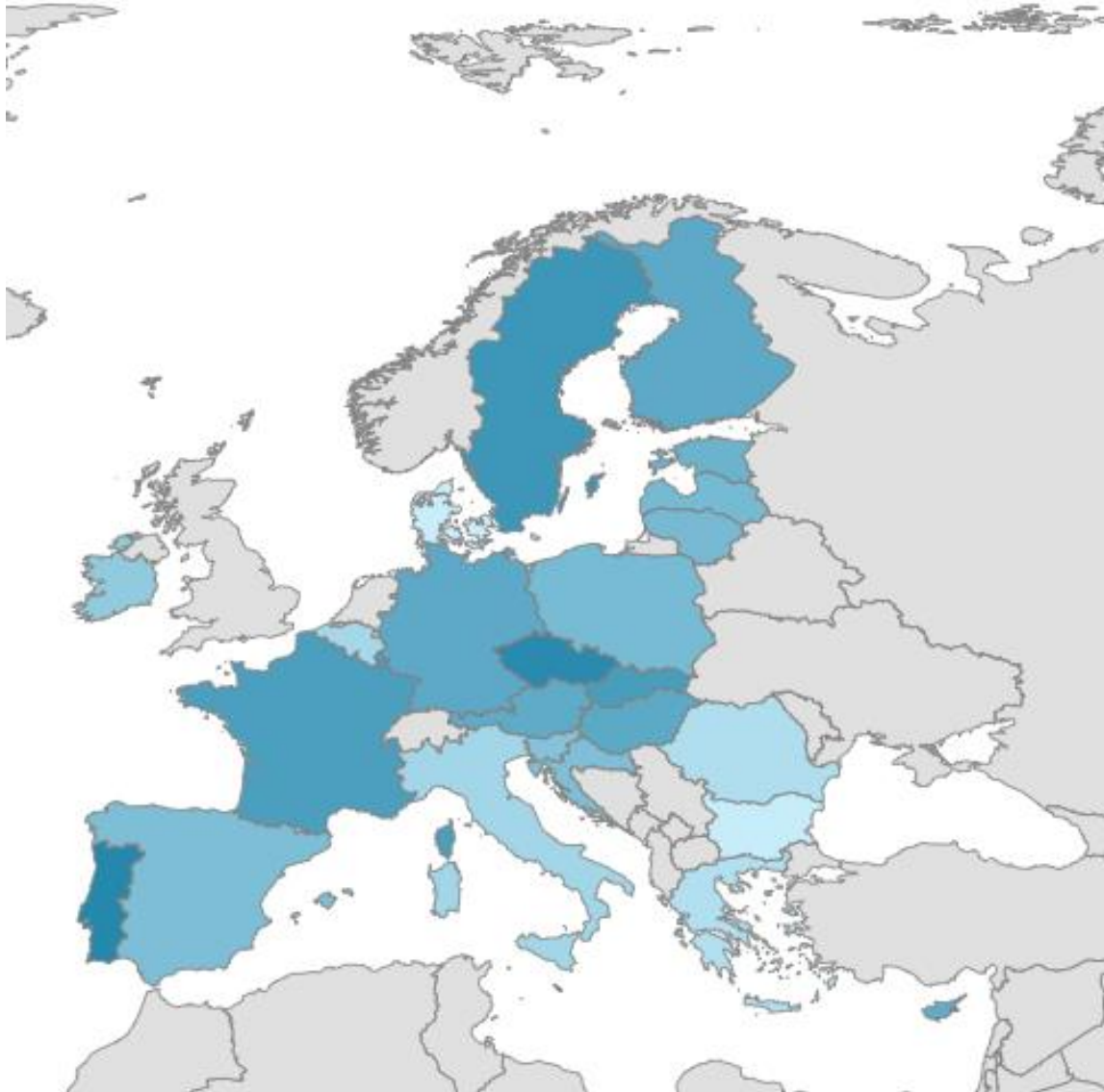


Figure 2. Geographical distribution of housing price residuals relative to income levels

Despite its statistical foundation, the proposed regression model is characterized by a surprising degree of simplicity and intuitive clarity. Its core consists of a linear relationship between the logarithmically transformed average housing price and the logarithm of average annual income, which enables the capture of the general trend in the relationship between the two variables. The advantages of this approach lie not only in its low computational complexity but, above all, in the greater stability of the results and their robustness to extreme values when compared with traditional ratio-based indicators (e.g., price-to-income ratios or per capita measures), which are often strongly affected by small bases in low-population countries.

Another significant strength of the regression framework is its methodological flexibility. The model can be readily extended to include additional variables that have been empirically identified as relevant determinants of housing affordability. These factors include:

- Level of urbanization: higher population concentration in urban agglomerations is typically associated with stronger demand and rising prices (see, e.g., OECD, 2021).
- Population density: as an indicator of pressure on space and infrastructure that influences housing markets.
- Demographic structure: the proportion of young households entering the housing market, representing a key demand group.
- Interest rates: a factor affecting practical housing affordability even when nominal housing prices remain unchanged.
- Share of rental housing: different ownership and rental arrangements influence mobility, price dynamics, and the vulnerability of specific population groups.

By incorporating these variables, the predictive power of the model can be strengthened, while simultaneously creating a multidimensional tool suitable for both academic comparison and practical policymaking in the housing field.

3.2. Formatting of Mathematical Components

Following the methodology proposed by Kratochvíl and Havlíček (2024), a log–linear regression model is employed to analyze the relationship between population size and median dwelling prices across EU Member States. Given the assumed nonlinearity of the relationship and the presence of scaling effects between variables, the model is specified as:

$$\log(Y_i) = a \cdot \log(X_i) + b + \varepsilon_i, \quad (1)$$

where:

Y_i denotes the median dwelling price in each country.

X_i represents the population size.

a is the scaling coefficient describing the elasticity of prices with respect to population.

b is a constant capturing the baseline price level.

ε_i is the residual, i.e., the deviation of the observed value from the value predicted by the model.

The model is estimated using the ordinary least squares method after applying a logarithmic transformation to both variables, which removes nonlinearities and stabilizes variance.

Interpretation of residuals:

$\varepsilon_i = 0$ corresponds to the trend.

$\varepsilon_i > 0$ is higher than the expected trend.

$\varepsilon_i < 0$ is lower than the predicted trend.

The residual component thus enables the identification of whether housing price levels in each country are above or below average relative to population parameters, providing an alternative to traditional per capita indicators.

3.3. Interpretation of the Relationship between Absolute and Relative Indicators in the Functional Space

The analysis of functional relationships between absolute and relative indicators identifies the conditions under which ratio-based measures are analytically meaningful. A functional perspective clarifies how growth patterns between the variable and population size affect the stability of per capita indicators.

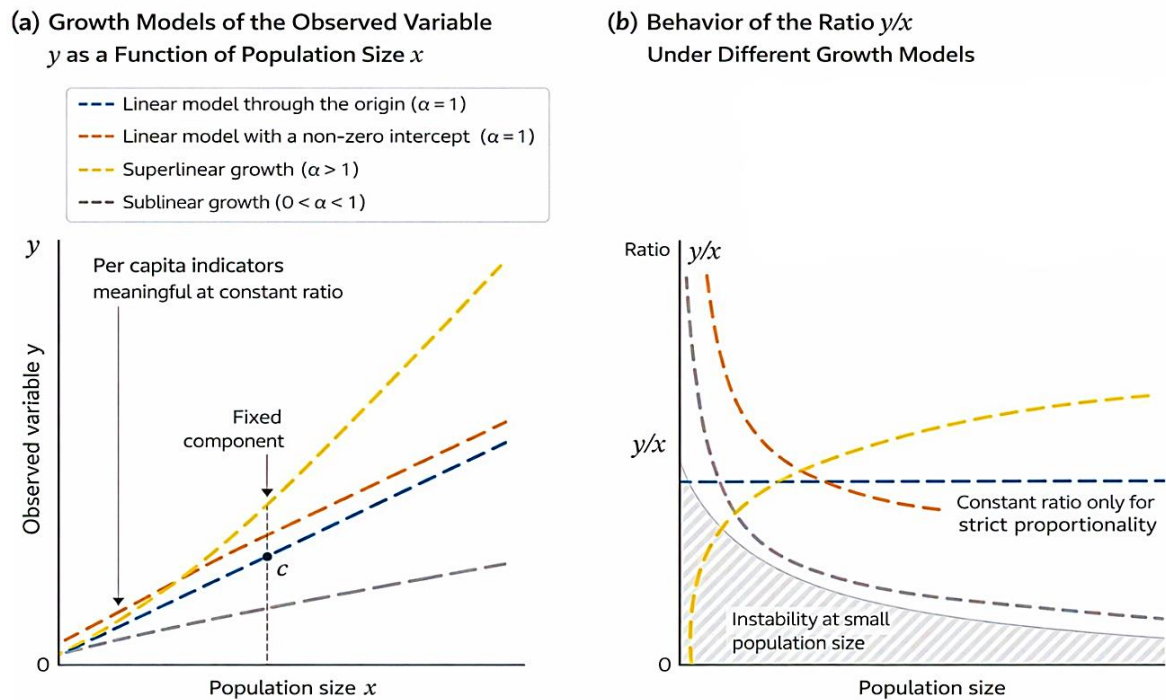


Figure 3. Interpretation of the Relationship between Absolute and Relative Indicators (Kratochvíl & Havlíček, 2024)

Figure (a) illustrates different growth models of the observed variable y (e.g., GDP or housing prices) as a function of population size x .

The blue curve represents a linear relationship passing through the origin—an ideal case in which the observed variable increases in direct proportion to population size. If the population doubles, the value of y also doubles. Only in this case is it meaningful to use ratio-based “per capita” indicators (i.e., y/x), as the ratio remains constant.

The orange curve depicts a linear relationship that does not originate at the origin, corresponding to a situation in which each unit (e.g., a country) has a certain fixed component independent of population size. In this case, ratio-based indicators primarily distort results for small countries.

The yellow curve represents exponential growth with an exponent greater than one, meaning that larger countries generate more than proportionally higher values of y , which is often the case for aggregated variables such as GDP. In this scenario, per capita indicators systematically overestimate smaller countries.

The grey curve corresponds to sublinear growth ($0 < \alpha < 1$), where increments in y decrease as population size increases.

Figure (b) shows how the ratio y/x changes with population size. It is evident that only for the blue curve does the ratio remain constant, which justifies the use of per capita indicators exclusively in cases of direct proportionality.

For the other types of relationships, however, the ratio exhibits substantial instability, particularly at low values of x : the ratio y/x may take extremely high or low values as a result of the limiting behavior of the functions as $x \rightarrow 0$. This phenomenon has important implications for international comparisons, as in countries with small populations even minor absolute changes can significantly affect relative indicators, leading to unreliability and interpretative bias.

It therefore follows that the use of “per capita” indicators is justified only when it can be statistically demonstrated that a direct proportional relationship exists between the variable y and population size x .

4. Conclusions

The application of the log–linear regression model proposed by Kratochvíl and Havlíček (2024) to the assessment of housing affordability offers an alternative to traditional per capita indicators, which often exhibit systematic biases, particularly in relation to differences in population size across countries. This approach enables the elimination of such distortions, thereby allowing for a more accurate capture of the actual economic affordability of housing in individual countries.

Log-linear regression offers a more robust alternative to ratio-based indicators for comparing housing affordability. The residuals reveal the actual deviations of housing prices from the expected price level implied by the average income of a given country's population. The method is computationally simple, extendable to additional factors (e.g., interest rate, unemployment, mobility), and suitable for the design of practical policies and official statistics.

The findings of this study provide an opportunity for a broader revision of the evaluation tools currently used in the field of housing affordability. Owing to its novel computational framework, this method can significantly contribute to revising existing assessment standards. It may serve as a starting point for the development of integrated, internationally comparable indices. It is therefore desirable that this approach be further tested, refined, and implemented within official statistics and EU strategies. The results of this analysis have direct applicability for formulating more effective, data-driven housing policies.

Conflict of interest: none

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Venture Capital Constraints and the Growth of Academic Spin-offs: Evidence from the Czech Republic

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Abstract: Academic spin-offs play an important role in transferring university research into economic and societal value, yet their development often depends on access to external financing, particularly venture capital. This study examines how limited access to venture capital affects the growth and sustainability of academic spin-offs in the Czech Republic. The research combines semi-structured interviews with founders of academic spin-offs, technology transfer representatives, and innovation financing experts with secondary data on venture capital markets and innovation policy. The findings suggest that limited venture capital availability represents a structural barrier within the Czech academic entrepreneurship ecosystem. As a result, many spin-offs rely primarily on public grants, which support early technological development but rarely enable rapid scaling. This leads to delayed commercialization, slower internationalization, and limited managerial development. The study highlights the need to strengthen science-oriented venture capital instruments and improve investor–university linkages to enhance the commercialization potential of academic research.

Keywords: academic spin-offs; technology transfer; innovation ecosystem; Czech Republic; university entrepreneurship

JEL Classification: O31; O38; L26

1. Introduction

Academic spin-offs are widely recognized as a central mechanism of knowledge transfer within innovation-driven economies. By commercializing research results originating from universities and public research organizations, spin-offs contribute to technological advancement, regional development, and long-term economic competitiveness (Etzkowitz & Leydesdorff, 2000; Rothaermel et al., 2007). In the European context, academic entrepreneurship has become a strategic policy priority, particularly within the framework of smart specialization and innovation ecosystems (European Commission, 2020; OECD, 2019).

Despite increasing institutional support structures such as technology transfer offices, incubators, and public grant schemes, academic spin-offs frequently face structural disadvantages compared to commercially founded start-ups. One of the most frequently identified barriers is constrained access to private risk capital, particularly venture capital

(VC) (Lockett et al., 2003; Wright et al., 2004). Academic spin-offs often operate in high-uncertainty environments characterized by longer development cycles, complex intellectual property arrangements, and limited immediate market validation. These characteristics may reduce their attractiveness to venture capital investors who typically prioritize scalability, rapid commercialization, and clear exit strategies.

Access to venture capital plays a crucial role in firm growth and survival. Financial constraints limit the ability of young firms to hire managerial talent, invest in business development, expand internationally, and accelerate product-market fit (Clarysse et al., 2005). From the perspective of financial theory, information asymmetry and risk perception can significantly affect investment decisions, particularly in technology-intensive ventures with strong scientific origins (Akerlof, 1970; Harrison & Leitch, 2010). Academic founders often possess strong technical expertise but limited entrepreneurial experience, which may further amplify perceived investment risk.

In post-transition economies such as the Czech Republic, the challenge of financing academic spin-offs is further intensified by structural characteristics of the national innovation system. Venture capital markets remain relatively shallow compared to Western European countries, and risk aversion among private investors persists (OECD, 2023). As a result, academic spin-offs frequently rely on public grants as their primary source of early-stage financing. While public funding can support research and prototype development, it may not provide sufficient resources for scaling activities or market expansion. This creates what can be described as a “financing gap” between research commercialization and sustainable market growth.

The consequences of constrained access to venture capital extend beyond individual firms. From a macroeconomic perspective, limited scaling of university-based innovations may weaken the overall efficiency of the national innovation system and reduce the return on public investment in research and development (Bercovitz & Feldman, 2006; Siegel et al., 2007). If academic spin-offs fail to transition successfully from laboratory to market, the knowledge transfer function of universities remains underutilized, diminishing their contribution to economic growth.

Against this background, this article addresses the following research question: How does constrained access to venture capital affect the growth and survival prospects of Czech academic spin-offs?

2. Methodology

2.1. *Study Design*

This study adopts a qualitative-quantitative exploratory research design focused on identifying the mechanisms through which constrained access to venture capital affects the growth and survival prospects of Czech academic spin-offs. An exploratory design is appropriate given the limited empirical evidence on financing constraints in academic spin-offs within post-transition innovation systems such as the Czech Republic. Given the structural and institutional nature of the research problem, the study does not aim to

construct a causal econometric model. Instead, it applies a structured analytical framework combining: qualitative evidence from semi-structured interviews and secondary macro-level data on venture capital markets and innovation systems. This approach enables triangulation between micro-level entrepreneurial experience and macro-level characteristics of the national innovation ecosystem.

2.2. Research Question

The study addresses the following primary research question: How does constrained access to venture capital affect the growth and survival prospects of Czech academic spin-offs?

This question is operationalized through three analytical sub-dimensions:

- Does limited access to venture capital delay commercialization and revenue generation?
- Does financial constraint reduce the ability of spin-offs to scale operations (e.g., hiring, internationalization)?
- Does dependence on public grant financing substitute or structurally limit private capital-driven growth?

The analytical framework assumes that venture capital is not only a source of financing but also a provider of strategic guidance, monitoring, and market-oriented discipline. Therefore, its absence may generate both financial and managerial constraints. The framework draws on the literature on entrepreneurial finance and academic entrepreneurship, which highlights the role of venture capital in supporting scaling, governance, and strategic development of technology-based firms.

2.3. Data Sources

The analysis is based on three categories of data: primary qualitative interviews, secondary statistical data, and policy and institutional documents.

Primary qualitative data were obtained through semi-structured interviews with founders and co-founders of academic spin-offs, representatives of university technology transfer offices, and experts in innovation financing. Respondents were selected using purposive sampling to ensure representation of different institutional backgrounds, technological sectors, and stages of spin-off development.

In total, 22 respondents representing spin-offs established between 2012 and 2022 across different regions of the Czech Republic were interviewed. The interviews were analyzed using thematic coding, with particular attention to recurring patterns related to financing barriers and growth limitations.

Secondary data sources include: OECD Science, Technology and Innovation Outlook reports, European Commission innovation performance reports, national innovation strategy documents, reports from Czech technology transfer offices and existing empirical studies on academic entrepreneurship and venture capital.

3. Results

3.1. Perceived Accessibility of Venture Capital

Table 1,2 provides a snapshot of venture capital investment intensity in the Czech Republic between 2019 and 2023. Early-stage venture capital investment in the Czech Republic remains extremely low (e.g., 0.012 % of GDP in 2023), which is well below levels typically observed in more mature VC ecosystems. In a global context, European venture capital accounts for only about 5 % of worldwide VC investment, despite recent growth in absolute terms. These tables support the contention that structural supply constraints in VC exist at both national and regional levels, thus contextualizing the micro-level findings reported in subsequent subsections.

Table 1. Venture capital investment indicators: Czech Republic (2019–2023)

Indicator	Value
Early-stage venture capital investment (% of GDP) – 2019	0.009 %
Early-stage venture capital investment (% of GDP) – 2020	0.005 %
Early-stage venture capital investment (% of GDP) – 2021	0.005 %
Early-stage venture capital investment (% of GDP) – 2022	0.010 %
Early-stage venture capital investment (% of GDP) – 2023	0.012 %
European VC share of global VC (EU % of global total) – 2023	~5 % of global VC
VC investment total – Europe 2023	€12.9 billion

Table 2. Early-stage venture capital investment (% of GDP), Czech Republic (2019–2023)

Year	VC Investment share (% GDP)
2019	0.009 %
2020	0.005 %
2021	0.005 %
2022	0.010 %
2023	0.012 %

The findings indicate that constrained access to venture capital represents a significant structural barrier for Czech academic spin-offs. Survey results show that 71% of respondents evaluated access to venture capital as either “very difficult” or “difficult” (Likert scale 1–2). In contrast, public grants were perceived as comparatively more accessible, although frequently associated with administrative burden and delayed disbursement.

Interview evidence further clarifies the mechanisms behind this constraint. Founders repeatedly emphasized that venture capital investors tend to prioritize shorter commercialization timelines, scalable business models, and clearly defined exit strategies. Academic spin-offs, particularly those originating from deep-technology or research-intensive domains, often require extended development phases and face higher technological uncertainty. As a result, they are perceived as high-risk investments.

Several respondents noted that investors frequently questioned the commercial readiness of university-based technologies and expressed concerns about intellectual property arrangements involving public institutions. This reflects classical information

asymmetry problems typical for innovation-intensive ventures, where investors face difficulties in evaluating technological quality and market potential.

Moreover, respondents reported limited availability of specialized investors familiar with academic commercialization processes within the Czech venture capital ecosystem. Compared to established innovation hubs in Western Europe, the domestic venture capital market remains relatively shallow, with fewer funds focusing on early-stage science-based ventures.

These findings suggest that the financing constraint is not merely perceptual but structurally embedded in the characteristics of both academic spin-offs and the Czech venture capital market. The evidence therefore supports the assumption that limited access to venture capital constitutes a binding constraint in the early growth stages of Czech academic spin-offs.

3.2. Financing Structure and Dependence on Public Grants

The evidence indicates that constrained access to venture capital has led many academic spin-offs to rely predominantly on public grant financing during their early development stages. While public funding schemes provide essential support for research validation and prototype development, they appear insufficient for scaling and market expansion activities.

Interview respondents frequently described grant funding as “project-based” and temporally limited. Although grants supported technological refinement, they rarely covered business development activities such as international marketing, professional sales recruitment, or strategic partnerships. Several founders emphasized that grant schemes are typically aligned with research milestones rather than market performance indicators.

Survey results further support this pattern. A majority of respondents reported that public grants constituted their primary source of financing during the first three years of operation. However, 82% indicated that limited private capital constrained their ability to hire specialized managerial staff or expand internationally.

This financing structure creates a structural substitution effect: public funding replaces private equity at early stages but does not provide equivalent growth acceleration. Unlike venture capital, grant financing does not usually involve strategic mentoring, governance oversight, or market-oriented performance pressure. As a result, spin-offs remain technologically advanced but commercially underdeveloped.

The findings suggest that while public funding mitigates initial liquidity constraints, it does not eliminate the growth bottleneck associated with limited venture capital access.

3.3. Impact on Growth Dynamics

A recurrent theme across interviews was the prolonged transition from research to revenue-generating activities. Spin-offs without private equity backing reported extended pre-revenue phases, often exceeding two to three years. Founders noted that without venture capital support, commercialization efforts were gradual and resource-constrained. In several cases, scientific founders had to combine research responsibilities with business development tasks, leading to slower market entry and limited customer acquisition. Survey data reveal

that spin-offs lacking external equity financing reported a significantly longer average time to first revenue compared to those that had secured private investment. This pattern aligns with theoretical expectations from the financing constraints literature, where limited access to external capital reduces firms' ability to exploit growth opportunities. The absence of venture capital thus appears to delay the critical transition from technology validation to market validation.

Another direct consequence of constrained venture capital access is limited organizational professionalization. Interview respondents repeatedly emphasized difficulties in hiring experienced business development managers, marketing specialists, or financial officers. Without sufficient equity financing, many spin-offs remained founder-centric organizations. Academic founders frequently assumed multiple operational roles, reducing strategic focus and increasing managerial overload. This organizational limitation has two important economic implications:

1. Reduced absorptive capacity for market opportunities.
2. Slower scaling and weaker investor attractiveness in subsequent funding rounds.

Venture capital typically provides not only financial resources but also governance structures and access to professional networks. In its absence, spin-offs face a capacity ceiling that restricts growth potential.

Internationalization was identified as another growth dimension affected by financing constraints. Spin-offs operating without private equity reported difficulties in entering foreign markets due to limited marketing budgets and insufficient managerial expertise. Respondents located outside major innovation hubs highlighted that lack of venture capital further compounded regional disadvantages. Without investor networks or accelerator connections, expansion remained predominantly domestic and incremental. These findings suggest that constrained venture capital access not only limits immediate liquidity but also reduces strategic growth options, particularly in technology-intensive sectors where international scaling is critical.

3.4. Survival Risk and Long-Term Sustainability

The cumulative effect of delayed commercialization, hiring constraints, and limited expansion contributes to elevated long-term survival risk.

While many spin-offs remain operational due to continued grant participation, respondents acknowledged a persistent "growth ceiling." Firms frequently stabilize at a small organizational size without achieving significant market penetration. This stagnation increases vulnerability to market shocks, policy changes in public funding, or technological obsolescence. In several cases, founders described dependence on public support as a double-edged sword: it ensures short-term survival but does not guarantee long-term competitiveness. The evidence therefore supports the proposed mechanism model. Constrained venture capital access does not necessarily result in immediate firm failure, but it significantly reduces scaling capacity and increases long-term sustainability risk (Table 3).

Table 3. Financing barriers, firm-level impacts, and strength of supporting evidence

Mechanism Stage	Empirical Evidence	Strength of Support
Limited VC accessibility	Survey + interviews	Strong
Grant substitution effect	Interviews + survey	Strong
Delayed commercialization	Survey + interviews	Moderate–strong
Hiring constraints	Interviews	Strong
Limited international scaling	Interviews	Moderate
Increased survival vulnerability	Qualitative synthesis	Moderate

The findings consistently indicate that constrained access to venture capital constitutes a structural growth barrier for Czech academic spin-offs. The mechanism operates through organizational and commercialization limitations rather than immediate firm exit.

4. Discussion

The findings of this study indicate that constrained access to venture capital represents a structural bottleneck in the Czech academic spin-off ecosystem. Rather than leading to immediate firm exit, financing constraints operate through gradual growth limitations, delayed commercialization, and reduced scaling capacity. This pattern corresponds with recent evidence from innovation finance research, which emphasizes the critical role of equity financing in scaling knowledge-intensive ventures (OECD, 2023; European Commission, 2022). Recent analyses of European innovation systems highlight that early-stage science-based firms face disproportionately high capital intensity and longer time-to-market compared to digital start-ups (European Commission, 2022). Venture capital markets, however, increasingly prioritize scalable, platform-based business models with shorter exit horizons. This structural mismatch particularly affects academic spin-offs operating in deep-tech domains. The OECD (2023) stresses that shallow domestic venture capital markets in smaller or post-transition economies significantly constrain the scaling of research-based firms. Compared to Western European innovation hubs, Central and Eastern European countries exhibit lower VC intensity relative to GDP, fewer specialized science-focused funds, and weaker investor–university linkages. The findings of this study are consistent with this systemic gap.

Recent empirical research further demonstrates that access to venture capital affects not only firm survival probabilities but also organizational professionalization and internationalization capacity (Bertoni et al., 2019; Croce et al., 2021). Venture-backed firms tend to hire managerial talent earlier, adopt structured governance mechanisms, and expand internationally more rapidly. In contrast, firms relying primarily on public grants often display slower scaling trajectories and prolonged dependence on project-based funding. Importantly, the substitution effect between public grants and venture capital identified in this study reflects broader European trends. While public funding instruments play a crucial role in supporting early-stage research validation, they rarely provide sufficient incentives for aggressive market expansion (European Investment Fund, 2022). Equity-based financing, by contrast, aligns investor returns with firm growth, thereby introducing performance pressure and strategic focus.

From a policy perspective, recent EU-level initiatives such as the European Innovation Council (EIC) Fund attempt to address precisely this financing gap by combining grant funding with equity instruments. However, national ecosystems remain uneven in their ability to attract and retain private venture capital (European Commission, 2023). The Czech case appears to illustrate this structural imbalance: strong public research capacity coexists with relatively limited private risk capital depth. Furthermore, recent literature on regional innovation ecosystems underscores the importance of investor density and network embeddedness in fostering high-growth academic entrepreneurship (Colombo et al., 2022). Venture capital functions not only as a financial input but also as a connector to global markets, mentors, and follow-on funding rounds. In regions where such ecosystems remain underdeveloped, academic spin-offs face compounded disadvantages.

The findings therefore suggest that financing constraints are not merely firm-level challenges but systemic characteristics of the national innovation architecture. Addressing them requires coordinated intervention at multiple levels:

1. strengthening early-stage science-focused VC funds,
2. improving regulatory clarity around university equity participation,
3. enhancing commercialization readiness programs within universities,
4. and supporting hybrid public–private financing instruments.

In line with recent policy-oriented research (OECD, 2023; European Commission, 2022), improving access to risk capital for research-based ventures is likely to increase the economic return on public R&D investment. Without adequate scaling finance, academic spin-offs risk remaining technologically competent yet commercially marginal.

5. Conclusions

This study examined how constrained access to venture capital affects the growth and survival prospects of Czech academic spin-offs. The findings demonstrate that limited availability of private equity financing represents a structural growth barrier rather than an immediate cause of firm failure. Venture capital constraints operate indirectly by delaying commercialization, restricting managerial professionalization, and limiting international expansion capacity.

The results suggest that academic spin-offs in the Czech Republic often substitute venture capital with public grant financing. While public funding effectively supports early-stage research validation, it does not provide sufficient incentives or resources for rapid scaling. This substitution effect contributes to prolonged pre-revenue phases and organizational stagnation, increasing long-term vulnerability despite short-term operational survival.

From a systemic perspective, the findings highlight a misalignment between public R&D investment and private capital market development. Although universities generate commercially relevant research outputs, insufficient depth of the domestic venture capital market constrains the translation of knowledge into scalable economic value. As a result, the economic return on public research funding may remain below its potential.

The study contributes to the literature on academic entrepreneurship by isolating venture capital access as a central determinant of spin-off sustainability within a post-transition innovation ecosystem. Rather than treating institutional, regional, and human factors simultaneously, it demonstrates how financing constraints alone can shape growth trajectories.

Policy implications follow directly from these findings. Strengthening science-oriented venture capital instruments, improving regulatory clarity regarding university equity participation, and fostering stronger investor–university linkages appear critical for enhancing commercialization outcomes. Without coordinated development of private risk capital markets, academic spin-offs risk remaining technologically advanced but commercially constrained.

While the study relies on qualitative and descriptive quantitative evidence, it provides a conceptually grounded foundation for future longitudinal and econometric research. Further studies could examine comparative data across Central and Eastern European countries to assess whether similar venture capital constraints systematically affect academic entrepreneurship in post-transition economies.

In conclusion, venture capital accessibility should be understood not merely as a financial variable but as a structural condition shaping the effectiveness of national innovation systems. Addressing this constraint is essential for enabling academic spin-offs to fulfil their potential as drivers of innovation-led economic growth.

Acknowledgments: The research/work was supported by the internal funding University of Hradec Králové, Faculty of Informatics and Management, Czech Republic. Additionally, I acknowledge the use of AI-based tools (ChatGPT by OpenAI) for selected language editing and stylistic corrections of the English version of the text. All content, structure, and conclusions presented in this work remain the responsibility of the author.

Conflict of interest: none

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Divergent Paths to Participatory Budgeting: Poland's Experimentation vs. Czech Caution in Gorzów Wielkopolski and Hradec Králové

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Abstract: The article compares the evolution and current design of participatory budgeting (PB) in Poland and the Czech Republic, focusing on the case studies of Gorzów Wielkopolski and Hradec Králové. It shows that although both countries began implementing PB after 2010, in Poland the process took on a more experimental and large-scale character (over 300 local government units), and in later years became regulated by national legislation, whereas in the Czech Republic development was slower, based on the good practices of other municipalities and lacking dedicated nationwide regulations. The PB processes in both cities fit into a typology typical of wealthier democracies, with common requirements such as consistency of projects with strategic documents, implementation within the city's territory, public accessibility, and the possibility of rejecting projects that generate excessive maintenance costs. At the same time, they differ in scope (in Hradec Králové only "hard" investment-type projects), process design (territorial units and deliberation in Gorzów versus a purely city-wide level in Hradec), and voting techniques (D21 versus conventional voting supported by public debate). The comparative analysis indicates that adopting the D21 method in Gorzów could better reflect the distribution of opinions where not all residents are able to participate in deliberative meetings, whereas Hradec could benefit from introducing local (neighbourhood) projects and formal spaces for discussion of proposals prior to their submission, which could potentially increase residents' interest and improve the quality of submitted projects.

Keywords: public participation; participatory budget; social innovations

JEL Classification: D72; H70; R38

1. Introduction

Strengthening the role of citizens in the decision-making processes of public authorities has long been one of the key directions of reform in most countries around the world. The debate initiated in the second half of the twentieth century on the need to enable citizens to co-govern public affairs directly affecting them has generated numerous practical instruments within the broad field of public participation (Fung, 2006; Rowe & Frewer, 2005).

Public participation is defined in various ways, yet these definitions share a common core: the inclusion of residents in co-decision-making processes regarding issues that concern them. The use of different forms of public participation by public administration is expected, among other things, to increase administrative effectiveness and improve the efficiency of public spending by aligning the types and scope of services provided with citizens' needs (Barbera et al., 2016; Creighton, 2005; Everatt et al., 2010).

These practical solutions are grounded in earlier research such authors like S.ArNSTein (1969), S.Langton(1978), D.M.Connor(1988) or D.Wilcox(1994), 1994). In 2006, the International Association for Public Participation developed a set of core principles for the practice of public participation (the "IAP2 Spectrum of Public Participation" (IAP2, 2018)). In line with the core idea of public participation, it states that citizens affected by decisions should take part in the decision-making process. Their participation should be empowering, and citizen involvement should lead to decisions that represent a consensus between the needs of both sides (citizens and decision-makers). Participants should influence both the decisions taken and the course of the consultation process itself. At the same time, the process should guarantee access to information necessary for participants to express their views, as well as access to information on how their involvement has influenced final decisions. The Spectrum of Public Participation distinguishes five main levels of participation (defined by aims and expected outcomes/promises) and example tools for each level: Inform (fact sheets, websites, open houses), Consult (public comment, focus groups, surveys, public meetings), Involve (workshops, deliberative polling), Collaborate (citizen advisory committees, consensus-building, participatory decision-making) and Empower (citizen juries, ballots, delegated decisions). As Rowe and Frewer note, "in public participation, information is exchanged between members of the public and the sponsors [government bodies]" (Rowe & Frewer, 2005).

One mechanism that meets these criteria is participatory budgeting (PB). Its origins date back to the 1980s in Porto Alegre (Cabannes, 2004), and its grounding in universal principles, combined with its flexibility and ability to be adapted to local specificities, has led to its diffusion worldwide (Dias, 2018). The main distinguishing features of PB compared to other instruments are usually captured in five criteria that it must satisfy (Sintomer et al., 2008). First, "the financial and/or budgetary dimension must be discussed; participatory budgeting involves dealing with the problem of limited resources." Second, "the city level has to be involved, or a (decentralized) district with an elected body and some power over administration (the neighbourhood level is not enough)." Third, "it has to be a repeated process (one meeting or one referendum on financial issues does not constitute an example of participatory budgeting)." Fourth, "the process must include some form of public deliberation within the framework of specific meetings/forums (the opening of administrative meetings or classical representative instances to 'normal' citizens is not participatory budgeting)." Fifth, "some accountability on the output is required."

Goldfrank (2021) argues that PB was initially perceived as a way to give voice to the excluded, to stimulate the development of civil society organisations, to make infrastructure and service provision more equitable, and to enhance transparency while limiting corruption.

Sintomer, Herzberg and Röcke (2008) contend that “participatory budgeting allows the participation of non-elected citizens in the conception and/or allocation of public finances.”. It should be noted that the goals and format of participatory budgeting (PB) vary significantly depending on the world region. Wampler, McNulty, and Touchton (2021) identify four distinct groupings of PB adaptation based on a systematic multi-factor analysis (table 1).

Table 1. Groupings of PB adaptation (Wampler et al., 2021)

Type	Primary Regions	Key Drivers	Core Objectives
Deepening Democracy through Community Mobilization	Wealthier democracies	Centrist/center-left governments, inspired by Porto Alegre	Promote social inclusion, combat apathy among marginalized groups (without full redistribution rules)
Social Development and Accountability	Global South, resource-strapped countries	International organizations (e.g., World Bank, USAID)	Small-scale projects for development outcomes and accountability foundations
Mandated by National Government	Geographic variation	National directives to local governments	Alter local policymaking processes via top-down mandates
Efficient Governance and Digital Participation	Wealthier democracies	Government officials with resources/staff	Modernize policymaking (consultative for efficiency); enable digital tools for participation

As can be observed, it is not always possible to directly compare the solutions applied in participatory budgeting across countries. In this context, the comparison of PB arrangements in Poland and the Czech Republic undertaken in this article appears well justified. These countries belong to the Visegrad Group (V4 – Poland, Czechia, Slovakia, Hungary), and a comparative perspective is enabled by their shared history, similar geopolitical conditions, economic interdependence and convergent interests within the EU. They form part of a relatively coherent region of Central Europe that exhibits similar developmental and political trends.

2. Research Aim and Method

The widespread diffusion of participatory budgeting processes worldwide has led most countries, to a greater or lesser extent, to attempt to use this instrument. In Poland and the Czech Republic, the beginnings of PB date back to the years 2012–2014. In subsequent years, however, the trajectories of development in the two countries diverged. The primary aim of this article is to analyse and compare the evolution, institutional architecture and practical functioning of participatory budgeting in Poland and the Czech Republic through the lens of two medium-sized regional centres: Gorzów Wielkopolski and Hradec Králové. By focusing on cities that share similar demographic and functional characteristics yet operate within different national regulatory and participatory contexts, the study seeks to identify both convergences and divergences in PB arrangements, to reconstruct residents’ preferences as expressed in project proposals and voting, and to derive context-sensitive recommendations for the further development of PB in each city. In doing so, the article links local-level institutional design choices to broader debates on public participation, co-production and the typologies of PB observed in wealthier democracies, particularly the “Mandated by National

Government” and “Efficient Governance and Digital Participation” models. The following research questions were formulated:

- RQ1: How have participatory budgeting processes evolved in Poland and the Czech Republic?
- RQ2: Do cities in Poland and the Czech Republic with similar demographic and functional characteristics employ comparable PB solutions?
- RQ3: What are the patterns of residents’ preferences as expressed through proposals submitted to participatory budgets?
- RQ4: Which solutions can be indicated as feasible or desirable for implementation in the PB processes of the analysed cities?

These research questions translate into the following more detailed objectives:

- To reconstruct the national trajectories of PB development in Poland and the Czech Republic, with particular attention to the role of legal regulations, incentives and constraints on local governments, and the diffusion of organisational know-how (RQ1).
- To map and compare the institutional design of PB in Gorzów Wielkopolski and Hradec Králové, including the scope and types of eligible projects, the division of funds, procedural stages (submission, verification, deliberation, voting), and the voting techniques used (RQ2).
- To examine the thematic structure, spatial focus and investment vs. “soft” character of projects submitted and selected within PB in both cities, treating them as an empirical expression of residents’ preferences and needs in the context of relatively well-developed infrastructure (RQ3).
- To assess the scale and dynamics of citizen participation in PB processes and to interpret these patterns in light of broader trends in active citizenship in the V4 countries, as documented by Eurostat surveys and the literature on determinants of participation (RQ3, RQ4).
- To identify, on the basis of the comparative analysis, those institutional solutions (e.g. voting methods, territorial structuring of funds, deliberative elements, measures counteracting digital exclusion) that appear transferable or adaptable between the two cases and could enhance the inclusiveness, legitimacy and effectiveness of PB in each city (RQ4).

Methodologically, the article adopts a qualitative, comparative case study design, combining elements of horizontal institutional comparison with document analysis and basic quantitative description of PB processes and outputs. The selection of Gorzów Wielkopolski (Poland) and Hradec Králové (Czech Republic) was based on purposive criteria: both are regional capitals with comparable population size and functional importance in their national settlement systems, both have relatively high levels of infrastructural development, and both have implemented PB for several years (in Gorzów since 2013 and in Hradec Králové since 2024), which makes it possible to analyse not only institutional blueprints but also actual practice.

The empirical material comprises three main groups of sources. First, a review of international and national literature on public participation and participatory budgeting was conducted, including classic works on ladders and spectrums of participation and more recent studies on PB typologies, diffusion and regional specificities. This review made it possible to situate the analysed cities within broader theoretical frameworks, especially the typology of PB adaptations proposed by Wampler, McNulty and Touchton (2021), which distinguishes, among others, PB mandated by national governments and PB oriented towards efficient governance and digital participation. Second, extensive desk research was carried out on source documents produced by local authorities, such as municipal council resolutions, mayoral decrees, PB regulations, explanatory notes, official reports, and information published on the cities' and PB platforms' websites. These materials provided the basis for a horizontal comparison of design features in both cities, including eligibility criteria, cost thresholds, categories and pools of projects, age and residency requirements, submission channels, verification procedures, appeal mechanisms, deliberative formats and voting rules.

Third, the study analyses data on PB projects and participation in both cities. For Gorzów Wielkopolski, the evolution of the PB model is traced from its introduction in 2013 to the 2025 edition, taking into account changes in the territorial division (from 5 to 12 districts), the introduction of city-wide and educational categories, the differentiation between “hard” (investment) and “soft” (non-investment) projects, and the development of deliberative “networking” meetings as a central mechanism for project selection and modification. The analysis includes the number of submitted, positively verified and ultimately selected projects, the distribution of funds across categories, and voter turnout levels in subsequent editions. For Hradec Králové, the focus is on the 2024–2025 PB editions, characterised by a city-wide model with small and large investment projects, clear cost thresholds guaranteeing minimum numbers of implemented projects, and the use of the D21 voting method with positive and negative votes and an exclusion threshold for highly polarising projects. Here, too, the number of submitted and approved projects, their thematic orientation (recreation, sports, leisure, public space) and participation levels are examined.

The comparative analysis proceeds in several steps. In the first step, the national context of PB development in Poland and the Czech Republic is reconstructed, with emphasis on the presence or absence of legal mandates, the stability of PB processes over time and the role of external actors such as NGOs and ICT providers (RQ1). In the second step, the institutional design of PB in Gorzów Wielkopolski and Hradec Králové is compared dimension by dimension (scope and nature of eligible projects, territorial vs. city-wide structuring, categories and pools, submission and verification, deliberative components, voting systems and measures addressing digital exclusion), in order to identify convergent and divergent features (RQ2). In the third step, the thematic structure of submitted and selected projects and the dynamics of participation are analysed, allowing for the identification of dominant patterns of resident preferences and engagement (RQ3). Finally, these findings are synthesised into a set of practically oriented recommendations regarding potential adaptations in each city, such as the introduction of the D21 method in Gorzów Wielkopolski

or the development of neighbourhood-level projects and pre-submission deliberative forums in Hradec Králové (RQ4).

The study is subject to several limitations, which should be acknowledged when interpreting the results. First, it focuses on two specific cities and a limited time horizon (especially in the case of Hradec Králové), which restricts the possibility of generalising the findings to all municipalities in Poland and the Czech Republic. Second, the analysis relies primarily on documentary and quantitative data provided by local governments and PB platforms; it does not incorporate direct surveys or interviews with participants, officials or facilitators, which would allow for a deeper insight into motivations, perceptions of fairness and satisfaction with PB processes. Third, while the study draws on Eurostat data and the literature on factors shaping citizen participation to contextualise observed participation levels, it does not attempt to statistically isolate the specific impact of PB design choices from broader macro-contextual, demographic, social and psychological determinants. Despite these constraints, the chosen research design makes it possible to provide a nuanced and empirically grounded comparison of two distinct PB models in Central Europe and to derive practically relevant lessons for local governments seeking to refine their participatory budgeting practices.

3. Results

3.1. Development of Participatory Budgeting in Poland and the Czech Republic

In Poland, the introduction of the first participatory budgets dates back to 2011/2012 and took the form of bottom-up initiatives (Kębłowski & Van Criekingen, 2014). Growing public interest in PB processes prompted Polish local governments to begin implementing such mechanisms in subsequent years (Pytlik, 2017). These initiatives were initially based on general provisions concerning public consultations. Despite the absence of dedicated regulations, PB gradually gained popularity among Polish cities as a tool of public participation, functioning *de facto* as an informal agreement between local authorities and residents, even where local by-laws were adopted. Commonly noted weaknesses included, among others, its voluntary nature, the lack of transparent procedures for programme design, the instrumental use of PB as a public relations tool for local authorities, and the absence of any obligation to incorporate consultation outcomes into local budget plans (Błaszak, 2019; Sroka et al., 2022). In addition, the acceptance of projects selected by residents, as well as the scale of expenditure and the implementation timetable, largely depended on the municipality's financial situation and the political decisions of the authorities (Olejniczak & Bednarska-Olejniczak, 2021). Nevertheless, by 2018 more than 300 local government units (out of approximately 2,400) had implemented PB.

The year 2018 marked a significant change in the functioning of PB in Poland, as nationwide regulations were introduced to define its framework in local government units. These provisions established PB as a specific form of public consultation. They allowed residents, through annual direct voting, to decide on the use of a portion of municipal expenditure, while imposing an obligation to include the projects selected within the civic

budget in the municipality's budget resolution. The regulations also introduced requirements for equality and directness in voting rules, a prohibition on the municipal council removing or substantially modifying selected projects during budget deliberations, and an obligation for cities with county rights to establish civic budgets on an annual basis. At the same time, they left local governments considerable autonomy in designing PB, including the definition of formal project criteria, minimum numbers of supporting signatures, project evaluation procedures, appeal mechanisms against project rejection, voting formats, limits on the number of votes per resident, and methods for determining results. The introduction of these new regulations did not significantly affect the number of local governments implementing participatory budgeting.

Participatory budgeting in the Czech Republic started around 2014 in Prague (Svidroňová et al., 2025). According to Kukučková, Sedmíhřadska and Bakos, by 2018 nearly 20% of Czechs had the opportunity to participate in PB through 133 processes in 59 municipalities (Kukučková et al., 2025). The authors emphasise that, as local governments actively searched for more favourable arrangements in the areas of electoral rights, voting methods and the use of information and communication technologies, the number of PB processes steadily increased. Data collected by Agora CE indicate that in subsequent years the number of local governments implementing PB rose to over 90 (not all of them organise PB every year—for instance, in 2024 there were 94 such local governments, compared with 83 in the previous year)(AGORA CE, 2025).

PB in Czech municipalities is not regulated by specific, dedicated legislation. Instead, it operates on a voluntary basis under general public participation provisions in municipal budgeting—for example, citizens may submit proposals, comments or requests relating to the budget and have access to budget documents, minutes and resolutions. There are no formal participatory mechanisms such as project voting or earmarked PB funds (Brabec, 2019; Culková, 2024; Kukučková & Bakos, 2019; Marczevska-Rytko & Maj, 2021). Subsequent PB schemes in the Czech Republic are often developed by drawing on the experiences of other cities, while external support is frequently sought from organisations and companies that offer partially pre-designed solutions—adaptable to the specific characteristics of a given municipality—for the entire PB process, mainly in the form of ICT platforms. In practice, there is still an ongoing debate as to whether nationwide regulations, analogous to those in Poland, should be introduced to support these processes (Tomaskova & Buzkova, 2020).

3.2. Case Study – Participatory Budgets in Gorzów Wielkopolski and Hradec Králové

The participatory budget in Gorzów Wielkopolski was first introduced in 2013 as a follow-up to a survey conducted in December 2012 (U M Gorzowa Wielkopolskiego, 2026). From 2013 onwards, it operated on the basis of City Council resolutions on public consultations. Initially (2014), its design diverged from universal PB standards, as decision-making competences regarding which projects would be submitted to residents' vote were vested in the municipal authorities. As a result, residents were unable to vote on some projects in their districts (the city was divided into five districts) despite their formal and substantive correctness, and ultimately only about half of the duly submitted proposals

were put to a vote. In addition, the rules introduced a limit of one project that could be submitted by a resident and a maximum of two projects per district that could be implemented, regardless of the remaining budget.

In the next PB edition, the restriction on the number of projects submitted to voting was lifted and a second, city-wide category of projects was introduced, which allowed residents to cast two votes. From that point on, eligible projects had to fall within the catalogue of the municipality's own tasks, be publicly accessible and align with the city's development strategy. A major change occurred in the 2017 PB edition, when newly introduced discussion meetings (aimed at presenting projects and facilitating the exchange of views) enabled residents to decide on the implementation of district-level projects without the need for a general vote. At the same time, projects were evaluated during these meetings, which could grant positively received proposals additional points in the subsequent vote. In the first year, these changes resulted in the approval of all 39 district projects in 9 out of the 10 districts into which the city had been divided. Moreover, an educational projects category was introduced due to strong interest from the school community and the fact that educational projects had captured a large share of funds in previous years. However, in 2017 educational projects were only subject to submission and discussion by residents at a separate deliberative meeting.

Amendments to national legislation and the introduction of regulations governing PB in Poland influenced the formula adopted in subsequent years. To preserve the deliberative character of the process, a rule was maintained that each project had to be presented and discussed at such meetings. At the same time, the number of districts was increased to twelve and the number of categories to four, with city-wide projects divided into "hard" (investment) and "soft" (non-investment) types. To avoid fragmentation of projects and dispersion of votes, the possibility of "networking" was retained—that is, combining several projects into one larger project during deliberative meetings, up to the maximum cost threshold per district project. These combined projects did not have to concern similar themes (for instance, "green" projects were merged with safety-improvement measures). For each category, maximum cost thresholds per project and total available funds were specified. Every district was guaranteed implementation of at least one project with the highest number of votes, while further projects were selected in descending order of votes until the allocated funds were exhausted.

The introduction of new categories increased the number of votes that each resident could cast (one vote in each category). To prevent the exclusion of residents from voting after abandoning the hybrid (paper-plus-electronic) voting system, mobile electronic voting points were introduced as a complement to online voting. To further enhance the inclusiveness of the process, the hybrid formula for project submission (both paper and electronic) was retained.

The analysis of the topics of submitted and voted projects indicates that, in terms of both scale and spatial coverage, the dominant initiatives concern the improvement of shared public space through the addition of small architectural elements (benches, waste bins), the expansion of green areas, and enhanced safety (new lighting, pavement reconstruction).

Table 2. PB in Gorzów Wielkopolski and Hradec Kralove

Type	2013	2014	2017	2019	2025	2024/2025
Allocation of funds	5 districts	5 districts	8 districts, City-wide, Educational	10 districts Educational	12 districts City-wide soft and hard Educational	Small and large
Limit on tasks to select	Yes - 2 per district	No - until funds exhausted	No - until funds exhausted	No - until funds exhausted	No - until funds exhausted	No - until funds exhausted
Limit on funds per task		Yes	Yes - per category (soft/hard split for city-wide)	Yes - per category and type (soft/hard)	Yes - per category and type (soft/hard)	Yes - per category
Number of votes	1	1	2	3	4	14 (10 "yes" and 4 "no")
Discussion meetings			Yes - binding decision for acceptance	Yes - as opinion form	Yes - opinion form and condition for voting submission	No
Submission form	Hybrid	Hybrid	Hybrid	Hybrid	Hybrid	Hybrid
Voting form	Hybrid	Hybrid	Hybrid	Hybrid	Electronic, with additional mobile points	Electronic
Submitted projects	273	228	150	191	169	49/54
Positively reviewed	140	125	109	103	101	21/16
Selected in voting	10	5	10	36	36	10/10
Selected in discussion			37+8			
Number of voters	15,774	50,216	15,340	9,227	4,420	2587/2406

The participatory budget in Hradec Králové has been in operation since 2024 (Magistrát města Hradec Králové, 2026). When preparing its first editions, the city authorities drew on the experience of other municipalities and on the support of the Munipolis (Mobilní rozhlas) online platform, which enabled the implementation of a framework solution tested in many local governments and its adaptation to the specific context of Hradec Králové. The model adopted in 2024 was not substantially modified in 2025. The core premise was to introduce a participatory mechanism at the city-wide level; within this framework, projects were divided into large and small categories. In 2024, 40% of the total PB budget was reserved for small projects, with the cost of an individual small project capped at one tenth of this amount, which guaranteed the possibility of implementing at least ten selected small projects. For large projects, the cost of a single project could not exceed one third of the funds earmarked for this category, meaning that at least three large projects could be implemented. According

to the adopted definition, a project is an investment (construction or acquisition of a facility) that brings benefits to the city and its residents, is accessible to the public for most of the day and free of charge, is non-profit in operation, can be implemented by the municipality of Hradec Králové on city-owned land, has annual operating costs not exceeding 10% of its acquisition cost, does not conflict with the city's strategic plan, land-use plan or planned investments, and can be completed within two years of the end of the voting in which it was selected. This definition effectively excludes the implementation of "soft" (non-investment) projects.

Partial age restrictions were introduced (minimum 15 years), but participation was opened not only to residents, but also to those working or studying in Hradec Králové. The city authorities also chose to limit the "excessive activity" of individual citizens in terms of the number of submitted proposals, allowing each person to submit a maximum of three projects.

Table 3. Voting algorithm (Magistrát města Hradec Králové, 2026)

Number of approved projects	Total positive votes per voter	Total negative votes per voter	Max votes per project per voter
1–5	2	0	2
6–15	5	2	2
16–30	9	3	3
31–50	13	4	3

The adopted D21 voting method (see more: Kukučková & Poláková, 2021) provides for the allocation of both "positive" and "negative" votes. The voting algorithm (the number of positive and negative votes) is determined on the basis of the number of approved projects. A proposal that receives more than 33% negative votes out of all votes cast for it is not implemented. In 2024, voters could cast five positive and two negative votes for both - 12 small and 9 large voted projects (14 votes in total), and the same arrangement applied in 2025. After voting, separate rankings are compiled for small and large projects, and projects are selected for implementation in descending order until the budget allocated to each category is exhausted.

Analysis of projects submitted for voting in the years 2024–2025 indicates that they are primarily devoted to enhancing the functionality of public spaces associated with recreation (benches, meeting areas), sports (pump tracks, sports fields), and leisure activities (walking paths, informational boards at nature reserves)

4. Discussion

Although the first participatory budgeting processes in Poland and the Czech Republic emerged in a similar period – after 2010 – their implementation progressed at different speeds in the two countries (RQ1). In Poland, many local governments, including Gorzów Wielkopolski, chose to experiment with PB and to search for their own institutional solutions, which is clearly visible in the evolution of PB in that city. In the Czech Republic, by contrast, the process was less intensive, and successive municipalities tended to adopt solutions already tested elsewhere, as in the case of Hradec Králové. A further factor shaping the scale

of PB use has been the legal framework: unlike in the Czech Republic, in Poland PB has been regulated as a distinct – and in part mandatory – form of consultation with residents. Gorzów and Hradec Králové thus represent types of PB processes characteristic of wealthier democracies, namely “Mandated by National Government” (Gorzów Wielkopolski) and “Efficient Governance and Digital Participation” (Hradec Králové and Gorzów Wielkopolski).

An analysis of the legal regulations shows that, in both cities, projects must be beneficial for residents and located within the city, and residents decide on the use of part of the municipal budget through projects that fall within the municipality’s own tasks. In Hradec Králové, these tasks are restricted to investment “hard” projects. Projects must be consistent with strategic and spatial planning documents and legal regulations and may not infringe third-party rights or ownership; they must also be generally accessible to the public. In both systems, projects that would generate disproportionately high maintenance costs may be rejected. In each city, project selection is based on the number of votes obtained, yet the voting systems differ considerably. In Hradec Králové, the D21 method is a tool that enables a much more nuanced assessment of the degree of public acceptance of individual projects, since negative votes are visible and the adopted formula ensures that projects which sharply divide the community are not implemented. In Gorzów, this function is performed by discussion meetings; the developed model – involving project presentation, debate, networking and recommendation – embeds deliberation as an integral element of the process. This means that the role of residents who do not submit their own projects does not boil down merely to casting a vote. On the other hand, this may contribute to a decline in voter turnout, as there are districts in which only a “networked” project (composed of all projects in the district) is ultimately submitted to a vote and being chosen.

It should also be noted that in Hradec Králové PB participants may be both residents and persons studying or working in the city (with a lower age limit of 15), whereas in Gorzów Wielkopolski only residents are entitled to participate. This difference may stem from the fact that Hradec Králové is a major university center, which means that the actual number of people using public infrastructure on a daily basis significantly exceeds the number of permanent residents. Both cities currently rely on electronic voting, but Gorzów Wielkopolski has introduced additional arrangements to mitigate the effects of digital exclusion. On the basis of the above analyses, it can be stated that both cities use participatory budgeting to allow residents to propose and vote on projects, but they differ in scope, institutional design, project types and voting systems (RQ2).

With regard to the thematic focus of projects submitted and selected by residents (RQ3), it should be noted that it is typical of municipalities with a high level of development and good access to public infrastructure (Olejniczak & Bednarska-Olejniczak, 2025). In both cities, projects are concentrated on infrastructure (“hard” projects) serving leisure, sport, recreation and broadly understood safety improvements. In Gorzów, “soft” projects constitute only a minor complement to “hard” projects, enabling the organisation of joint activities. The creation of a separate educational category and the increase in the number of districts from

the initial five to twelve are further examples of the evolutionary adaptation of PB to the specific characteristics of the city and the needs of its residents.

The final issue concerns the scale of residents' participation in PB. In terms of the number of submitted projects, residents of Gorzów Wielkopolski have been more active from the very beginning of the process, which is also reflected in higher numbers of voters. At the same time, after 2020 there has been a visible downward trend in voter turnout in Gorzów, which can be partly explained by the aforementioned “networking” of projects that reduces competition and, in turn, the perceived need to participate in voting. Additionally to the above-mentioned a wide range of other factors can influence citizen participation. Barrett and Brunton-Smith distinguish macro-contextual factors (e.g. the electoral system, the structure and design of political institutions, and the historical, economic and cultural characteristics of countries), demographic factors (socio-economic status, ethnicity, generational cohort and gender), social factors (family, education, workplace) and psychological factors.

Eurostat surveys on public participation levels in 2015 and 2022 distinguish three types of citizen activity, capturing both horizontal participation (participation in formal voluntary work and participation in informal voluntary work) and vertical participation (active citizenship) (Eurostat, 2024). According to the survey methodology, participation in formal voluntary work is recorded when “the respondent [...] did any unpaid non-compulsory work for or through an organisation, a formal group or a club. It also includes unpaid work for charitable or religious organisations”, whereas participation in informal voluntary activities denotes that a person “undertook any informal unpaid activities that were not arranged by any organization” (e.g. helping other people, including family members not living in the same household, or helping animals, such as caring for homeless or wild animals).

From the perspective of this article, the most relevant dimension is the level of active citizenship, understood as engagement in activities “such as participation to the activities of a political party or a local interest group, participation in a public consultation, peaceful protest including signing a petition, participation in a demonstration, writing a letter to a politician, writing a letter to the media”. Participation in elections is excluded from this measure, as in some countries voting is compulsory. Among V4 countries, levels of the three forms of citizen activity differ. Notably, the level of active citizenship in the Czech Republic increased between 2015 and 2022, while in Poland it declined significantly, which may be one of the factors contributing to the decreasing number of PB participants in Gorzów Wielkopolski.

Table 4. Public participation levels in 2015 and 2022 (Eurostat, 2024)

Area/country	Voluntary Activities				Active citizenship	
	Formal		Informal			
	2015	2022	2015	2022	2015	2022
EU 27	18.9	12.3	22.5	13.8	12.1	7.2
Czechia	12.2	10.2	16.6	12.2	4.2	5.2
Hungary	6.9	5.8	7.8	10.1	4.7	3.6
Poland	13.8	7.4	50.6	22.1	7.3	3.6
Slovakia	8.3	7.5	18.8	10.6	2.8	4.1

Given that increasing citizen participation in co-governance processes is one of the key priorities of participatory budgeting, it appears that the two analysed local governments can meaningfully draw on each other's experiences (RQ4). In the case of Gorzów Wielkopolski, adopting the D21 voting method could be particularly important, as it more strongly reflects differences in residents' views, especially where some inhabitants are unable, for various reasons, to attend discussion meetings at which decisions on networking projects are made. In turn, in Hradec Králové, given the differentiated characteristics of particular neighbourhoods, it would be worth considering the introduction of local (neighbourhood-level) projects, which could increase engagement among residents of specific areas. In addition, formally enabling residents to discuss project ideas before their official submission could help to develop more robust and widely accepted solutions.

5. Conclusions

This comparative analysis of participatory budgeting in Gorzów Wielkopolski and Hradec Králové reveals distinct evolutionary paths and design features of PB. Emerging post-2010, Poland's PB advanced more dynamically through local experimentation and national mandates, as seen in Gorzów's deliberative "networking" model, while Czech PB emphasized tested, digital-efficient approaches in Hradec Králové (RQ1). Both cities prioritize resident-beneficial, city-bound projects aligned with strategic plans, but diverge in scope—Hradec restricting to "hard" investments—and voting mechanisms: D21's nuanced scoring in Hradec versus Gorzów's debate-driven deliberation, which risks lowering turnout via reduced competition (RQ2).

Thematically, projects focus on leisure, sports, and safety infrastructure, typical of well-developed locales, with Gorzów evolving "soft" complements and district expansions (RQ3). Participation scales higher in Gorzów initially but trends downward post-2020, contrasting Hradec's stability; broader Eurostat data (2015–2022) highlights Poland's declining active citizenship amid Czech gains, underscoring macro-, demographic, and psychological influences (RQ4). Ultimately, these cases exemplify "mandated" and "efficient digital" PB archetypes, enabling co-governance yet revealing trade-offs in inclusivity, turnout, and project viability.

Conflict of interest: none

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Analysis of Changes in Fish Acquisition and Consumption in Poland: Selected Aspects

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Abstract: This study analyzes fish catches and consumption in Poland. The specific objectives include examining the structure of marine fish catches by fishing location and species, analyzing the dynamics of marine and freshwater catches, and evaluating fish consumption. The study is based on desk research methods, including descriptive, analytical, and statistical approaches. The results show a decreasing share of Baltic catches and an increasing share of distant-water catches in Polish marine fisheries, with distant-water catches growing relatively dynamically, while Baltic catches show a low average annual growth rate. Baltic catches are mainly composed of sprat, herring, flatfish, and cod, with sprat and herring dominating. Catch limits introduced to protect declining stocks are reflected in catch volumes. Poland is one of the largest carp producers in Europe and the largest in the European Union, with production mainly intended for the domestic market, while the Czech Republic is the largest exporter of carp in Europe. Fish consumption in Poland increased to nearly 14 kg per capita in 2024, which is about half of the European Union average. Despite FAO recommendations and the nutritional benefits of fish, rising prices of fish and their substitutes limit consumption.

Keywords: nutritional value of fish; fish catches; fish consumption; fish prices

JEL Classification: P2; P22; Q00

1. Introduction

Fish have been harvested by humans and formed part of their diet since prehistoric times, with archaeological evidence indicating their consumption at least 10–12 thousand years ago. Numerous archaeological findings from different geological periods across all continents confirm this. These include remains of fishing tools such as bone and horn harpoons used for large fish or hooks made of shells and bones, as well as fish remains found in ancient settlements (Cios, 2007; Rudnicki, 1989; Rybacy.com, 2026a). Fishing practices have evolved alongside the development of human civilization. Aquatic organisms harvested from marine and freshwater environments gradually ceased to serve solely subsistence needs and became objects of trade.

Fish are of considerable economic and nutritional importance. They provide high-value meat and roe and constitute a significant source of dietary protein. The nutritional value of their meat is very similar to that of livestock. The content of high-quality, easily digestible protein in fish meat ranges from 8-20% (in livestock meat, it is 15-20% respectively). Fish contain easily digestible proteins with a digestibility of over 90%. They have essential amino acids with a very favorable composition, allowing for optimal utilization of proteins by the body. Fish contain minerals important for the human body, such as phosphorus and calcium, as well as vitamins, including those from the B group. Marine fish additionally contain iodine and fat-soluble vitamins A and D (vitamin D3 is responsible for calcium-phosphorus metabolism in the body and regulates insulin levels, which affects blood sugar levels). Moreover, fish are a key source of essential unsaturated fatty acids, particularly long-chain omega-3 polyunsaturated fatty acids such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), which are scarce in many other food products. Omega-3 fatty acids play an important role in human health. They are associated with the prevention of cardiovascular diseases, support brain development and cognitive functioning, contribute to proper vision, and help reduce blood triglyceride levels. Their intake is also linked to a lower risk of certain chronic diseases (Mania et al., 2012).

FAO and WHO recommend regular fish consumption, typically one to two portions per week. In Poland, however, fish consumption remains relatively low, averaging approximately 14 kg per capita annually. For comparison, the average fish consumption in the European Union over a similar period was almost twice as high (23.7 kilograms). Among EU countries, the highest fish consumption is in Portugal (53.6 kilograms), followed by Spain (40.7 kilograms) and France (32 kilograms), while the lowest is in the Czech Republic (5.6 kilograms) (EUMOFA, 2026).

Despite their nutritional benefits, fish and seafood may also contain harmful substances resulting from environmental pollution, including methylmercury, dioxins, polychlorinated biphenyls, and radionuclides. For this reason, authors like: Mania et al. (2012) point out that in many European Union countries with high fish and seafood consumption, dietary recommendations have been introduced regarding the limitation of consumption of certain types of fish. These recommendations mainly concern women planning pregnancy, pregnant women, breastfeeding mothers, and children. The importance of these issues is reflected in Commission Regulation (EU) No 617 of 12 April 2022 regarding the maximum permissible levels of mercury in fish and salt (Mania et al., 2012; European Commission, 2026; Commission Regulation (EU) 2022/617).

However, there is a potential risk resulting from increased fish consumption in the presence of substances that have a harmful effect on the human body, as noted by Kołodziejczyk (2007).

Beyond their direct role as food, fish constitute an important raw material for the production of pharmaceuticals (e.g., cod liver oil), fertilizers, glues, and animal feed.

Globally, the largest producer of fish and other aquatic organisms in the world (catch and aquaculture together with aquatic plants) is China (40.2% in 2023). It is followed by Indonesia (10.2%), India (7.7%), Vietnam (3.9%), Russia (2.5%), and Bangladesh (2.2%). The

countries of the European Union together account for approximately 2% of the global supply. Within the EU, Spain is the largest producer (0.4%). This ranks the country 26th in the world, while Poland occupies a much lower position- only 67th (Hryszko, 2024; Szymańska, 2020).

Poland is nevertheless one of the largest producers of carp in Europe and the leading producer within the European Union– a warm-water freshwater fish (30% of the entire EU production). The next places are taken by the Czech Republic and Hungary. Carp farming in Poland is based primarily on traditional earthen pond systems. The Czech Republic, on the other hand, is the largest exporter of carp in Europe and also exports trout (Portal spożywczy., 2026 b)

Fish resources are considered an important renewable and relatively low- emission source of food. According to FAO, they may play a significant role in ensuring food security and supporting healthy diets for the growing global population (FAO, 2024).

2. Methodology

To assess changes in fish catches and consumption in Poland, the study relied on secondary data obtained from specialized reports published by the Institute of Agricultural and Food Economics- National Research Institute, as well as from the official electronic database of Statistics Poland.

The analysis covers the period 2005–2024. The subject scope includes marine fish catches conducted by Polish fisheries in the Baltic Sea, the Szczecin and Gdańsk Lagoons, and outside Polish maritime areas (distant-water fisheries), as well as inland fisheries. In addition, the study examines fish consumption in Poland and trends in retail prices of selected fish products.

The research employed a desk research approach supported by descriptive, analytical, and quantitative statistical methods. The applied measures included structure indices, absolute and relative changes, and individual dynamics indices.

3. Results and Discussion

3.1. *Marine Fishing*

Polish marine fisheries consist of the following two segments: Baltic, including lagoon fishing, and deep-sea fishing. In the years analyzed, 2005-2024, Baltic catches had a dominant share in Polish marine fishing, especially in the initial period. In year 2004, these catches accounted for slightly over 91% of the total Polish marine catches. In the later period, a decrease in their share of total catches is observed, down to almost 58% in year 2024. The declining Baltic catches were mainly due to restricted fishing quotas (Hryszko, 2024; Szymańska, 2021). At the same time, the share of distant-water fisheries increased (from 8.8% in year 2005 to 42.3% in year 2024).

Polish marine catches, despite some variability, were characterized by an average annual growth rate of around 1.59 thousand tons in live fish weight in the years 2005-2024. A similar situation applied to distant-water fisheries (average annual growth rate of 1.56 thousand tons in live fish weight). Although an average annual increase was observed for Baltic catches, its

growth throughout the entire analyzed period was relatively much lower (0.03 thousand tons in live fish weight, respectively). This limited growth was influenced by a noticeable decline in Baltic catches during the years 2019–2024 (Figure 1).

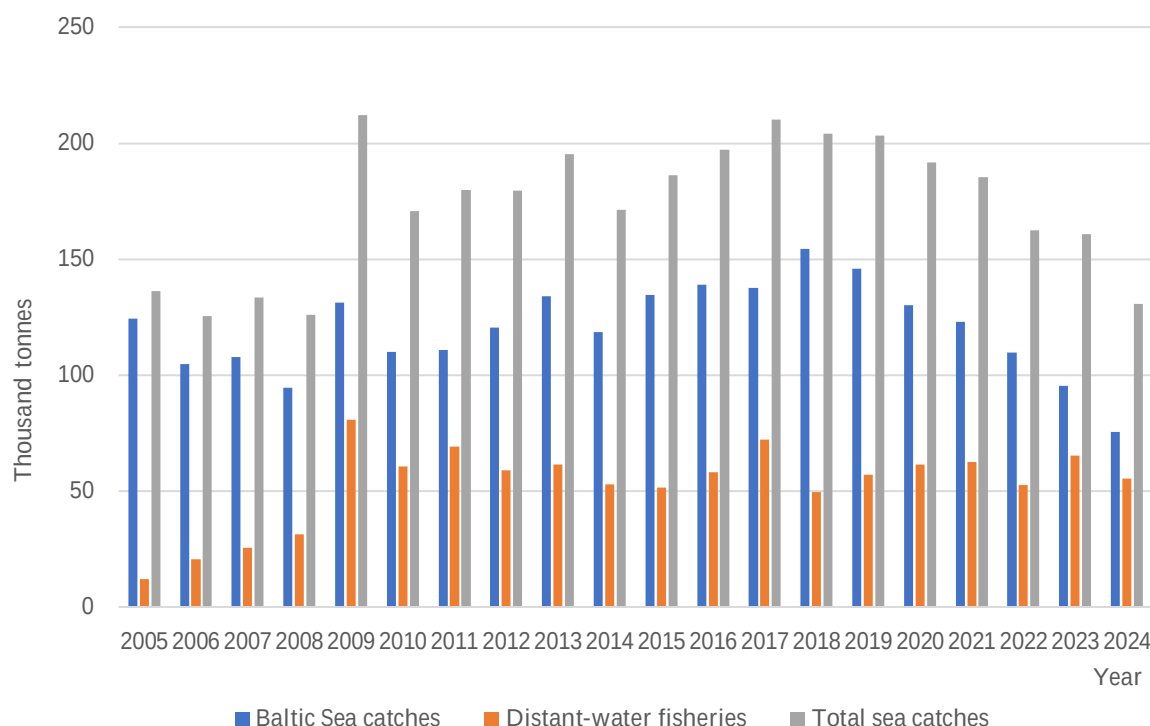


Figure 1. Volume of Polish marine catches, 2005–2024 (thousand tonnes, live weight)

The structure of Baltic catches is dominated by four species: sprat, herring, flatfish, and cod. The total average annual share of catches of these fish in the years 2005–2024 was 94.5%. The largest share was of sprats (54.8%), followed by herring (23.6%), with less for flatfish (9.2%) and cod (7%). Despite fluctuations, over the analyzed years there has been a strengthening in the share of sprat catches (69.9% in year 2024, compared to 43.3% in year 2016, when this share was the lowest among the years 2005–2024). The position of herring in catches has weakened (19.9% of catches in year 2024, compared to 36.2% in year 2018, when it was the highest among the analyzed years). A similar situation applies to flatfish (5.2% of catches in year 2024, compared to 12% in year 2012, when it was the highest among the analyzed years) and cod (0.1% of catches in year 2024, compared to 14.4% in year 2006, the year when it was the highest among the analyzed years).

Restrictions on catches introduced to protect declining fish stocks are reflected in the observed catch volumes. The observed variability in the catch of these fish species between year 2005 and year 2024 has resulted in the average annual catches of Baltic cod decreasing relatively the most (by 0.79 thousand tons), much less so for sprat (a decrease of 0.04 thousand tons). However, an increase in herring catches was noted (an average of 0.46 thousand tons per year) along with a relatively small increase in flatfish catches (by 0.03 thousand tons, respectively). Nevertheless, in 2024 the catches of all these species were lower than in 2005: cod (as much as 99.2% less, only 0.1 thousand tons), flatfish (respectively 64.9% less, 3.9 thousand tons), herring (31.2% less, 15 thousand tons), sprat (29.2% less, 52.7 thousand tons).

The total catch of other fish species also decreased (by 11.9%, to 3.7 thousand tons in 2024) (Figure 2).

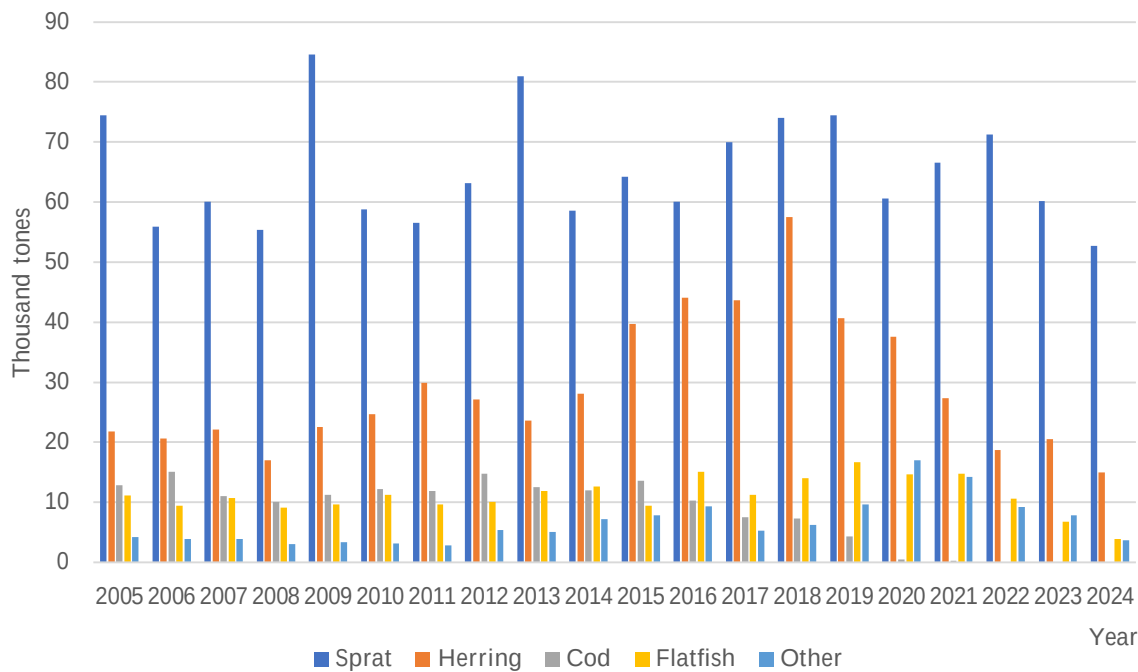


Figure 2. Baltic Sea catches by species in Poland, 2005–2024 (thousand tonnes, live weight)

Analysts point out the factors limiting the development of the analyzed market, including rising production costs and high inflation correlated with interest rates, which affect both the shaping of domestic demand and the investment opportunities in the industry (Hryszko, 2024).

In the final years of the analyzed period, Polish distant-water fisheries operated mainly in the Pacific Ocean (grenadiers and chub mackerels) and the North Atlantic (blue whiting). In the structure of these catches, blue whiting dominated (68.7%), followed by Chilean grenadiers (18%) and chub mackerels (4.5%). Together, these fish species accounted for just over 91% of Poland's distant- water fisherie. In earlier years, mainly pollock and krill were caught (Hryszko, 2024; Szymańska, 2021).

3.2. Freshwater Fishing

Freshwater fish are considered an important source of supply for the Polish fish market. Their production includes aquaculture (fish and crustacean farming), commercial inland fisheries conducted in fishing areas such as lakes, reservoirs, and river sections, as well as recreational fishing (angling) (Regulation No 1380/2013 of the European Parliament and of the Council of 11 December 2013; Hryszko, 2024).

The largest share in the production and consumption catches of freshwater fish in Poland in the analyzed years 2005–2024 was held by aquaculture, whose share increased (from 62.6% in year 2005 to 79.9% in year 2024). Recreational fishing and professional catches had significantly smaller shares, which decreased (in year 2005 compared to year 2024, from 31.5% to 17.8% and from 5.9% to 2.3%, respectively).

Over the analyzed years, the volume of fish catches from aquaculture increased, while that from commercial fishing and angling decreased. In year 2024, 49.4 thousand tons came from aquaculture (34.3% more than in year 2005). The average annual increase of these catches is estimated at 0.79 thousand tons, despite fluctuations in some periods. Commercial catches in year 2024 amounted to 1.4 thousand tons (59.7% less than in year 2005, decreasing on average by 0.01 thousand tons per year). In year 2024, 11 thousand tons of fish were obtained from recreational fishing (40.5% less than in year 2005). The average annual decrease in these catches is estimated at 0.33 thousand tons (Figure 3).

Poland is one of the largest producers of carp in Europe and the largest in the European Union – a freshwater, warm-water fish. Almost the entire production (about 18 thousand tons) is intended for the domestic market. Fish farms are located in various regions of the country (Hryszko, 2024; Szymańska, 2021).

Carp farming in Poland is carried out mainly in earthen fish ponds, utilizing the natural production capabilities of the land and its waters. This type of activity is considered to be extensive production, sometimes referred to as ecological (organic) production, which does not negatively affect the state of the natural environment.

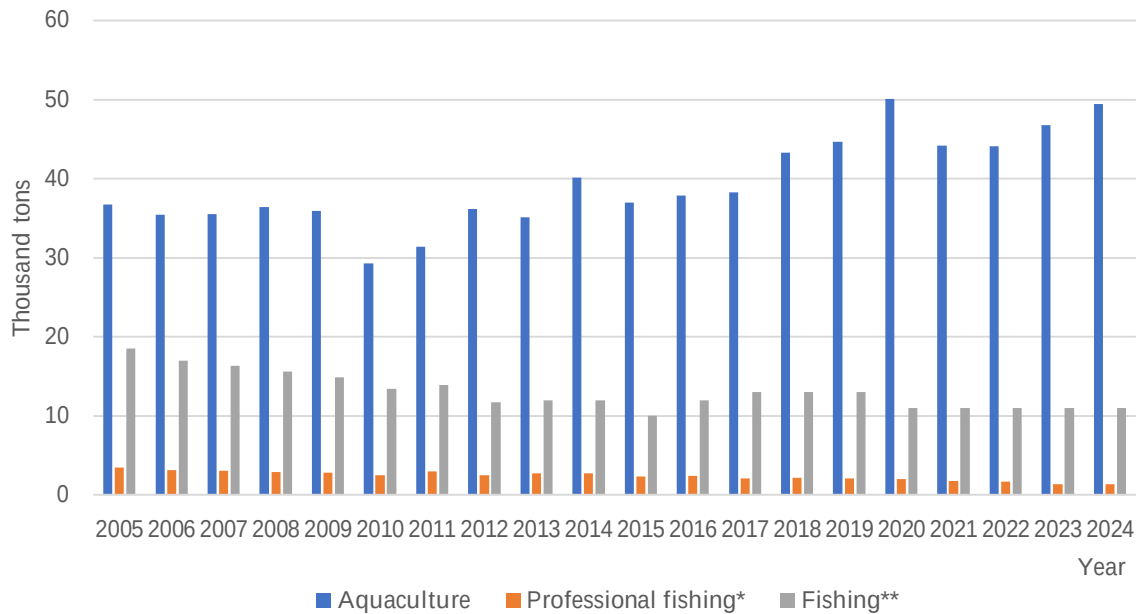


Figure 3. Catch of freshwater fish for consumption, 2005–2024 (thousand tonnes)
 Note: *In fishing areas covering lakes, reservoirs, and river sections **estimate

The average annual national supply of fish, seafood, and their products is increasing, and by the end of the studied period (year 2024) it amounted to almost 523 thousand tons in live weight equivalent. This was solely due to an increase in net imports, with a significant decline in domestic catches, which led to a decrease in the self-sufficiency rate to 34.7%, as analysts emphasize (Hryszko, 2024).

The use of fixed-base indices (2015=100) allows the identification of three phases shaping the contemporary architecture of trade exchange: the pre-referendum stabilization period, the uncertainty phase (2019–2020), and the period of operation outside the EU single market (after 2021).

3.3. Fish Consumption

Over the analyzed period, fish consumption in Poland, measured in live weight per capita (according to FAO calculations), increased to almost 14 kilograms in year 2024 (up 2.7 kilograms compared to year 2005). The fluctuations in this consumption between year 2005 and year 2024 resulted in a relatively modest average annual growth (by 0.07 kilograms) (Figure 4).

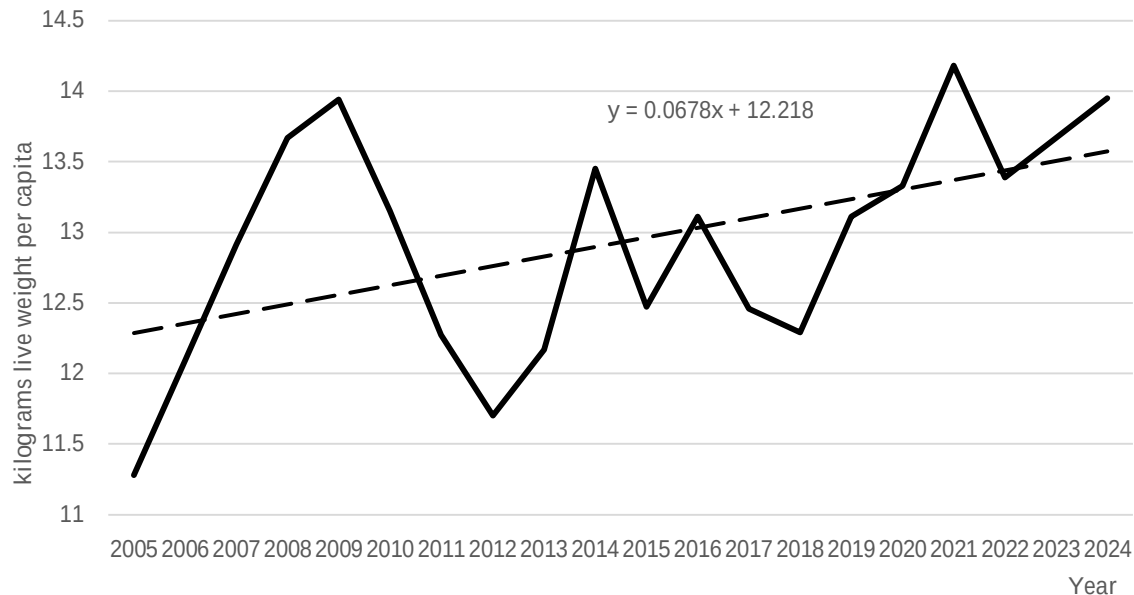


Figure 4. Fish consumption in Poland, 2005–2024 (kg live weight per capita)

Despite the observed increase, per capita fish consumption in Poland remains lower than both the European Union and global averages. In year 2024, this difference was nearly 10 kilograms (on average, almost 24 kilograms of fish were consumed in the European Union over a comparable period), while worldwide, 20 kilograms of fish were consumed, compared to just under 14 kilograms in Poland (Hryszko, 2024; EUMOFA, 2026)

Analysts note that in Poland fishery products are generally regarded as a third-choice source of animal protein, after meat and dairy products. Additionally, demand for fish and fish products responds relatively quickly to changes in buyers' incomes and the prices of these products, in situations of changes in the market value being analyzed; in the last years studied, the increase in the value of the fish market in Poland was caused by rising product prices (Tubilewicz, 2026; Hryszko, 2024). Fish consumption in Poland also exhibits clear seasonal patterns, with the highest demand occurring during the Christmas period. Analysts emphasize the strong role of freshwater fish (especially carp) and imported and farmed sea fish (trout, salmon) in this consumption.

Average fish consumption in Poland also varies by species. Over the period 2005–2024, the highest average annual consumption per capita was recorded for pollock (2.72 kilograms per year in live weight equivalent), followed by herring (2.4 kilograms) and mackerel (0.97 kilograms) (Figure 5).

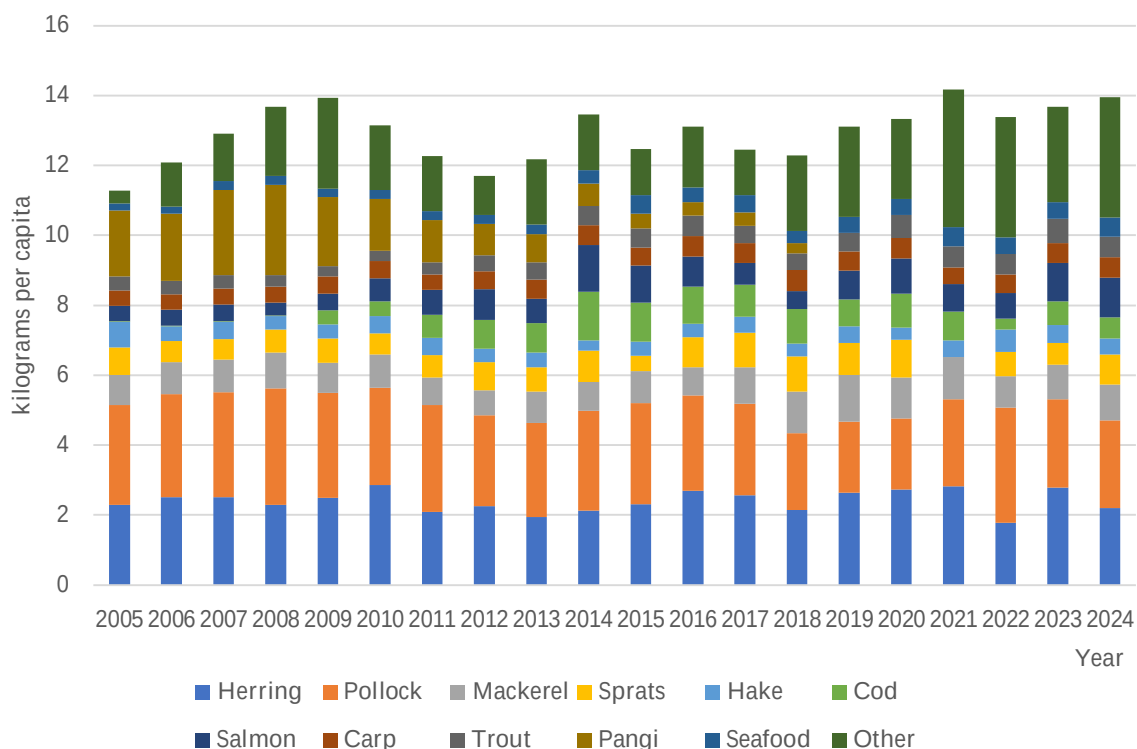


Figure 5. Structure of fish consumption by fish species and seafood consumption in Poland in 2005-2024 (kilograms of live weight per capita)

In the years analyzed, changes in the consumption of individual fish species were observed. Cod consumption grew relatively most dynamically (on average by 0.04 kilograms per year in live weight equivalent), followed only slightly slower by salmon (0.03 kilograms, respectively), then by trout and seafood (0.02 kilograms each), and mackerel and carp (0.01 kilograms each). Consumption of herring and sprat was characterized by a small growth dynamic (both less than 0.00 kilograms). On the other hand, the average annual consumption of pangasius decreased (by 0.14 kilograms), followed by pollock (by 0.03 kilograms) and slightly by hake (less than 0.00 kilograms). The remaining types of consumed fish were characterized overall by an average annual growth dynamic of 0.11 kilograms.

In the final year of the analyzed period, per capita consumption of fish and seafood slightly exceeded their recorded supply. Analysts attribute this discrepancy partly to Poland's declining population in 2024 (Hryszko, 2024).

Over 2005–2024, retail prices of fish and fish products increased. Data analysis shows that the most dynamic growth occurred for frozen hake fillets (an average of 1.21 PLN per kilogram annually, reaching 40.10 PLN per kilogram in year 2024), followed by fresh trout (0.99 PLN per kilogram, reaching 37.97 PLN per kilogram), live carp (0.97 PLN per kilogram, reaching 37.60 PLN per kilogram), and gutted salted herring (0.72 PLN per kilogram, reaching 23.22 PLN per kilogram) (Figure 6).

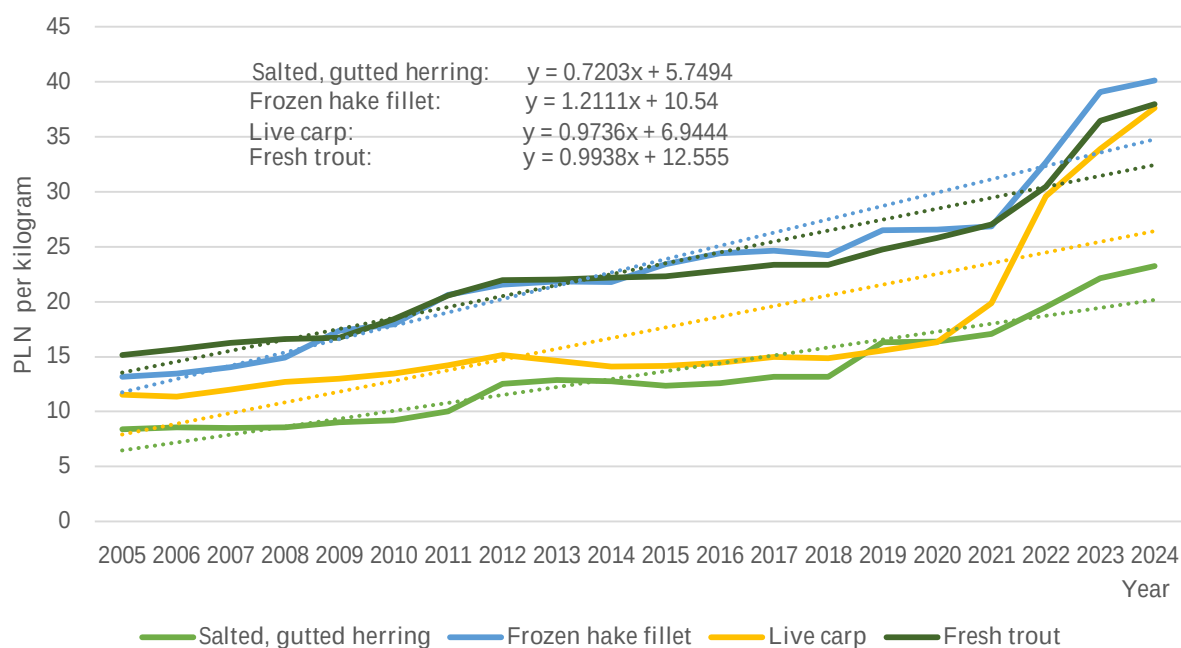


Figure 6. Retail prices of selected fish and fish products in Poland, 2005–2024 (PLN per kg)

The average increase in fish and seafood prices in Poland in year 2024 was 1.6% compared to the previous period (rising twice as slowly as the increase in food and non-alcoholic beverage prices over the same period). It was also lower than the average increase in these prices in the European Union countries (2.1%). Fish and seafood prices increased the most in Romania (by 6.4%), Greece and Croatia (by 5.7% each), and Malta (by 5.5%). A decrease in prices for these products occurred, however, in Lithuania, Hungary, Cyprus, Finland, and the Czech Republic (from 0.1% to 4.4%) (Hryszko, 2024; Szymańska, 2021; Statistical Office in Szczecin, 2026; Statistics Poland, 2025). Changes in retail prices of fish and fish products influenced demand conditions in the market.

Retail prices of selected substitutes for fish and fish products also increased. For frozen hake fillet, whose prices are monitored by the Central Statistical Office (Statistics Poland, 2025), the following substitutes were considered: gutted chickens, central pork loin (with bone since 2016), and beef with bone – ribeye.

In the years analyzed, the relationship between the average retail price of 1 kilograms of frozen hake fillet and the corresponding price of 1 kilograms of beef with bone – sirloin – changed. In year 2024, for the equivalent of 1 kilograms of frozen hake fillet, the average consumer could buy 0.84 kilograms of sirloin (less in year 2005, only 0.79 kilograms). The ratios of the average retail price of 1 kilograms of frozen hake fillet to the corresponding prices of 1 kilograms of center-cut pork loin and eviscerated chickens have also changed. In year 2024, for the equivalent of 1 kilograms of frozen hake fillet, the average consumer could buy 1.54 kilograms of bone-in center-cut pork loin (less in year 2005, only 1 kilograms, but boneless center-cut pork loin) or 3.35 kilograms of eviscerated chickens (respectively 2.84 kilograms). These relative price changes may have encouraged some consumer groups to substitute frozen hake fillet with beef, pork, or poultry products.

5. Conclusions

The study showed that the share of Baltic catches in Polish marine fisheries is decreasing (to almost 58% in 2024), while the share of distant-water fisheries is increasing. The observed changes are mainly due to restricted fishing quotas (EU Common Fisheries Policy), as analysts emphasize.

The volume of distant-water catches is growing relatively dynamically. The average annual growth rate was estimated at 1.56 thousand tons in live fish weight for the years 2005-2024. On the other hand, Baltic catches are characterized by a small average annual growth rate (0.03 thousand tons, respectively) over the same period.

The majority of Baltic catches (on average over 94% annually) are based on the following four fish species: sprat, herring, flatfish, and cod. On average, in the years 2005-2024, the most caught was sprat (about 55%), followed by herring (over 23%), then less of flatfish (slightly over 9%) and cod (7%). Applying catch limits to these fish (sprat, herring, cod, and flatfish), in the context of protecting their declining stocks, is reflected in the volume of catches. On average per year, the catches of Baltic cod decreased relatively the most (by 0.79 thousand tons), followed by a much smaller decrease in sprat (down by 0.04 thousand tons). However, an increase was noted in herring catches (on average 0.46 thousand tons per year) and a relatively small increase in flatfish catches (by 0.03 thousand tons, respectively).

In the analyzed years, aquaculture, which supports sustainable fisheries, has the largest share in the production and consumption of freshwater fish in Poland, and its share is increasing.

Poland remains one of the largest carp producers in Europe and the leading producer within the European Union. Nearly all production is allocated to the domestic market. On the other hand, The Czech Republic is the largest exporter of carp in Europe.

In the years analyzed, fish consumption in Poland increased to almost 14 kilograms in 2024. On average, in the European Union during the same period, almost twice as much fish was consumed. Among EU countries, the most fish is consumed in Portugal, followed by Spain and France, while the least is consumed in the Czech Republic.

FAO recommends regular consumption of fish (1 to 2 times a week). Fish contain minerals important for the human body, such as phosphorus and calcium, as well as vitamins. The content of essential unsaturated fatty acids in fish meat, including those from the omega-3 family, makes fish and their products very valuable nutritional components.

A limiting factor in the consumption of fish and fish products is the observed rising prices of these products. During the period under study, the retail prices of frozen hake fillets increased relatively the most dynamically, followed by fresh trout, live carp, and headless salted herring. The volume of fish consumption is also influenced by the retail prices of substitute products for fish, which include dressed chicken, center-cut pork loin, and bone-in beef – roast beef. The prices of these products also increased. The relationships between the retail prices of the monitored fish species and the corresponding prices of their substitutes were unfavorable.

Market forecasts indicate a continued gradual increase in fish consumption in Poland. The annual growth of the fish market value is expected to be around 5-7%. An increase in the share of inland aquaculture, especially in the trout segment, is forecasted, along with the development of production for orders from large processing plants (Rybacy.com, 2026 b). According to analysts of this market, the main factors shaping the development of the fish market are: increasing consumer health awareness (the benefits of a diet rich in omega-3 fatty acids), rising incomes and changes in consumer culinary preferences, support for sustainable fisheries, and investments in gastronomy infrastructure and retail networks developing fish sections.

Conflict of interest: none

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Sustainability in Czech Consumers' Purchasing Decisions: Motivation, Barriers, and Trust in Certification

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Abstract: Interest in sustainable products has increased in recent years, yet significant barriers still limit their broader adoption. This study examines how sustainability influences purchasing behaviour among Czech consumers, identifies key drivers of sustainable product selection, and explores barriers to their wider use. Data were collected through a 2025 survey of 449 respondents, followed by a focus group to deepen understanding of consumer attitudes. Findings show that sustainability is perceived as important but not decisive in purchasing decisions. Product quality, price, and health safety have a stronger influence. Awareness of environmental and ethical certifications remains low; consumers often do not understand them, question their credibility, or find them too complex. These insights are relevant for both theory and practice, particularly in marketing communication, retail, and commerce. Although sustainable consumption has been widely studied internationally, empirical research in the Czech Republic remains limited and fragmented. Existing studies often focus narrowly on specific products, population segments, or variables. There is a lack of comprehensive analysis of sustainability as a multidimensional factor and its interaction with trust, information sources, and perceived “green” costs. This study addresses this gap by providing new empirical evidence from the Czech context.

Keywords: sustainable consumption; purchasing behavior; decision-making; certification; barriers

JEL Classification: M31; D12; Q56

1. Introduction

In recent years, sustainability has become an increasingly important topic not only in political and environmental debates but also in the area of everyday consumption (Akenji & Bengtsson, 2014; Syed et al., 2024). In this study, sustainability is defined as the integration of environmental, social, and economic concerns in our production and use of goods with the goal of reducing our negative impacts on the environment and society while keeping our economic system viable in the long run. A sustainable product is therefore one that, in its entire life cycle, reduces negative impacts on the environment, maintains high ethical and social standards (for example, in terms of labor practices), and uses resources productively. From the consumer's point of view, however, sustainability in a product is sometimes

subjective and cannot be solely based on objective criteria. For one consumer, sustainability might be based on their subjective experience or feeling about a product based on their observations of its packaging, country of origin, or claims by the manufacturer. For another consumer, sustainability in a product might be based on their perception that it is certified by an organization that promotes environmental or ethical practices. The study will look into both perspectives: the actual product that consumers buy might be based on their subjective experience of sustainability as well as their trust in certification schemes. Although sustainability is often presented as a key value that should influence consumer decisions, actual consumer purchasing behavior often paints a different picture (Rausch & Kopplin, 2021). The literature consistently highlights the discrepancy between declared attitudes and actual purchasing of sustainable products (Munro et al., 2023; Sharma et al., 2023). Although people declare an interest in sustainable lifestyles, when it comes to shopping, they often make decisions based on price, availability, habit, or ignorance (Hoffmann et al., 2025; Tawde et al., 2023). In recent studies, barriers are also operationalized as "green costs" and as cognitive (involving the understanding of information) and transactional (involving time/effort) costs (Feuß et al., 2022; Majer et al., 2022). The concept of "green costs" provides a better understanding of what prevents consumers from making a purchase that is sustainable in nature. These green costs are not only associated with higher prices but are also a function of cognitive cost, where consumers try to make sense of the label, claims, and certifications; transaction cost, where consumers need to search and find products; and psychological cost, where consumers experience a degree of uncertainty or doubt in relation to green claims. Barriers, in this context, are associated with the perceived green cost, and if the green cost is high, sustainability will not drive the purchase decision. From a trust perspective, it is essential that eco-labelling can only work if it is perceived as credible (Gorton et al., 2021; Khachatryan et al., 2021). Current research highlights the risk of "greenwashing perceptions" and the fact that vague or poorly substantiated messages can undermine trust (Zioło et al., 2024). There is growing mistrust and concern about "greenwashing," which can diminish the value of environmental claims in consumer decision-making (Fella & Bausa, 2024; Gorton et al., 2021; Koch & Denner, 2025; Santos et al., 2024; Xiang et al., 2024). Customers often do not understand the significance of certifications, are unsure of their credibility, or consider them too complicated. Practical implications, therefore, point towards improved accessibility, comprehensibility, and transparent communication at the point of sale (Bashir, 2022).

Consumers are not a homogeneous group. Their perceptions of sustainability, willingness to change their purchasing habits, and trust in certifications or labels vary significantly. According to the literature, the factors contributing to the phenomenon of green or sustainable purchasing are varied, and sociodemographic factors only contribute to a part of the explanation. In the literature on green or sustainable purchasing, gender, age, education, and income are found to be significant factors. Women and more educated consumers are found to exhibit higher pro-environmentalism and green product purchase tendencies (Sharma et al., 2023). However, the impact of age is found to vary depending on the product category and the country. Nevertheless, it has been found that sociodemographic

factors do not entirely explain green purchasing behavior, as other factors like values, environmental concern, perceived consumer effectiveness, and consumer trust are found to be more significant predictors. Moreover, the impact of sociodemographic factors tends to become insignificant once the impact of attitude and knowledge is taken into consideration (Cook et al., 2023). In other words, researchers now consider consumer segments to be varying not only according to “who they are” but also according to “how they process the information”—the way they process the information, including their ability to interpret the label and their susceptibility to greenwashing concerns (Bastounis et al., 2021). Another important factor affecting the heterogeneity is the product category. This means that the way consumers respond to sustainability cues and their willingness to pay a higher price for a product varies depending on the product category. In the food product category, the impact of sustainability cues like the label “organic” or “eco-friendly” has been found to be significant in several studies. According to recent findings on the impact of environmental sustainability claims in food products in several countries, the impact of trust and willingness to pay varies depending on the claim type and product category. This shows that sustainability is not a single cue but a complex decision driver in consumer purchase decisions. In other words, the importance of sustainability and the impact of sustainability cues like the label “sustainable product” on consumer purchase decisions vary depending on the product category (Grunert et al., 2014). This selective approach suggests that sustainability only becomes a priority for most customers if it does not require a fundamental change in their purchasing habits or significant effort. It is therefore necessary to acknowledge that the key barriers, in particular, include higher prices, distrust of environmental claims and certifications, limited availability, and a lack of information (Dong et al., 2022; Ladwein & Sánchez Romero, 2021; Munro et al., 2023). Current research shows that the effectiveness of labelling and certification depends on the form of visual stimuli, the amount of information, and the context of purchase (Dorisse et al., 2025; Hoffmann et al., 2025; Majer et al., 2022; Piracci et al., 2024; Weber, 2021).

This article aims to empirically assess the extent to which sustainability influences the purchasing decisions of Czech consumers and to identify key motivational factors and barriers to purchasing sustainable products, with a particular emphasis on trust in environmental and ethical certifications, awareness of them, and their relationship to the frequency of purchasing sustainable products based on a combination of a quantitative questionnaire survey and a qualitative focus group survey.

2. Methodology

The empirical part of the study is based on quantitative research, which involves testing statistical hypotheses and subsequent conditional probabilities, as well as qualitative research. The quantitative part was conducted using an online questionnaire survey. Data collection took place in the first half of 2025. The questionnaire was created and distributed via the Survio.cz platform, and then further disseminated through Facebook and Instagram. A total of N respondents initially participated in the survey. Based on a filter question assessing self-reported familiarity with the concept of sustainability, 52 respondents who

declared no knowledge of the concept were excluded from further analysis. The final analyzed sample therefore consisted of 499 respondents. All statistical analyses reported in this study are based on this final sample ($N = 499$). The filter question was included to ensure that subsequent answers to the sustainable buying behavior questions came from individuals who at least a basic understanding of what sustainability means. We used a simple self-reporting method to gauge this by asking the participants if they were at least familiar with the concept of sustainability. The rationale behind this was to exclude those who clearly have no understanding of the concept at all, as their understanding of sustainable products would be based on confusion or random interpretation. So, 52 respondents were excluded from the sample (9.4% of the initial sample). This was done to improve the internal validity of the results. As this research seeks to examine the relationship between buying frequency, trust in certification, and sustainability, at least a basic understanding of the concept was a precondition for answering the subsequent questions.

The study finally analyzed 499 responses. The composition of the group was also indicated by gender, age, educational level, and where they live. Women dominated the respondents at 61.12%, while men made up 38.88%. Most respondents belonged to the age bracket 21-25 years at 18.24%, followed by those aged 18-20 years at 16.83%. By educational level, those who completed secondary education and obtained a diploma were the majority at 47.09%, followed by those who completed their studies at the university at 22.24%. Regarding place of residence, 28.06% lived in municipalities under 2,000 inhabitants, 15.03% in municipalities with 2,000–4,999 inhabitants, 11.22% in municipalities with 5,000–9,999 inhabitants, 9.62% in towns with 10,000–19,999 inhabitants, 11.82% in towns with 20,000–49,999 inhabitants, 6.81% in towns with 50,000–99,999 inhabitants, and 17.43% in cities with more than 100,000 inhabitants.

The questionnaire contained 22 questions (14 substantive, six identification, one filter, and one supplementary). The substantive questions focused on respondents' attitudes toward sustainable shopping, their willingness to prefer sustainable products, and the factors that influence their decisions, including their perception of environmental and ethical certifications and their level of trust in them. Categorical responses were evaluated using absolute and relative frequencies. For responses on five-point scales, the mean, standard deviation, and median were calculated. Spearman's correlation coefficient was used to test hypotheses; the significance level was set at $\alpha = 0.05$ (5%), and calculations were performed using TIBCO Statistica software. To decide whether to reject or not reject the null hypothesis, the p-value was compared with $\alpha = 0.05$. Box plots showing the median and quartiles were used to clearly visualize the distribution of data and compare responses between categories.

Tested hypotheses:

H1: H0: There is no correlation between the frequency of purchasing sustainable products and the number of sources of information about the sustainability of these products monitored.

H2: H0: There is no correlation between the frequency of purchasing sustainable products and trust in sustainability certifications.

H3: H0: There is no correlation between the preference for purchasing products with environmental or ethical certifications and the assessment of their low availability in regular stores.

The Spearman coefficient was calculated based on the order of values. For each pair of values, the difference in order d_i is determined and the coefficient is determined by the relationship:

$$r_s = 1 - \frac{6 \sum_{i=1}^n d_i^2}{n(n^2 - 1)} \quad (1)$$

where d_i = the difference between the order of values x_i and y_i of the corresponding correlation pairs

n = number of correlation pairs

To analyse differences between ratings of multiple categories within a single variable, a one-way analysis of variance for repeated measures was used. If the null hypothesis based on the F-statistics was rejected, a comparison between pairs of categories was performed using a post-hoc paired t-test. To avoid type I error accumulation in multiple testing, the Holm-Bonferroni correction was applied; p-values are ranked in ascending order and compared with the adjusted significance level.

Based on these absolute frequencies, relative frequencies were first calculated, i.e., the proportions of individual categories in the total sample. Subsequently, the conditional Probability was calculated for each combination of categories using the formula:

$$P(A|B) = \frac{P(A \cap B)}{P(B)} \quad (2)$$

where: $P(A | B)$ = Conditional probability. Indicates the probability that event A will occur if event B has already occurred.

$P(A \cap B)$ = Joint probability of events A and B

$P(B)$ = Probability of occurrence of phenomenon B

A qualitative focus group survey was conducted on February 21, 2025. The focus group took place via the Microsoft Teams platform, lasting 60 minutes. Respondents were selected based on their voluntary interest expressed at the end of the questionnaire survey. Six participants aged 23 to 60 were included in the group. The discussion was conducted in a free-form manner and moderated according to pre-prepared questions, focusing on the perception of environmental and ethical certifications, motivations and barriers to purchasing sustainable products, and the overall relationship to the concept of sustainable consumption. The focus group consisted of six participants, which represents a small qualitative sample. The purpose of this component was not to confirm the quantitative findings through statistical generalization, but rather to provide exploratory insight into consumer reasoning, perceived barriers, and interpretations of sustainability-related concepts. The qualitative part was therefore designed as complementary to the quantitative survey, aiming to deepen understanding of patterns identified in the statistical analysis.

3. Results

The results of the quantitative part evaluate the relationships between the frequency of purchasing sustainable products, consumer information behavior, trust in certification, and perceived barriers. At the same time, differences in the importance of factors in purchasing decisions and differences in the importance of motivational factors for purchasing sustainable products were compared.

H1 (purchase frequency × number of information sources monitored): The P-value of Spearman's test was 0.002, lower than 0.05. The correlation coefficient reached 0.14. The result shows a weak positive correlation (Figure 1). The null hypothesis was rejected. Purchasing sustainable products more frequently is associated with monitoring more sources of information.

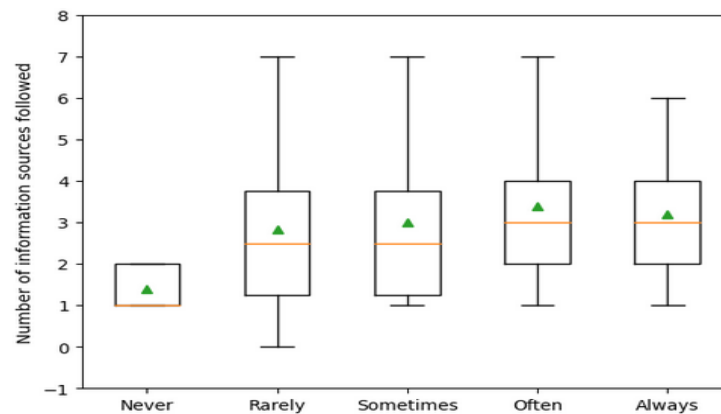


Figure 1. Frequency of purchase × number of monitored sources of information

H2 (purchase frequency × trust in sustainability certifications): Spearman's correlation coefficient reached 0.18, and the P-value was $p < 0.001$, lower than 0.05. The null hypothesis was rejected. A correlation between the frequency of purchasing sustainable products and trust in certifications was demonstrated (Figure 2). As trust increases, so does the frequency of purchasing.

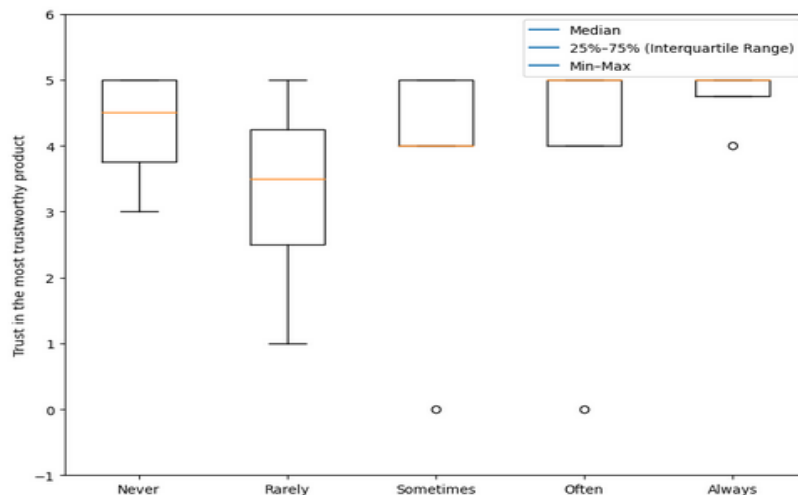


Figure 2. Purchase frequency × confidence in sustainability certifications

H3 (preference for certified products × low availability rating): The Spearman coefficient is 0.04 and the P-value is 0.496, which is higher than 0.05. The null hypothesis was not

rejected. At a significance level of 0.05, no dependence was found between the preference for certified products and the perceived low availability in regular stores (Figure 3).

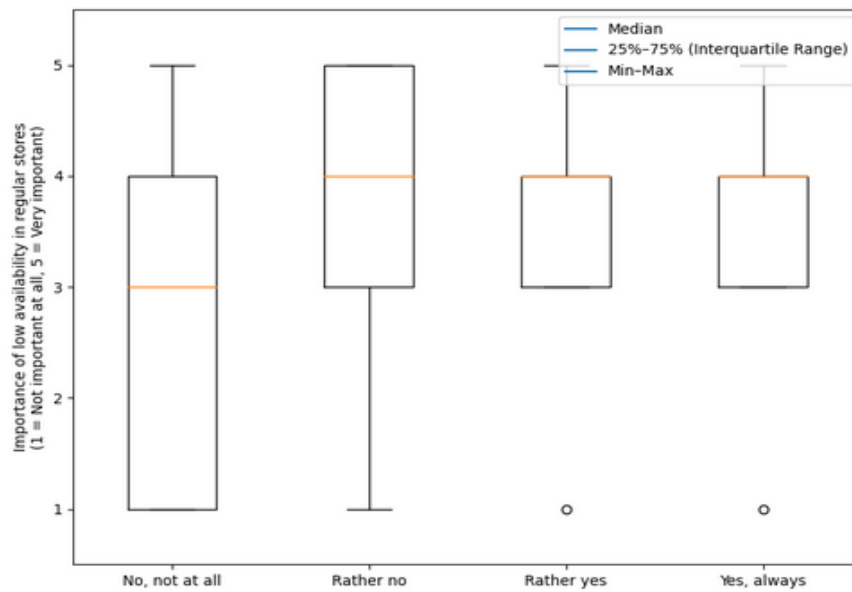


Figure 3. Preference for certified products × low availability rating

To better understand the relative importance of individual factors in purchasing decisions, a comparative analysis of mean evaluations was conducted. The results show that price and product quality remain the most influential criteria in consumer decision-making, while sustainability ranks lower in direct importance. Similarly, among motivational factors for purchasing sustainable products, product quality and health-related considerations were evaluated more strongly than broader environmental or ethical motivations. These findings suggest that sustainability-related attributes are evaluated in relation to traditional economic and quality-based considerations rather than independently dominating decision-making.

The qualitative part supplemented the results with information on barriers and uncertainty. Higher prices repeatedly emerged as the main barrier. Volume discounts or loyalty programs were mentioned as possible tools that could reduce the price difference compared to conventional options. The discussion emphasized the need for better communication and transparency. Respondents reported that they find it challenging to navigate the multitude of different labels and certificates and are unsure what exactly makes a product sustainable. Some of the statements also referred to the limited availability of sustainable products in smaller towns and villages.

The results indicate a correlation between purchase frequency, the number of monitored sources, and trust in certification. At the same time, it confirms that quality, safety, and price are more important than sustainability, and that brand is the least important factor in the context of regular purchases.

4. Discussion

The results show that Czech consumers continue to place the highest value on factors related to personal benefit (especially health/safety) and economic considerations (price)

when making purchasing decisions. Sustainability typically ranks behind these factors. This pattern corresponds to the fact that consumers are aware of sustainability, but when it comes to making actual choices, price, taste, convenience, and health often prevail (Van Bussel et al., 2022). In the food sector, it has also been repeatedly observed that "green" choices are more strongly supported when they are framed as beneficial to health (or "self-oriented" motivations; Gauthier et al., 2022). Our data also shows that a higher frequency of purchasing sustainable products is associated with more intensive information seeking (a higher number of sources monitored). However, this relationship is relatively weak, which is consistent with findings that the information environment can not only "empower" consumers, but also overwhelm them and increase uncertainty (Shahid et al., 2025). Although the correlations reached statistical significance, their strength remains weak according to conventional effect size interpretation thresholds. Therefore, sustainability-related information exposure and trust in certification appear to contribute to purchasing frequency only to a limited extent. Other factors such as price sensitivity and product quality likely play a more substantial role in decision-making.

As we consider these results from the perspective of the Czech Republic, it is helpful to consider the knowledge we already have from the results of the studies about sustainable consumption at the national level. In the Czech Republic, we know that people are aware of a great deal about sustainability and the environment, but their purchasing behavior is largely influenced by price and how good the product is. This was supported by the results from the CZSO (2023) survey for the year 2023. STEM/MARK (2022) also found that the situation is the same in the Czech Republic. Although the inhabitants of the Czech Republic talk positively about eco-friendly products, they are not willing to pay a higher price for them. According to the results from the Ministry of the Environment (2022), which were obtained in the year 2022, the level of trust in environmental labels is quite different among the inhabitants of the Czech Republic. As we found in our study, the level of trust in certification only weakly influences the frequency of purchase. In other words, certification by itself is not enough to change purchasing behavior without additional support from other factors. Further studies about the food habits of the inhabitants of the Czech Republic found that the sustainability of a product is important only in the case of health-related or locally produced products, such as organic or regional foods, but in other product categories, money is more important (STEM/MARK, 2022; CZSO, 2023). Our qualitative results support these findings. As we see, the results from the Czech Republic support the general results at the national level. In other words, sustainability is recognized as important by the inhabitants of the Czech Republic, but other factors, such as price sensitivity, trust in certification, and the complexity of the message, play a role as well.

Current literature suggests that a high number of claims and labels may lead to awareness only among a subset of the population. In contrast, others may resort to snap decisions or resignation (Torma & Thøgersen, 2024). Trust in certifications is linked in our results to a more frequent choice of sustainable products, which supports the interpretation that certifications act as a signal of trustworthiness and reduce transaction uncertainty (Boe-Lillegraven & Demmers, 2025). At the same time, however, qualitative findings suggest that

some consumers have an ambivalent attitude toward certifications and feel uncertain about "what is truly sustainable" and what standards certifications guarantee. This picture aligns well with experimental findings that while education can enhance the ability to identify greenwashing, it can also reinforce general skepticism, even toward legitimate messages. This is particularly true for lesser-known brands (Timmons et al., 2024). Similarly, studies focusing on greenwashed advertising show that consumers adopt defensive strategies (avoiding claims, questioning the company's motives) that reduce their willingness to act on environmental messages (Matthes et al., 2025). Price barriers appear to be significant in our research and correspond well with the fact that the "green" premium and price sensitivity are key moderators of behavior, in categories where consumers can easily compare alternatives (Chen et al., 2024). At the same time, evidence from the real online environment suggests that ecolabels can increase the likelihood of purchase, and that price signals (premiums/discounts) can further influence the effect of ecolabels (Feuß et al., 2022). This is important for interpreting our findings. The price barrier may not indicate a lack of interest in sustainability, but rather sustainability is conditional on price acceptability and understandable information. Interestingly, the perceived low availability of sustainable products did not emerge in our data as a factor that systematically explained the preference for certified products. One possible explanation is that in the context of regular retail offerings, consumers do not perceive availability as a primary barrier as long as they can make decisions based on price, habit, and trust in simple signals (e.g., certification) (Boncompagni et al., 2025). At the same time, some of the barriers are cognitive rather than logistical. Consumers can find the product, but they do not believe the claims or understand the differences between labels (Shahid et al., 2025). In addition, it appears that knowledge of certifications and the ability to interpret them are uneven, and this discrepancy significantly influences whether certification strengthens trust or, conversely, arouses suspicion (Sparacino et al., 2025). In a broader context, the results can be interpreted as indicating that certifications have the potential to reduce information asymmetry, provided they are stable, comprehensible, and perceived as independent (Aminravan et al., 2025). Furthermore, regulatory developments in the EU directly target the issue of unsubstantiated environmental claims and have the potential to strengthen consumer confidence through requirements for substantiation and verification (European Commission, 2023; Council of the EU, 2024). At the same time, however, uncertainty surrounding the legislative process may fuel continued public skepticism, as the topic of greenwashing remains highly visible in the media and political debate. In terms of implications, our results support an emphasis on transparent and verifiable rules for claims and certifications, and on communication that links sustainability to the motives that consumers value most highly (health/safety, price, quality; Van Bussel et al., 2022).

Overall, the findings suggest that sustainability-related factors are associated with purchasing behavior among Czech consumers; however, their influence appears limited in magnitude. Although statistically significant relationships were identified between purchase frequency, information exposure, and trust in certification, the observed correlations were weak, indicating modest practical effect sizes. This implies that sustainability functions as a

complementary rather than dominant purchasing criterion. Traditional factors such as price and perceived quality remain more influential in everyday decision-making. Therefore, while sustainability represents a relevant dimension of consumer behavior, its impact should be interpreted with caution and understood within the broader context of competing economic and cognitive considerations.

5. Conclusion

This study examined the role of sustainability in the purchasing decisions of Czech consumers using a mixed-method approach. The results indicate that sustainability-related factors, including exposure to information and trust in certification, are statistically associated with purchase frequency. However, the identified relationships were weak in strength, suggesting limited practical impact. Sustainability therefore appears to represent one of several considerations influencing purchasing decisions rather than a dominant determinant. Economic factors such as price and perceived product quality remain central in shaping consumer behavior. The focus group discussion identified three dominant themes: (1) price sensitivity as a primary barrier to sustainable purchasing, (2) uncertainty and confusion regarding certification schemes, and (3) perceived trade-offs between convenience and sustainability. Participants repeatedly emphasized that sustainability becomes relevant primarily when price differences are moderate and when information is clearly communicated. Trust in certification was described as conditional upon familiarity and perceived credibility of the label. These findings complement the quantitative results by illustrating how economic and informational factors interact in practical decision-making.

A comparison of the importance of decision-making criteria confirmed that consumers value quality, health, safety, and price the most. Sustainability ranks lower on average, and brand or manufacture is among the least important factors in terms of motivation. Reasons related to product quality and safety dominate. Environmental protection, personal values, ethical treatment, and support for local producers remain relevant, but they are often used as supplementary arguments. The qualitative part of the results was supplemented by repeatedly emphasized barriers, including higher prices, difficulty navigating the multitude of labels, and uncertainty about what exactly makes a product sustainable. The perceived need for better communication and transparency is also significant.

The practical implications are to enhance the clarity and credibility of certifications, to explain their content and verification transparently, and to reduce communication noise. In practice, pricing mechanisms that reduce the barrier of higher prices (e.g., promotions, loyalty programs, volume discounts) and consistent communication that links sustainability to health, quality, and safety can help. For further research, it is advisable to verify the transferability of findings across product categories, analyze differences between consumer segments by age, income, and value orientation, and test which information formats (symbols, brief explanations, digital links) best promote trust and real purchasing behavior.

Conflict of interest: none

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Digital Transformation and Sustainable Performance in Chinese Manufacturing Firms: Evidence from the Yangtze River Delta

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Abstract: Digital transformation (DT) has become an important pathway for manufacturing firms seeking sustainable development, yet empirical evidence on how it translates into sustainable performance (SP) remains limited, especially in emerging economies. Drawing on the Natural Resource-Based View (NRBV) and the Dynamic Capability View (DCV), this study examines the relationship between digital transformation and sustainable performance, focusing on the mediating role of green innovation in Chinese manufacturing firms. Using survey data from 310 firms in the Yangtze River Delta and applying partial least squares structural equation modeling (PLS-SEM), digital transformation is conceptualized as a multidimensional construct including digital capability, strategy, technology application, product value creation, and information sharing and analysis. Sustainable performance is assessed across economic, environmental, and social dimensions, while green innovation covers process, product, technology, and management innovation. The results show that digital transformation positively affects sustainable performance and enhances green innovation. Green innovation partially mediates this relationship, indicating that digital transformation improves sustainability outcomes by enabling the development and implementation of green innovations. The study contributes by clarifying the digital transformation–green innovation–sustainable performance mechanism and providing evidence from a major manufacturing region in an emerging economy, while also emphasizing the importance of aligning digital transformation initiatives with green innovation strategies.

Keywords: digital transformation; green innovation; sustainable performance; manufacturing firms; Yangtze river delta

JEL Classification: O33; L60; M15

1. Introduction

Digital transformation (DT) has become a critical strategic response for manufacturing firms facing intensifying sustainability pressures in an increasingly volatile global environment. Manufacturing activities contribute substantially to global greenhouse gas

emissions, resource depletion, and environmental degradation, thereby exacerbating climate change risks and threatening long-term industrial resilience (Xu et al., 2023; Luthra et al., 2022). Since 2019, global carbon dioxide emissions have continued to rise and have reached unprecedented levels, further highlighting the urgency of aligning industrial development with environmental and social responsibility (BP, 2024). These challenges are particularly pronounced in emerging economies, where rapid industrialization has historically emphasized output expansion at the expense of sustainable development (Wang & Wang, 2020).

Against this backdrop, digital technologies, such as artificial intelligence (AI), the Internet of Things (IoT), blockchain, and big data analytics, are increasingly regarded as key enablers of sustainability-oriented transformation in manufacturing. By enhancing real-time monitoring, optimizing resource allocation, and improving information transparency across supply chains, DT allows firms to reduce waste, enhance energy efficiency, and mitigate environmental risks (Patwa et al., 2021; Ghobakhloo et al., 2021). Accordingly, DT is no longer viewed merely as a technological upgrade; rather, it represents a strategic process that reshapes organizational capabilities, operational models, and mechanisms of value creation (Cai et al., 2023).

At the global level, sustainability has emerged as a central policy and strategic priority. International frameworks, including the Paris Agreement and the United Nations Sustainable Development Goals (SDGs), underscore the imperative of integrating environmental protection with economic development (Guan et al., 2023). Governments, investors, and consumers increasingly expect firms to demonstrate measurable sustainability outcomes, while sustainability-oriented investment criteria and regulatory regimes continue to reshape corporate decision-making. Within this context, sustainable performance (SP), encompassing economic, environmental, and social dimensions, has become a critical indicator of long-term organizational success.

China occupies a pivotal position in the global sustainability transition. As the world's largest manufacturing economy, China contributes substantially to global industrial output and carbon emissions, with manufacturing and industrial activities accounting for a significant share of national emissions (Wang & Wang, 2020). In response, the Chinese government has introduced a series of initiatives, including Made in China 2025 and the national Emissions Trading System, to promote digitalization, green innovation (GI), and high-quality industrial development (Liao et al., 2024). Meanwhile, structural pressures, such as slowing economic growth, rising labor costs, intensifying international competition, and weakening demand, have further underscored the urgency for Chinese manufacturing firms to pursue sustainable transformation rather than growth driven solely by scale expansion.

Despite strong policy support and rapid technological progress, the adoption and effectiveness of DT remain uneven across firms and regions in China. Advanced manufacturing clusters, such as the Yangtze River Delta (YRD), exhibit relatively high levels of digital adoption and innovation capability, whereas many firms, particularly small and medium-sized enterprises, continue to face constraints related to legacy systems, limited resources, and insufficient digital expertise (Kraus et al., 2021). These disparities raise critical questions

regarding how and through what mechanisms DT translates into sustainability outcomes, as well as the organizational conditions under which such transformation is most effective.

Despite the growing recognition of DT as a driver of sustainability, existing studies have examined DT, GI, and SP largely as independent or weakly connected research streams. Studies on DT frequently rely on Technology-Organization-Environment or diffusion-based frameworks, thereby conceptualizing digitalization primarily as a response to external pressures rather than as an internal capability that actively reshapes innovation processes (Sun et al., 2024; Feng et al., 2022). In contrast, research on GI, frequently grounded in the Resource-Based View, emphasizes green products or processes as strategic assets but offers limited insight into how digital capabilities facilitate the development and diffusion of such innovations across organizational domains (Hart, 1995; He et al., 2024). Similarly, studies on SP, particularly within ESG-oriented research, tend to focus on outcome measurement, leaving the internal mechanisms linking DT and sustainability insufficiently theorized.

To address these limitations, this study adopts an integrated theoretical perspective that combines the Natural Resource-Based View (NRBV) and the Dynamic Capability View (DCV). From the NRBV perspective, GI constitutes a critical sustainability-oriented resource that enables firms to achieve competitive advantage while reducing environmental impact (Hart, 1995). The DCV complements this perspective by emphasizing firms' ability to reconfigure resources and capabilities in response to dynamic environmental conditions (Teece et al., 1997). Within this integrated framework, DT is conceptualized as a digital dynamic capability that enables firms to sense opportunities, reconfigure resources, and facilitate GI across product, process, technology, and management domains.

Building on this perspective, the present study investigates how DT influences SP through the mediating role of GI in the Chinese manufacturing sector, with a particular focus on firms located in the YRD region. DT is operationalized as a multidimensional construct encompassing digital capability, digital strategy, digital technology application, product value creation, and information sharing and analysis. Using survey data collected from manufacturing firms of varying sizes, this study further examines whether firm size conditions the effectiveness of DT in promoting sustainable outcomes.

This study makes three primary contributions. First, it advances the DT-sustainability literature by elucidating the mechanism through which DT enhances SP via GI, thereby addressing a key gap in existing empirical research. Second, by integrating the NRBV and DCV, it provides a coherent theoretical framework that conceptualizes DT as a dynamic capability and GI as a strategic sustainability resource. Third, it offers empirical evidence from a leading manufacturing cluster in an emerging economy, thereby extending understanding of sustainability-oriented DT beyond developed-country contexts.

2. Methodology

Data for this study were collected through a structured survey administered to managerial personnel working in manufacturing firms in China's Yangtze River Delta (YRD). In total, 502 questionnaires were disseminated, and 310 usable responses were retained for empirical analysis, corresponding to a valid response rate of 72.5%. The survey instrument

was organized into two main components. The first component captured basic demographic characteristics of the respondents, whereas the second component assessed the key study variables, namely digital transformation (DT), sustainable performance (SP), green innovation (GI), and firm size. All participants were informed of the research objectives prior to participation and voluntarily consented to take part in the survey.

Table 1 presents the demographic characteristics of the 310 respondents. With respect to gender, 60% of the respondents were male and 40% were female. In terms of work experience, respondents were classified into four categories: less than one year (11.61%), 1-3 years (19.86%), 4-6 years (24.19%), and more than six years (44.52%). Regarding organizational position, the sample included directors (4.19%), chief executive officers (14.52%), senior managers (52.58%), senior engineers (26.13%), and administrative directors (2.58%).

Table 1 also reports firm-level characteristics. The surveyed firms operated across a range of manufacturing industries, including automotive manufacturing and electronics and electrical equipment. Firm types included state-owned enterprises, private enterprises, joint ventures, foreign-invested enterprises, and other ownership forms. Firm age ranged from less than five years to more than twenty years, and firm locations covered major manufacturing provinces and municipalities in the YRD region, including Shanghai, Zhejiang, and Jiangsu. In addition, firms served different primary markets, such as original equipment manufacturing (OEM), original design manufacturing (ODM), and contract manufacturing. Firm size was measured based on registered capital, ranging from less than one million to more than five million. Firms reporting a zero level of digitalization were excluded from the sample to reduce potential bias associated with non-digital operations.

Table 1. Demographic characteristics of respondents

Items	Variables	Frequency	Percentage (%)
Gender	Male	165	60
	Female	124	40
Year of Experience of Respondents	Less than 1 year	36	11.61
	1 to 3 years	61	19.86
	4 to 6 years	75	24.19
	More than 6 years	138	44.52
Position	Director	13	4.19
	CEO	45	14.52
	Senior Manager	163	52.58
	Senior Engineer	81	26.13
	Administrative Director	8	2.58
Firms' basic information			
Main Type	Automotive Manufacturing	81	26.13
	Electronics and Electrical Equipment	60	19.35
	Textiles and Apparel	113	36.45
	Machinery and Equipment	23	7.42
	Chemicals and Materials	33	10.65
	Others	0	0
Ownership	State-owned Enterprise	68	21.94
	Private Enterprise	181	58.39
	Joint Venture	33	10.65
	Foreign-owned Enterprise	25	9.03

Years	Less than 5 years	5	1.61
	5–10 years	113	34.45
	10–20 years	167	53.87
	More than 20 years	25	8.06
Location	Shanghai	33	10.65
	Zhejiang	180	58.06
	Jiangsu	97	31.29
Primary Market	Domestic Market (China)	198	63.87
	International Market	76	24.52
	Domestic and International	36	11.61
Manufacturing Activities	Original Equipment Manufacturer (OEM)	174	56.13
	Original Design Manufacturer (ODM)	64	20.65
	Contract Manufacturer	68	21.94
	Other	4	1.29
Registered Capital	Large or List Firm (5 million yuan ≤ Registered capital)	102	32.9
	Medium Firm (1 million yuan ≤ Registered capital < 5 million)	104	33.55
	Micro and Small Firm (Registered capital < 1 million)	104	33.55

2.1. Common Method Bias

Potential common method bias was examined using Harman's single-factor procedure. The analysis shows that a single factor accounts for 20.896% of the total variance, which is substantially below the conventional threshold of 50%, indicating that common method bias is not a critical issue in the present study. In line with established PLS-SEM research practices, DT, GI, and SP were specified as second-order constructs following a reflective-reflective measurement structure, with all lower-order dimensions modeled reflectively. Specifically, the repeated indicators approach was employed to estimate the higher-order constructs.

3. Results

The measurement model results presented in Table 2 indicate that all indicators exhibit adequate reliability, with standardized outer loadings exceeding the recommended cutoff value of 0.70. In addition, all constructs demonstrate satisfactory internal consistency, as their composite reliability (CR) values surpass the minimum threshold of 0.70. Convergent validity is further supported, given that the Average Variance Extracted (AVE) values for all constructs are above 0.50, ranging from 0.615 for product value creation to 0.960 for digital transformation (DT) and 0.888 for green innovation (GI). These findings suggest that each latent construct captures a substantial proportion of variance in its corresponding indicators. Taken together, the results confirm that the measurement model meets established criteria for indicator reliability, internal consistency, and convergent validity. The relatively high AVE values associated with the higher-order constructs can be attributed to the strong conceptual alignment among their underlying dimensions rather than to redundancy among measurement items, which is consistent with the hierarchical nature of the higher-order constructs.

Table 2. Reliability and validity analysis

Constructs		Items	Loading	Composite reliability	AVE
LOC	HOC				
Digital Capacity (DC)		DC1	0.873	0.941	0.761
		DC2	0.858		
		DC3	0.873		
		DC4	0.887		
		DC5	0.871		
Digital Strategy (DS)		DS1	0.874	0.943	0.768
		DS2	0.892		
		DS3	0.883		
		DS4	0.868		
		DS5	0.867		
Product Value Adding (PVA)		PVA1	0.886	0.905	0.615
		PVA2	0.859		
		PVA3	0.886		
		PVA4	0.859		
		PVA5	0.855		
Digital Technology Application (DTA)		DTA1	0.884	0.941	0.760
		DTA2	0.872		
		DTA3	0.861		
		DTA4	0.882		
		DTA5	0.859		
Information Sharing Analysis (ISA)		ISA1	0.835	0.926	0.715
		ISA2	0.826		
		ISA3	0.836		
		ISA4	0.864		
		ISA5	0.866		
	DC	0.842	0.827	0.960	
	DS	0.944			
	PVA	0.992			
	DTA	0.942			
	ISA	0.815			
Green Process Innovation (GPI)	GPI1	0.845	0.922	0.703	
	GPI2	0.844			
	GPI3	0.818			
	GPI4	0.846			
	GPI5	0.841			
Green Product Innovation (GPI_A)	GPI_A1	0.880	0.922	0.704	
	GPI_A2	0.879			
	GPI_A3	0.903			
	GPI_A4	0.884			
	GPI_A5	0.878			
Green Technology Innovation (GTI)	GTI1	0.889	0.939	0.756	
	GTI2	0.883			
	GTI3	0.859			
	GTI4	0.859			
	GTI5	0.859			
Green Management Innovation (GMI)	GMI1	0.842	0.929	0.724	
	GMI2	0.831			
	GMI3	0.867			
	GMI4	0.862			
	GMI5	0.852			

	GI	GPI	0.915	0.969	0.888
		GPI_A	0.980		
		GTI	0.987		
		GMI	0.884		
Sustainable Social Performance (SSP)		SSP1	0.872	0.937	0.747
		SSP2	0.873		
		SSP3	0.868		
		SSP4	0.849		
		SSP5	0.861		
Sustainable Economic Performance (SEP)		SEP1	0.851	0.919	0.697
		SEP2	0.835		
		SEP3	0.820		
		SEP4	0.816		
		SEP5	0.851		
Sustainable Environmental Performance (SEP_A)		SEP_A1	0.870	0.944	0.770
		SEP_A2	0.894		
		SEP_A3	0.856		
		SEP_A4	0.886		
		SEP_A5	0.881		
	SP	SSP	0.976	0.987	0.961
		SEP	0.988		
		SEP_A	0.977		

Discriminant validity was evaluated using the heterotrait–monotrait (HTMT) criterion, which assesses the extent to which latent constructs are empirically distinguishable by contrasting correlations across different traits and measurement methods. Smaller HTMT values indicate a higher degree of discriminant validity. Consistent with the guidelines proposed by Henseler et al. (2015), HTMT values below 0.85, or below 0.90 in the case of conceptually less related constructs, are regarded as acceptable.

Table 3. HTMT ratio result for lower order constructs

	DC	DS	DT	DTA	GI	GMI	GPI	GPI_A	GTI	ISA	PVA	SEP	SEP_A	SP
DC														
DS	0.191													
DT	0.681	0.633												
DTA	0.311	0.219	0.698											
GI	0.402	0.386	0.631	0.405										
GMI	0.274	0.342	0.472	0.275	0.714									
GPI	0.246	0.214	0.398	0.290	0.707	0.229								
GPI_A	0.301	0.249	0.403	0.275	0.758	0.280	0.269							
GTI	0.214	0.192	0.356	0.206	0.728	0.239	0.236	0.302						
ISA	0.226	0.222	0.691	0.265	0.374	0.266	0.312	0.189	0.203					
PVA	0.206	0.158	0.641	0.191	0.310	0.245	0.126	0.182	0.244	0.262				
SEP	0.275	0.181	0.368	0.171	0.314	0.307	0.189	0.098	0.220	0.201	0.267			
SEP_A	0.285	0.235	0.375	0.271	0.397	0.339	0.286	0.206	0.199	0.164	0.156	0.121		
SP	0.433	0.320	0.581	0.329	0.548	0.444	0.398	0.262	0.318	0.315	0.330	0.762	0.721	
SSP	0.286	0.208	0.393	0.198	0.358	0.220	0.300	0.204	0.203	0.251	0.226	0.284	0.179	0.798

The combined use of the Fornell–Larcker criterion and the heterotrait–monotrait (HTMT) ratio provides a robust assessment of discriminant validity in the measurement model. Figure 1 presents a graphical representation of the measurement model evaluation.

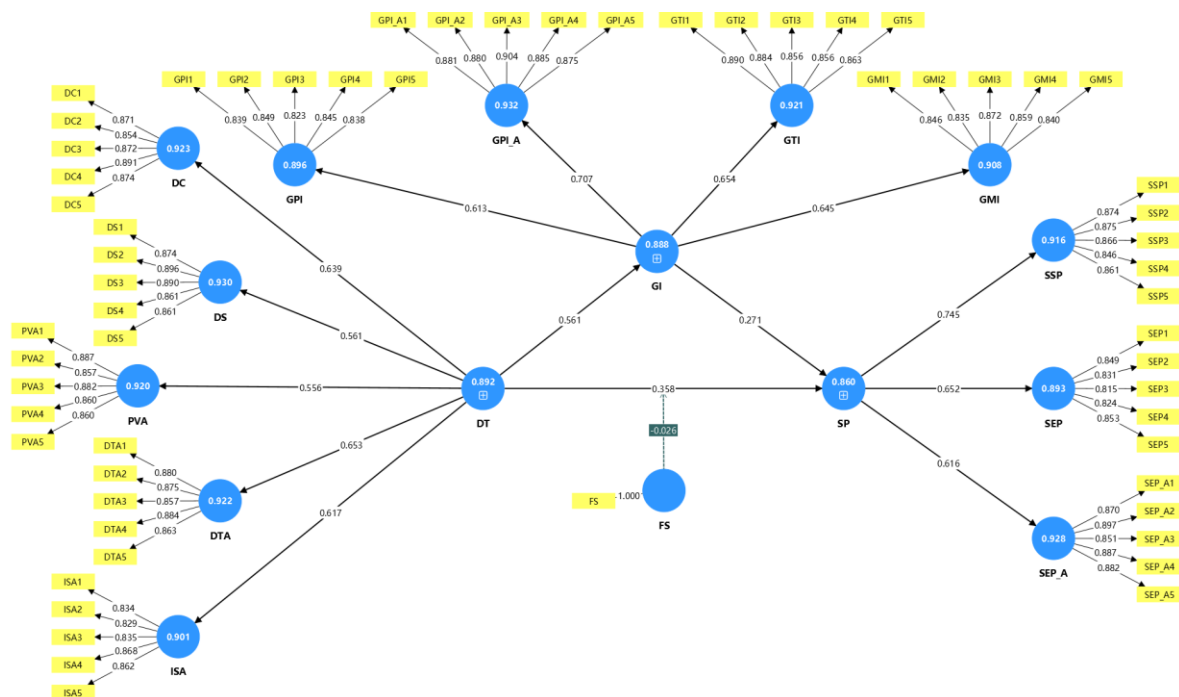


Figure 1. Measurement model results

Table 4 presents the results of the structural model and the hypothesis testing. Hypothesis H1 examines the direct effect of DT on sustainable performance (SP). The results indicate a positive and statistically significant relationship ($\beta = 0.347$, $t = 6.368$, $p < 0.001$), providing strong support for H1. This finding suggests that higher levels of DT are associated with superior SP outcomes.

Table 4. Hypothesis testing- direct effect

Relationship	β	STDEV	T-value	P-value	Decision
H1	0.347	0.054	6.368	0.000	Supported
H2	0.572	0.037	15.416	0.000	Supported
H3	0.294	0.054	5.435	0.000	Supported
H4	0.168	0.033	5.106	0.000	Supported
H5	-0.024	0.049	0.498	0.309	Not Supported

The influence of DT on GI is examined in Hypothesis H2. The analysis identifies a strong and statistically significant association between the two constructs ($\beta = 0.572$, $t = 15.416$, $p < 0.001$), indicating that higher levels of DT are closely linked to increased engagement in GI activities among manufacturing firms.

Hypothesis H3 evaluates the relationship between GI and SP. The results demonstrate a positive and significant effect of GI on SP ($\beta = 0.294$, $t = 5.435$, $p < 0.001$), underscoring the importance of GI as a key contributor to sustainability outcomes. This evidence supports the view that environmentally oriented innovation practices can be effectively translated into improved SP.

To further explore the causal mechanism, the mediating effect of GI in the DT–SP relationship is analyzed. The indirect effect of DT on SP through GI is positive and statistically significant ($\beta = 0.168$, $t = 5.106$, $p < 0.001$). At the same time, the direct effect of DT on SP remains significant ($t = 5.368$, $p < 0.001$), providing evidence of a partial mediation effect. These findings indicate that DT contributes to SP both directly and through its capacity to stimulate GI.

Finally, the moderating role of firm size in the relationship between DT and SP is assessed. The results show that firm size does not exert a statistically significant moderating effect on this relationship ($p = 0.309$, $t = 0.498$), and thus Hypothesis H5 is not supported. The estimated structural model is presented in Figure 2.

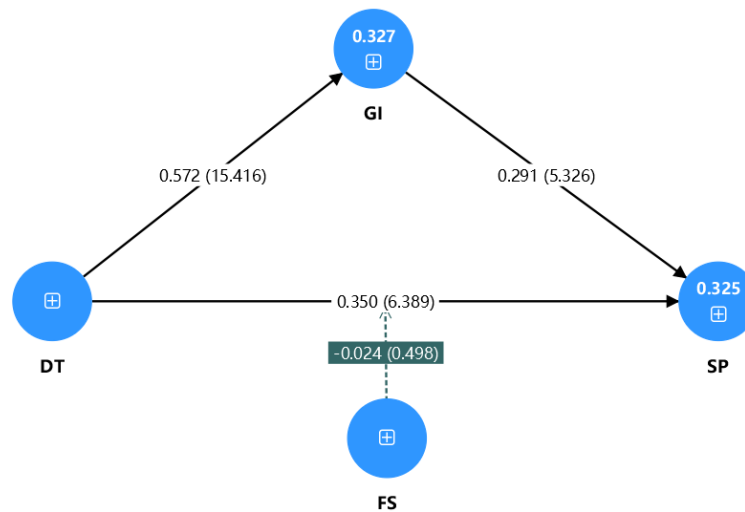


Figure 2. Structural model

Table 5 reports the explanatory power and effect sizes of the structural model. DT explains a substantial proportion of variance in SP ($R^2 = 0.325$) and GI ($R^2 = 0.327$). Regarding effect sizes, DT exerts a small effect on SP ($f^2 = 0.122$) and a large effect on GI ($f^2 = 0.487$), highlighting its critical role in driving GI. GI shows a small effect on SP ($f^2 = 0.084$). Overall, the f^2 values indicate varying strengths of influence among the latent variables, with the DT–GI relationship representing the strongest effect in the model.

Table 5. Coefficient of determination results

Latent Variables	Explanatory Power (R^2)	Effect Size	
		(f^2)	Magnitude
DT->SP	0.325 (substantial)	0.122	Small
GI->SP		0.084	Small
DT->GI	0.327 (substantial)	0.487	Large

4. Discussion

The empirical evidence indicates that digital transformation (DT) is positively associated with sustainable performance (SP), supporting the expectations outlined in the research hypotheses. This result is consistent with earlier studies showing that digital technologies contribute to sustainability by improving operational efficiency, optimizing resource allocation, and strengthening environmental governance mechanisms (Ghobakhloo et al.,

2021; Guan et al., 2023). Within the Chinese manufacturing context, DT facilitates the incorporation of advanced digital tools, such as artificial intelligence, big data analytics, and the Internet of Things, into core production and managerial activities. As a result, firms are better able to rely on data-driven decision processes and to achieve more coordinated economic, environmental, and social performance outcomes (Xu et al., 2023). From the perspective of the Dynamic Capability View (DCV), DT enhances firms' capacities to recognize sustainability-related challenges, capitalize on emerging green opportunities, and reconfigure internal resources to adapt to evolving environmental and technological pressures.

The results further confirm that DT significantly promotes green innovation (GI). This finding supports existing studies that identify DT as a key enabler of green process, product, technology, and management innovation by improving information sharing, technological integration, and organizational coordination (Zhou et al., 2020; Guo et al., 2023). Through enhanced digital capabilities and greater information transparency, manufacturing firms are better positioned to redesign production processes, develop environmentally friendly products, and adopt cleaner technologies. These outcomes are consistent with the Natural Resource-Based View (NRBV), which posits that environmentally oriented innovations constitute strategic resources capable of generating sustained competitive advantages (Hart, 1995).

More importantly, the mediation analysis further clarifies the mechanism through which DT contributes to SP. Specifically, GI serves as a key pathway that translates DT into sustainability outcomes, rather than DT exerting its influence solely through immediate operational efficiency gains. By enabling firms to develop and implement environmentally oriented innovations across products, processes, technologies, and management practices, DT facilitates deeper and more enduring sustainability improvements. This finding underscores the role of GI as a critical conduit through which digital capabilities are converted into tangible economic, environmental, and social benefits, reinforcing the view that sustainability-oriented DT depends on the effective integration of innovation activities rather than on digitalization alone.

Contrary to expectations, firm size does not significantly moderate the relationship between DT and SP. This result suggests that, once a certain level of digital adoption is achieved, the sustainability benefits of DT can be realized across firms of different sizes. While large firms typically possess greater financial and technological resources, small and medium-sized enterprises may benefit from greater organizational flexibility and agility when implementing digital initiatives (Song et al., 2024). In the Chinese manufacturing context, supportive industrial policies and the continuous development of digital infrastructure may have reduced size-related disparities, enabling firms of varying scales to leverage DT for sustainability objectives.

Overall, the findings indicate that DT, when strategically aligned with GI initiatives, constitutes a powerful pathway toward SP in the manufacturing sector. By integrating digital technologies with environmentally oriented innovation practices, firms can simultaneously respond to regulatory pressures, meet market demands, and pursue long-term sustainability goals.

4.1. Study Limitations and Future Directions

While this study offers meaningful insights, several limitations warrant consideration. First, the use of a cross-sectional research design constrains the ability to observe how DT and GI evolve over time and limits strong causal inference. Future research may address this issue by adopting longitudinal or panel data designs to capture temporal dynamics more effectively. Second, the empirical investigation is confined to manufacturing firms located in China's Yangtze River Delta. Although this region represents a highly developed manufacturing cluster, the results may not be readily generalizable to firms operating in other regional or national settings. Extending the analysis to different regions or other emerging economies would help improve the external validity of the findings. Third, this study focuses on GI as the primary mediating mechanism between DT and SP. Future studies could incorporate additional mediators, such as organizational learning capabilities, digital culture, supply chain collaboration, or environmental management systems, to develop a more comprehensive understanding of the transformation pathway. Furthermore, while firm size is examined as a moderating variable, other contextual factors, including the intensity of environmental regulation, competitive pressures, and technological turbulence, may also condition the DT–SP relationship and thus deserve further empirical attention.

4.2. Theoretical Contributions

This study makes several important theoretical contributions. First, it advances DT research by conceptualizing DT as a digital dynamic capability rather than merely a technological investment. By integrating the NRBV and the DCV, the study elucidates how DT enables firms to develop GI as a strategic sustainability resource, thereby enhancing SP. In addition, the study empirically validates the mediating role of GI in the relationship between DT and SP, addressing a key gap in the literature where the underlying mechanisms linking digitalization and sustainability outcomes remain insufficiently explored. By disaggregating GI into process, product, technology, and management dimensions, the study offers a more nuanced explanation of how digital capabilities are converted into sustainability gains. Moreover, the findings contribute to the ongoing debate on firm heterogeneity by demonstrating that firm size does not significantly moderate the impact of DT on SP. This result challenges the assumption that the sustainability benefits of DT are confined to large firms and highlights the inclusive potential of DT in emerging manufacturing economies.

4.3. Managerial Implications

The findings of this study offer several practical implications for managers and policymakers. Firstly, managers should regard DT as a strategic enabler of sustainability rather than merely an operational upgrade. Investments in digital capabilities, strategic digital alignment, and information-sharing systems can substantially enhance GI outcomes and SP. Secondly, firms should explicitly integrate GI objectives into their DT initiatives. Digital technologies can be leveraged to redesign production processes, develop green products, and strengthen environmental management practices, thereby maximizing the

sustainability returns of digital investments. Thirdly, policymakers should continue to support the development of digital infrastructure and provide targeted incentives for green digital innovation, particularly for small and medium-sized manufacturing enterprises. Such policy interventions can help reduce adoption barriers and promote more balanced and sustainable industrial development.

In sum, this study demonstrates that SP in the Chinese manufacturing industry can be achieved through the strategic integration of DT and GI, regardless of firm size, underscoring the critical role of digitalization in advancing sustainable industrial development.

5. Conclusions

Digital transformation (DT) has fundamentally reshaped the competitive logic of the manufacturing industry, compelling firms to reconsider how value is created, resources are deployed, and sustainability objectives are pursued. As manufacturing environments become increasingly complex and environmentally constrained, sustaining long-term performance can no longer rely solely on incremental efficiency improvements. Instead, firms must cultivate scalable digital capabilities and innovation-oriented processes that support continuous adaptation.

Against this backdrop, this study investigates the impact of DT on sustainable performance (SP) in the Chinese manufacturing industry, with particular emphasis on the mediating role of green innovation (GI) and the moderating effect of firm size. Using firm-level survey data from manufacturing enterprises in the Yangtze River Delta region, the study empirically tests a DT–GI–SP mechanism.

The results indicate that DT contributes positively to SP while simultaneously fostering GI, which itself exerts a favorable influence on sustainability outcomes. Evidence further suggests that GI operates as a partial intermediary through which DT affects SP, implying that the sustainability benefits of digitalization arise not only from immediate operational efficiencies but also from the stimulation of environmentally oriented innovations across products, processes, technologies, and managerial practices. In addition, the analysis reveals no significant moderating effect of firm size on the DT–SP relationship, suggesting that firms can derive sustainability gains from DT regardless of organizational scale, provided that a sufficient level of digital adoption has been achieved.

Overall, this study provides robust empirical evidence that SP in manufacturing firms depends not on digitalization alone, but on the strategic alignment between DT and GI. By integrating digital technologies with sustainability-oriented innovation practices, firms can simultaneously enhance economic efficiency, reduce environmental impacts, and strengthen social responsibility. These findings offer clear and actionable insights for both scholars and practitioners seeking to understand how DT can be strategically leveraged to support sustainable development in emerging manufacturing economies.

Conflict of interest: none

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Tourist Destinations Under the Radar? A PRISMA-Driven Bibliometric Exploration of Tourism

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Abstract: Tourist destinations represent the fundamental arenas in which tourism activities are organized, governed, and experienced. Despite this central role, their explicit treatment within tourism business scholarship often remains underexplored. This study applies a PRISMA-guided bibliometric analysis to examine how destination-related concepts are positioned within tourism business, management, and marketing research published between 2000 and 2025. Bibliographic data were retrieved from the Web of Science Core Collection, resulting in an initial dataset of over 25,000 records. Following predefined inclusion and exclusion criteria, a subset of highly cited publications was selected for detailed analysis. The data were processed using a custom Python script to construct co-word and co-citation networks, which were subsequently analyzed and visualized in Cytoscape. The results reveal a strong concentration of research around themes such as sustainability, consumer behavior, service quality, competitiveness, and digital transformation. In contrast, destination-focused perspectives—particularly destination management, destination governance, and smart destinations—remain comparatively underrepresented. These findings point to a structural and methodological imbalance in the intellectual landscape of tourism business research, explaining why destination-centered perspectives have largely remained under the radar and highlighting the need for stronger theoretical and empirical engagement with destination-centered and network-oriented approaches.

Keywords: tourism business; tourist destination; bibliometric analysis; PRISMA; destination management

JEL Classification: Z30; L83; O33

1. Introduction

Tourist destinations constitute the core spatial and organizational units of tourism systems (Leiper, 2000; Ritchie & Crouch, 2003). They are the settings in which tourism demand and supply intersect, where experiences are co-created (Pine & Gilmore, 1999; Buhalis, 2000), and where economic, social, cultural, and environmental processes converge. As such, destinations provide the primary context in which tourism businesses operate and interact with public authorities, residents, and visitors (Dredge, 2006). Despite this centrality, tourism business research has traditionally emphasized firm-level performance, consumer

behavior, and market-oriented strategies (Enright & Newton, 2004; Porter, 1990), leaving destinations frequently “under the radar” as explicit analytical objects.

At the same time, the concept of the tourist destination has undergone substantial theoretical evolution. Early approaches primarily conceptualized destinations as geographically bounded collections of attractions, facilities, and services (Burkart & Medlik, 1974; Mill & Morrison, 2012). Subsequent research reconceptualized destinations as complex systems of interdependent actors whose interactions shape destination performance and competitiveness (Ritchie & Crouch, 2003; Baggio & Sainaghi, 2011). This systemic perspective underscores the importance of coordination, governance, and collaboration among heterogeneous stakeholders, including tourism firms, public authorities, local communities, and visitors (Provan & Kenis, 2008).

Building on this systemic understanding, network-based approaches have become increasingly prominent in destination research, emphasizing relational structures, cooperation patterns, and knowledge exchange (Scott, Cooper & Baggio, 2008; Borgatti & Halgin, 2011). Destinations are now viewed as networked systems in which value creation emerges from interorganizational relationships rather than isolated business activities (Granovetter, 1985). Baggio (2011) demonstrates how network topology shapes collaboration patterns within destinations. More recently, these ideas have been extended through the concept of smart tourism destinations, which integrate digital infrastructures to support real-time information sharing, collective learning, and continuous co-creation of experiences (Buhalis & Amaranggana, 2015; Gretzel et al., 2015). Jovicic (2017) argues that smart destinations represent not merely a technological advancement but a qualitatively different mode of destination organization and governance.

Against this backdrop, questions arise regarding the extent to which tourism business scholarship has incorporated destination-centered and systemic perspectives. If destinations are the primary arenas of tourism activity, their limited visibility within highly cited tourism business research suggests a potential misalignment between the realities of tourism practice and the analytical focus of the field.

The present study addresses this issue by systematically examining how destination-related concepts are represented within tourism business, management, and marketing research. Specifically, it applies a PRISMA-driven bibliometric analysis to highly cited publications from 2000 to 2025 indexed in the Web of Science Core Collection. By mapping dominant research themes, intellectual structures, and collaboration patterns, the study identifies which destination perspectives have gained prominence and which remain underrepresented. In doing so, the article contributes to ongoing debates about the scope and future direction of tourism business research and highlights pathways for integrating destination management, governance, and network-oriented approaches into the core of the field.

2. Literature Background

Tourism business scholarship has long focused on issues such as competitiveness, productivity, marketing effectiveness, and consumer behavior (e.g., Porter, 1990; Enright &

Newton, 2004; Pine & Gilmore, 1999). While these research streams have generated valuable insights, they often approach tourism phenomena through a firm-centric lens, emphasizing individual organizational strategies and outcomes. Within this perspective, destinations are frequently treated as spatial backdrops or market contexts rather than as dynamic systems with their own internal structures and governance mechanisms (Ritchie & Crouch, 2003).

Destination-oriented research offers an alternative perspective by conceptualizing destinations as complex systems composed of multiple interdependent actors (Leiper, 2000; Baggio & Sainaghi, 2011). This view emphasizes that destination performance emerges from interactions among firms, public institutions, residents, and visitors rather than from isolated business decisions. Network-based approaches further advance this understanding by highlighting relational structures, collaboration patterns, and knowledge flows as key determinants of innovation and competitiveness (Granovetter, 1985; Borgatti & Halgin, 2011). Baggio (2011) demonstrates that the topology of stakeholder networks shapes collaboration capacity within destinations.

Empirical studies further show that innovation in tourism destinations is closely linked to the structure of inter-organizational networks (Hjalager, 2010; Denicolai et al., 2010). Actors occupying central or brokerage positions play a crucial role in facilitating knowledge exchange and coordinating collective action (Burt, 1992). Zach and Hill (2017) demonstrate that betweenness centrality is associated with innovation prominence, while collaboration intensity and shared knowledge stocks influence partner selection. These findings suggest that destination governance and coordination mechanisms are essential for translating individual firm capabilities into destination-level outcomes (Provan & Kenis, 2008).

More recently, the concept of smart tourism destinations has broadened the analytical lens of destination research by integrating digital technologies into systemic and network-oriented perspectives. Smart destinations rely on digital infrastructures that enable real-time data exchange, collective learning, and co-creation of experiences among stakeholders (Buhalis & Amaranggana, 2015; Gretzel et al., 2015). Jovicic (2017) conceptualizes smart destinations as knowledge-based systems in which ICT-enabled coordination reshapes governance and stakeholder interaction. This development reinforces the understanding of destinations as adaptive, knowledge-driven systems while simultaneously increasing their structural complexity.

Despite these advances, destination-centered and network-oriented perspectives remain unevenly integrated into tourism business scholarship. This gap raises important questions about the alignment between theoretical developments in destination research and the dominant analytical approaches employed within tourism business studies. It may also reflect a deeper structural divide between firm-level explanatory models and system-level analytical frameworks within the field.

3. Methodology

This study employs a bibliometric research design guided by the PRISMA 2020 framework (Page et al., 2021) to ensure transparency, systematic filtering, and reproducibility in the identification and selection process. Although PRISMA is traditionally associated with

systematic reviews, it is increasingly adopted in bibliometric research as a structured reporting framework that documents search strategies, screening procedures, and inclusion criteria transparently.

The methodological approach combines the systematic retrieval of bibliographic records from the Web of Science Core Collection (WoS CC) with bibliometric and network analysis. Bibliographic data were processed using a custom Python script, and network structures were analyzed and visualized in Cytoscape.

3.1. Data Source and Search Strategy

The WoS CC was selected as the primary data source due to its standardized metadata, robust citation indexing, and broad disciplinary coverage suitable for bibliometric and network analysis.

The search query was formulated as:

TS = ("tourism business" OR "tourism industry" OR "tourism management" OR "tourism marketing" OR "travel business" OR "hospitality industry")

The initial search yielded 25,518 records.

3.1. Filtering Procedure and Corpus Construction

A multi-stage filtering procedure was applied.

First, a time filter (2000–2025) was introduced to reflect the consolidation of tourism business research, the rise of digital transformation, and improved metadata reliability after 2000, reducing the dataset to 25,138 records.

Second, the document type was restricted to "Article," resulting in 19,192 records.

Third, the dataset was limited to relevant Web of Science categories to ensure disciplinary coherence while preserving interdisciplinary breadth. The included categories were:

- Hospitality, Leisure, Sport & Tourism,
- Business,
- Business, Finance,
- Management,
- Environmental Studies,
- Geography,
- Regional & Urban Planning,
- Computer Science, Information Systems,
- Information Science & Library Science.

After category filtering, 13,609 records remained.

From this refined corpus, 204 Highly Cited Papers (HCPs) were identified using the WoS citation classification system.

The focus on HCPs is based on the assumption that highly cited publications represent influential contributions that shape the intellectual structure of a field (Bornmann, 2014). In bibliometric research, HCPs are commonly used as proxies for agenda-setting and field-

defining scholarship (Bornmann & Daniel, 2008; Tahamtan & Bornmann, 2019). Although citation counts reflect scientific impact rather than intrinsic research quality, they provide an established indicator of intellectual influence.

The 204 HCPs constitute the final analytical corpus.

3.2. Inclusion Criteria and PRISMA Screening

Inclusion criteria were:

- publication years 2000-2025,
- document type: Article,
- thematic relevance to tourism business, management, marketing, or destination-related research,
- availability of complete metadata in English.

Duplicate records were removed during export from WoS. No additional exclusions were made after screening titles, abstracts, and metadata of the 204 HCPs.

The selection process followed the four-stage PRISMA 2020 structure (Identification, Screening, Eligibility, Inclusion) and is documented in Figure 1.

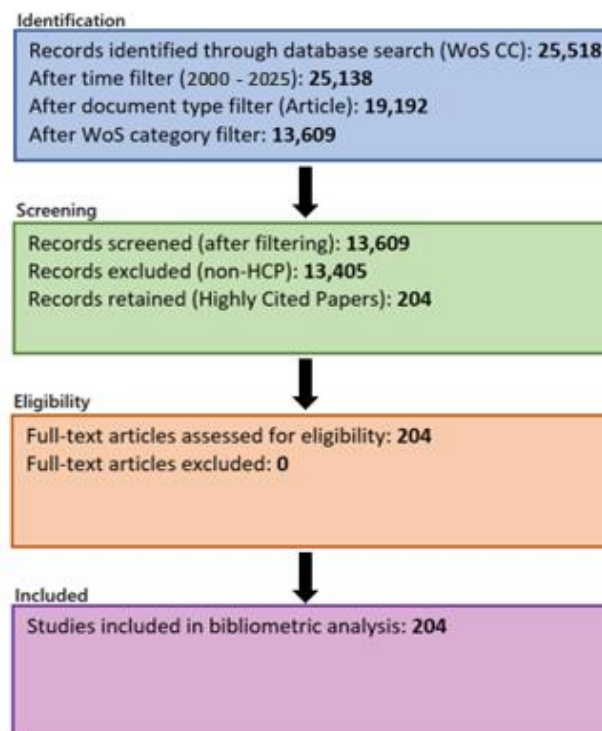


Figure 1. PRISMA 2020 flow diagram illustrating the identification, screening, eligibility assessment, and inclusion process of the bibliometric study (2000–2025)

3.3. Bibliometric and Network Analysis

Bibliographic metadata were exported in plain-text format and processed using a custom Python script to generate adjacency matrices for:

- co-word analysis (keyword co-occurrence),
- co-citation analysis.

These networks were subsequently analyzed and visualized in Cytoscape. Standard network metrics were applied to examine structural properties and to identify thematic clusters, intellectual linkages, and collaboration patterns within tourism business scholarship.

4. Results

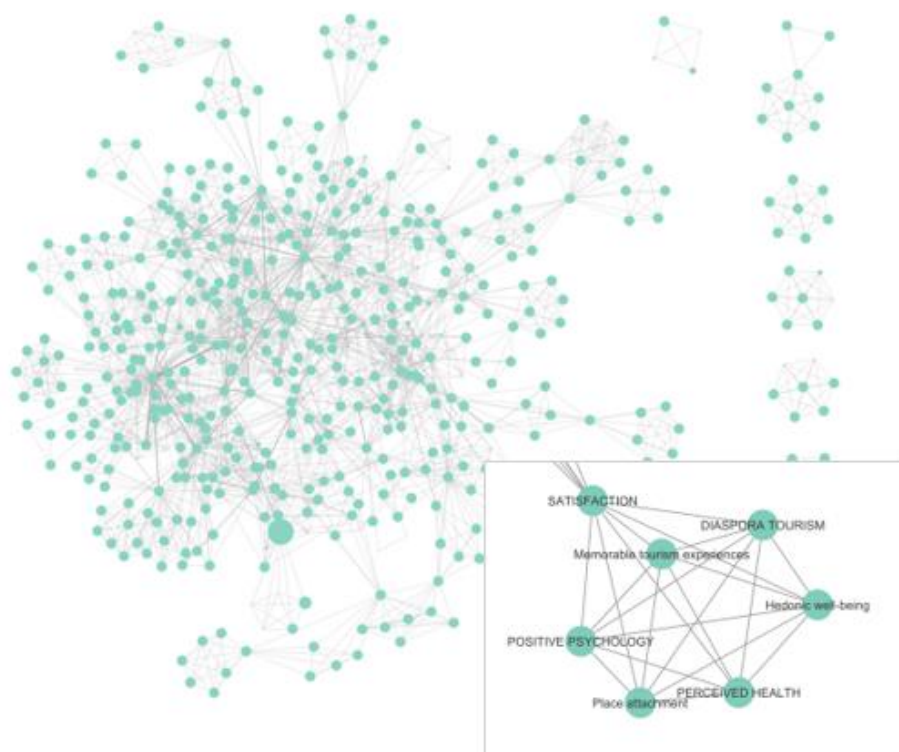


Figure 2. Global co-word semantic network (561 nodes; 2,456 edges); visualized in Cytoscape

Community detection using the Louvain modularity algorithm identified 17 thematic clusters. At the aggregated level, the meta-network of communities demonstrates relatively high interconnectivity (density = 0.404), suggesting the presence of integrative research trajectories. In particular, sustainability-related concepts and digitally oriented research streams (e.g., big data, smart tourism, precision marketing) function as bridging clusters that connect otherwise distinct thematic areas (Figure 3). These domains appear to constitute dominant integrative pillars within the field.

In contrast, destination-focused concepts occupy more peripheral positions within the co-word structure. Terms related to destination management, destination governance, and smart destinations occur less frequently and show weaker structural embeddedness compared to firm-level and consumer-oriented constructs. Rather than functioning as central organizing nodes, these concepts tend to appear within small subclusters or at the margins of broader thematic communities.

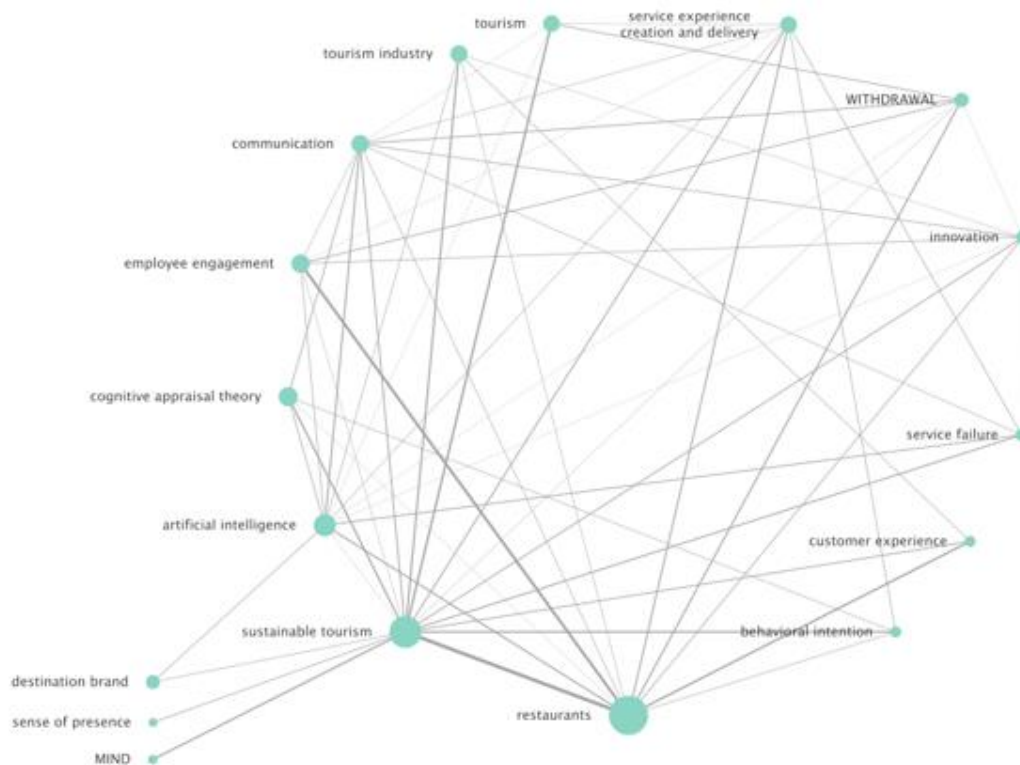


Figure 3. Meta-network of 17 thematic communities detected using the Louvain algorithm; visualized in Cytoscape

This peripheral pattern is clearly illustrated by Community 24, shown in Figure 4 (note: community numbers such as “24” are internal IDs automatically assigned by the Louvain algorithm and do not reflect sequential ordering). Community 24 consists of three disconnected dyads—tourism industry-virtual experiences, emotional message cues-social presence cues, and impulsive travel intention-tourism marketing—indicating maximal structural fragmentation and an absence of bridging links to core thematic areas. Such structurally isolated micro-clusters exemplify why destination-related concepts remain only weakly embedded within the dominant intellectual architecture of tourism business research.

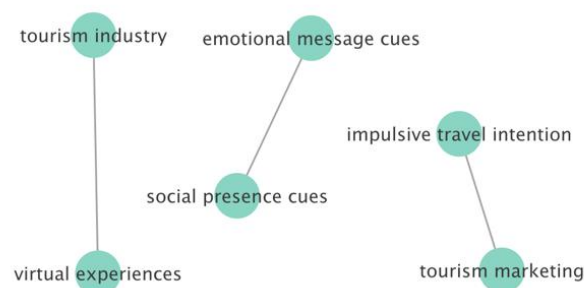


Figure 4. Structure of Community 24, showing three disconnected dyads; visualized in Cytoscape

Co-citation analysis reinforces this observation. Foundational works conceptualizing destinations as complex systems or stakeholder networks are less frequently co-cited within

tourism business journals compared to research focused on competitiveness, marketing performance, and consumer behavior. This indicates that destination-oriented theoretical frameworks are not fully integrated into the core citation structure of highly cited tourism business scholarship.

Taken together, the results reveal a clustered but asymmetrical intellectual structure. Firm-centric and market-oriented research streams dominate both semantic and citation networks, whereas destination-centered and system-based perspectives remain comparatively peripheral. This structural positioning provides empirical support for the study's central argument that destination-related concepts remain "under the radar" within the core body of highly cited tourism business research.

5. Discussion

The findings of this study indicate that the marginal position of destination-focused perspectives within tourism business scholarship cannot be attributed solely to thematic preferences. Rather, they reflect deeper methodological tendencies that privilege firm-level, descriptive, and cross-sectional analyses over relational and system-level approaches (Ritchie & Crouch, 2003; Baggio, 2011).

Much of the highly cited tourism business literature relies on analytical frameworks well suited to examining individual organizational performance or consumer behavior but less effective in capturing the complexity of destination systems (Porter, 1990; Enright & Newton, 2004). As a result, destinations are frequently treated as contextual environments rather than as analytical units with their own governance structures, coordination mechanisms, and evolving network dynamics.

Recent methodological research in destination studies proposes more differentiated analytical frameworks capable of capturing destinations as complex systems. For example, a ten-dimensional framework distinguishes network-based studies according to their analytical focus (description, hypothesis testing, dynamics), level of analysis (node, ego, whole network, temporal), and practical purpose (visualization, prediction, strategic application) (Toman et al., 2025). Application of this framework reveals a dominance of descriptive and nodal approaches, while dynamic and strategic models remain comparatively rare.

This methodological imbalance mirrors the conceptual underrepresentation of destination management and governance observed in the co-word and co-citation structures of the dataset. In other words, the peripheral structural position of destination-centered concepts is not only thematic but also methodological. This dual thematic-methodological marginality is consistent with the fragmented and weakly connected structures identified in peripheral communities (e.g., Community 24). Collectively, these patterns indicate that destination-focused research remains insufficiently integrated into the theoretical and empirical mainstream of tourism business scholarship.

Addressing this imbalance requires a closer integration of destination-centered theories with advanced analytical approaches. Network-based methodologies, in particular, offer strong potential for bridging tourism business research with destination governance,

innovation, and sustainability studies (Provan & Kenis, 2008). Such approaches can help move the field beyond predominantly descriptive analyses toward more comprehensive, system-level understandings of how destinations function, adapt, and evolve.

6. Conclusions

This study examined the position of tourist destinations within tourism business scholarship through a PRISMA-guided bibliometric analysis of highly cited publications from 2000 to 2025. The findings indicate that, despite the central role of destinations within tourism systems, destination-focused perspectives remain structurally peripheral within the dominant intellectual architecture of the field.

The prominence of business-oriented themes such as sustainability, consumer behavior, and digital transformation reflects important research priorities but also reveals a structural and methodological imbalance. Firm-centric and predominantly descriptive approaches continue to shape research agendas, limiting the visibility of destination management, governance, and network-based perspectives.

Future research would benefit from explicitly conceptualizing destinations as networked and governed systems and from adopting analytical frameworks capable of capturing relational structures, dynamic processes, and strategic interactions. Strengthening the integration of destination-centered and tourism business research holds significant potential for advancing theoretical understanding and enhancing the practical relevance of tourism scholarship.

Importantly, the methodological imbalance identified in this study is consistent with prior network-oriented reviews of destination research, which similarly highlight the predominance of descriptive and nodal analytical approaches over dynamic and strategic models. This convergence of findings reinforces the need for more sophisticated, system-level methodologies within tourism business scholarship.

Conflict of interest: none

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Eye-Tracking in Consumer Behaviour Research: A Systematic Review of Marketing Stimuli and Cognitive Responses

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Abstract: Eye-tracking is widely used in marketing research as an objective, real-time measure of visual attention, typically operationalised via fixations, dwell time, and Areas of Interest (AOIs). However, the fast-growing literature in consumer behaviour is fragmented across heterogeneous stimuli, diverse cognitive/affective constructs, and inconsistent reporting. This study presents a PRISMA-informed systematic review focusing on marketing stimuli and cognitive responses measured with eye-tracking. We map dominant stimulus categories, the most frequently used eye-tracking metrics, and the extent of methodological triangulation with complementary methods (e.g., surveys, interviews, EEG/fMRI). The review identifies recurring validity and reporting challenges (e.g., calibration/data loss and luminance confounds in pupillometry) and derives practical recommendations to improve comparability and inference. We conclude with research opportunities for integrating visual attention with cognitive and affective processing in contemporary digital marketing contexts.

Keywords: eye-tracking; consumer behaviour; marketing stimuli; visual attention; cognitive responses; systematic review

JEL Classification: M31; C91; M37

1. Introduction

Consumers increasingly decide under information overload, short attention windows, and highly optimised digital interfaces, making behaviour hard to infer from self-report alone because much processing is rapid, partly automatic, and not fully introspectable. In marketing, this is often framed via the stimulus-organism-response model, where stimuli affect internal “black box” states that drive attitudes, intentions, and choice. Eye-tracking helps probe this black box by capturing where, when, and for how long attention is allocated; eye movements offer high temporal sensitivity and are often outside conscious control, revealing unfolding cognition beyond reliable recall (Carter & Luke, 2020).

In consumer and marketing research, eye-tracking tests whether key stimulus elements are noticed (e.g., brand, price, claims/disclosures), how attention is distributed across competing cues, and how these patterns relate to decisions (Alsharif & Isa, 2024). Typical outputs include fixation metrics (e.g., time to first fixation, dwell time) and AOI analyses, often visualised via heat maps and gaze plots (Duchowski, 2002). This is especially relevant

in marketing communications, where small design changes can shift what is encoded and remembered (Chaudhuri et al., 2025). Evidence also indicates that emotionally salient cues can strongly capture attention, with effects depending on appeal–product congruence and varying across groups. Increasingly, studies combine eye-tracking with proxies of cognitive/affective intensity - particularly pupillometry - linked to cognitive load and arousal but sensitive to luminance and other confounds (Carter & Luke, 2020; Calderón-Fajardo et al., 2024; Chen et al., 2025).

Pupil-based metrics can complement fixation measures by extending inference from “what is looked at” toward “how demanding or arousing processing may be” (McInnes & Sung, 2024; Nakashima et al., 2023). However, evidence indicates that pupillometry is used less often than fixation metrics in mainstream consumer behaviour research, and its theoretical interpretation remains inconsistent across contexts (Riswanto et al., 2024). More broadly, eye-tracking applications are dispersed across online shopping, advertising effectiveness, usability/website optimisation, retailing, and social media influence (Moreno-Arjonilla et al., 2024). For example, a recent systematic review and meta-analysis synthesised eye-tracking dependent variables in online shopping across interface factors (brand, endorser, product, text), while also documenting substantial heterogeneity in operationalisation and reporting (Li et al., 2024). In retail research, scholars highlight an ongoing imbalance between lab experiments and field studies with higher ecological validity (Nordfält & Ahlbom, 2024). Eye-tracking has also been used diagnostically to optimise career websites for Generation Y, showing how information visibility and accessibility shape perceived attractiveness and decision processes (Mičík & Kunešová, 2020).

Fragmentation creates three practical problems (Štefko et al., 2025). First, stimulus taxonomies (by channel/format/mechanism) (Yin et al., 2025), second, outcome constructs with no shared interpretive framework (Gil-López et al., 2023; Alsharif et al., 2023), and high sensitivity to methodological choices (notably AOIs, calibration, participant constraints, and luminance control for pupil measures) (Carter & Luke, 2020). A marketing-focused synthesis linking eye-tracking measures to cognitive responses is therefore timely (Pšurný et al., 2024), since prior reviews are often narrow or subsume eye-tracking under broader neuromarketing, offering limited guidance on dominant stimuli, measure-to-construct mapping, and which findings are robust versus method-dependent (Rodrigues et al., 2025).

This paper aims to systematically review and synthesise empirical eye-tracking research in consumer behaviour and marketing, focusing on (1) marketing stimulus characteristics and (2) the operationalisation and reporting of cognitive responses, including visual attention measures and, where applicable, pupil-based indicators of cognitive load or arousal. Accordingly, we address the following research questions:

- RQ1: How can eye-tracking research in consumer behaviour be thematically structured based on bibliometric clustering of keywords and authors?
- RQ2: Which categories of marketing stimuli are most frequently examined using eye-tracking methods in consumer behaviour research?

- RQ3: How are cognitive responses operationalised in eye-tracking studies (e.g., fixation-based attention metrics, pupillometry), and which measures dominate the field?
- RQ4: To what extent do existing studies link eye-tracking measures to downstream consumer outcomes such as attitudes, trust, or behavioural intentions?
- RQ5: What methodological limitations and reporting gaps recur across the literature and constrain comparability and validity of findings?

By answering these questions, the review provides an integrative map of the field and a practical foundation for designing and reporting eye-tracking studies that are understandable and useful beyond specialist communities, linking observable gaze behaviour to interpretable marketing and psychological constructs.

2. Methodology

2.1. Research Design

This study applies a two-stage review design that combines bibliometric clustering analysis with a PRISMA-guided literature review. The procedure follows the framework proposed by Völkl (2024) and Krtička and Soukal (2025) and is adapted to eye-tracking research in consumer behaviour, focusing on marketing stimuli and cognitive responses.

Stage one uses keyword co-occurrence and clustering to identify dominant themes. Stage two synthesises studies within clusters to summarise methods, research foci, and gaps. Figure 1 presents the VOSviewer network, mapping the structure of eye-tracking research in consumer behaviour and marketing; it yields two clusters, addressing RQ1 and highlighting dominant themes for RQ2.

The search was conducted in the Title, Abstract, and Keywords fields using terms related to eye-tracking and consumer behaviour/marketing contexts. The core search string (adapted to database-specific syntax) was: (marketing AND „eye tracking“ AND behaviour). To improve coverage of specific marketing applications, additional targeted searches included disclosure, native advertising, packaging, sustainability claims, usability, and Generation Y / millennials. Reference lists of key review and methodological papers were also screened via backward and forward citation tracking.

2.2. Bibliometric Clustering Analysis

The first analytical stage involved bibliometric mapping and clustering using VOSviewer software. Following the procedure described by Krtička and Soukal (2025), keyword co-occurrence networks were generated separately for Web of Science and Scopus datasets.

Units of analysis consisted of author keywords and index keywords; in cases of sparse keyword usage, terms extracted from titles and abstracts were used to enhance robustness. A minimum occurrence threshold was set based on the dataset size to exclude weakly connected terms and avoid unstable clusters. The exact threshold value and counting method (full counting) are reported to enable replication. The output of this stage consisted of color-coded thematic clusters representing dominant research streams. These clusters guided the subsequent systematic review and interpretation.

2.3. Systematic Literature Review (PRISMA-guided)

In the second stage, a PRISMA-guided systematic literature review was conducted to ensure a transparent and replicable process of identification, screening, eligibility assessment, and inclusion. After duplicate removal, records underwent a two-step screening: (1) title/abstract screening against predefined criteria, followed by (2) full-text assessment with documented exclusion reasons.

Studies were included if they reported empirical eye-tracking research (screen-based or mobile/wearable) in consumer behaviour or marketing, provided at least one eye-tracking metric (e.g., fixation, scanpath/AOI, pupil-based measures), and were published as peer-reviewed journal articles or indexed conference proceedings. Studies were excluded if they were purely technical, conceptual, or lacked sufficient methodological detail to extract stimulus characteristics and eye-tracking operationalisation. The selection process followed a PRISMA flow diagram.

The search was conducted in Web of Science. Only English-language publications were included, the timeframe was limited to 2023-2025, and records were restricted to predefined Web of Science research areas; items outside these criteria were excluded.

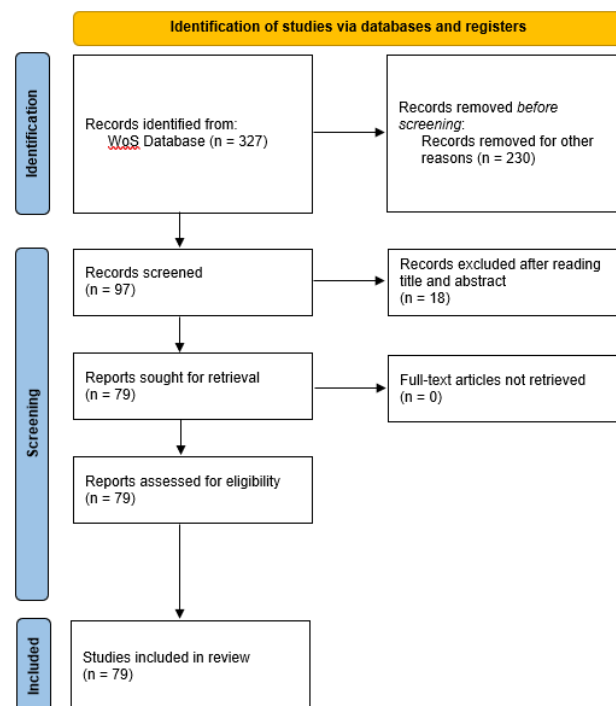


Figure 1. Publication search process according to PRISMA

- Identification – 327 records identified in Web of Science
 - o Records removed for other reasons: 230 (*Reason: application of criteria – years 2023-2025, English language, selected Research Areas – Business Economics, Computer Science, Communication, Social Sciences, Other Topics, Psychology and Behavioral Science*)
- Screening – assessment of titles and abstracts: 97, excluded 18
- Eligibility – full texts: 79, excluded 0
- Included – Included in the review: 79

2.4. Data Extraction and Coding

A structured data-extraction and coding protocol was applied to all eligible studies to ensure consistency and reproducibility. For each record, we extracted key bibliographic and design characteristics (publication year, outlet type, sample size, participant profile where reported, setting, and eye-tracking configuration). Studies were then coded by primary marketing stimulus category, including digital advertising, e-commerce/product pages, websites/UX, social media/influencers, email marketing, packaging/labels/claims (including sustainability cues), and retail/point-of-sale displays.

To operationalise “cognitive responses,” we coded the reported eye-tracking measures and analytical decisions, focusing on fixation-based metrics, scanpath/saccade indicators (where available), and the transparency and logic of Area-of-Interest (AOI) specification (e.g., theory-driven vs. post-hoc, number/granularity, and boundary reporting). For pupillometry studies, we extracted preprocessing and control procedures relevant to validity (e.g., baseline correction and luminance control). Outcomes were coded at two levels: (1) proximal cognitive/affective constructs (e.g., attention allocation, cognitive load, arousal proxies, comprehension/memory) and (2) downstream marketing outcomes (e.g., attitudes, credibility/trust, intentions, choice). We also recorded whether studies triangulated methods (e.g., surveys, interviews/retrospective protocols, behavioural measures, neurophysiological methods).

2.5. Reproducibility and Data Availability

To enable replication and future extensions, the review preserves the full search strings, PRISMA screening records, VOSviewer settings, and the coded extraction dataset. Where deposited in a public repository, the dataset will be cited in the manuscript as a publicly available dataset following APA 7th edition standards.

3. Results

3.1. Keyword Co-occurrence Structure of the Field (VOSviewer Map)

Figure 2 shows the keyword co-occurrence network generated in VOSviewer, offering a concise view of the intellectual structure of eye-tracking research in consumer behaviour and marketing. The network reveals a two-cluster solution, addressing RQ1 and highlighting the dominant themes for RQ2.

Cluster A (green) is anchored in visual attention and the operationalization and measurement (e.g., eye tracking study/data, participant, technology, context, effectiveness) and alongside marketing outcomes-oriented terms (purchase, purchase intention). Here, eye tracking is primarily used to quantify attention allocation to marketing stimuli and relate gaze patterns to behavioural or intention-based outcomes (Cenizo, 2025; Li et al., 2024; Riswanto et al., 2024; Carter & Luke, 2020).

Cluster B (red) centers on consumer theory and decision process constructs and connects to field-positioning terms (advertising, review, article). The presence of neuromarketing and EEG points to a stream that embeds eye tracking within broader cognitive and neuro-oriented

approaches, often using multi-method designs to enrich inference beyond gaze location alone (Carter & Luke, 2020; Clithero et al., 2023; Pšurný et al., 2024; Yfantidou et al., 2024).

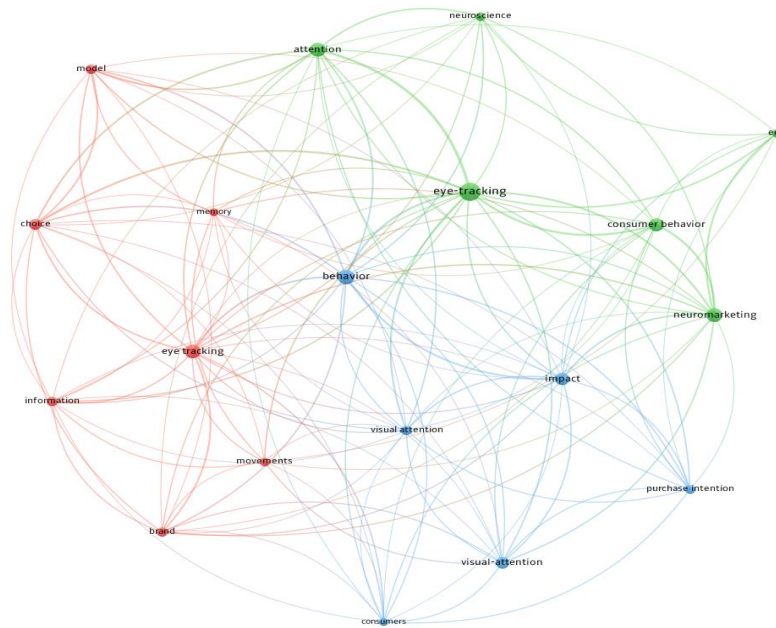


Figure 2. Keyword co-occurrence network (VOSviewer)

Cluster C (blue) captures methodological and analytical foundations: data processing and measurement (analysis, method, measure, technique) and frameworks that turn raw gaze data into interpretable indicators (fixation - and AOI-based metrics) and standardized reporting for cross-study comparability (Carter & Luke, 2020; Li et al., 2024; Ruppenthal & Schweers, 2024). and reporting practices that support cross-study comparability, alongside instrumentation extensions (webcam-/VR-based eye tracking) with implications for data quality and validity. It also reflects a shift toward advanced analytics (e.g., machine learning) and complementary indicators such as pupillometry (Heck et al., 2023; Moreno-Arjonilla et al., 2024; McInnes & Sung, 2024; Liu et al., 2023; Rodrigues et al., 2025; Skala & Kim, 2025).

Overall, dense cross-links suggest these strands co-occur rather than form isolated subfields. The map therefore supports three tightly related streams: (1) eye-tracking as a primary tool for evaluating attention to marketing stimuli and purchase-related outcomes (Riswanto et al., 2024; Cenizo, 2025; Chaudhuri et al., 2025; Li et al., 2024; Chen et al., 2024), (2) eye-tracking embedded in consumer decision-making and neuromarketing narratives emphasising cognitive-process explanation (Clithero et al., 2023; Alsharif et al., 2023; Wang et al., 2024; Pšurný et al., 2024; Isa et al., 2025), and (3) methodological and analytical frameworks underpinning eye-tracking applications (Carter & Luke, 2020; Ruppenthal & Schweers, 2024; Heck et al., 2023; Moreno-Arjonilla et al., 2024; McInnes & Sung, 2024).

3.2. Core Collaboration Pattern (Small-Network Author Map)

Figure 3 shows a compact author network with a limited number of nodes connected by multiple ties. The network topology indicates a closely interlinked collaboration core rather than several disconnected micro-groups. A small number of authors occupy relatively central

positions with multiple links, suggesting a bridging function between otherwise separate co-authorship relations. This pattern is typical of methodological or application niches where knowledge accumulation is driven by recurrent collaborations and stable research teams, a dynamic frequently observed in specialized experimental methods such as eye tracking (Ruppenthal & Schweers, 2024; Bhardwaj et al., 2024; Balli, 2024; Russo et al., 2023).

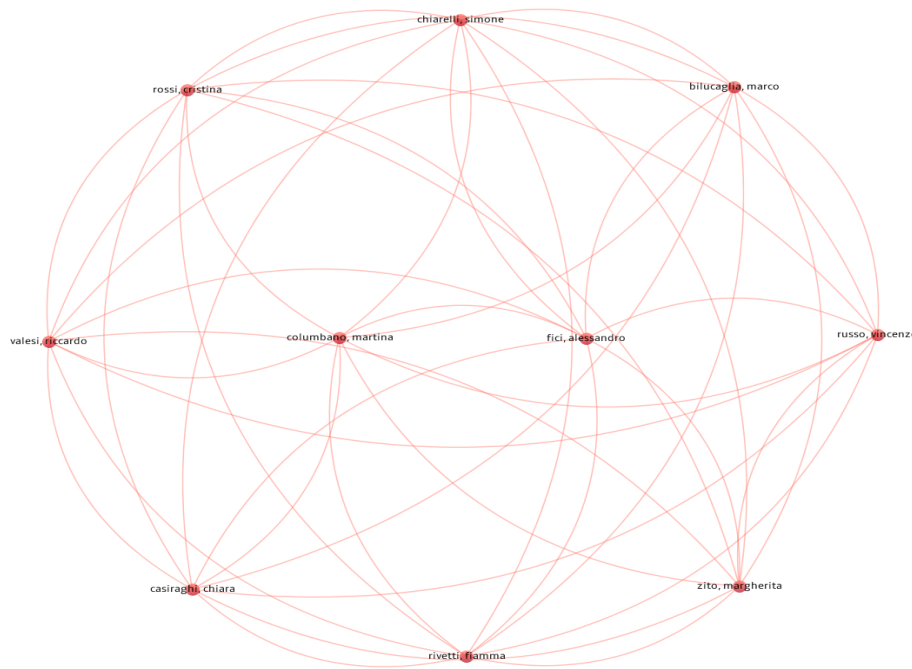


Figure 3. Author collaboration network (VOSviewer)

3.3. Broader Author Landscape and Research Communities (*Large-Network Author Map*)

Figure 4 extends the author-level analysis to a larger network and shows a more fragmented structure with multiple clusters, indicating distinct research communities. The pattern combines several medium-sized, internally coherent groups (suggesting topical or methodological specialisation) with many small, weakly connected nodes, consistent with an interdisciplinary domain in which eye tracking is applied across diverse marketing contexts and research designs (Balli, 2024; Alsharif et al., 2023).

Several authors stand out by label size, which in VOSviewer typically signals higher weight (e.g., connectivity or publication/citation prominence). Their dispersion across clusters implies that influence is distributed across multiple communities rather than concentrated in a single dominant “school,” reflecting the application-driven spread of eye-tracking research across advertising effectiveness, e-commerce interface evaluation, social media/influencer settings, and broader decision-making frameworks (Biswas et al., 2023; Rohrbach et al., 2024; Chen et al., 2024; Chygryn et al., 2024; Cenizo, 2025; Tang et al., 2024; Isa et al., 2025).

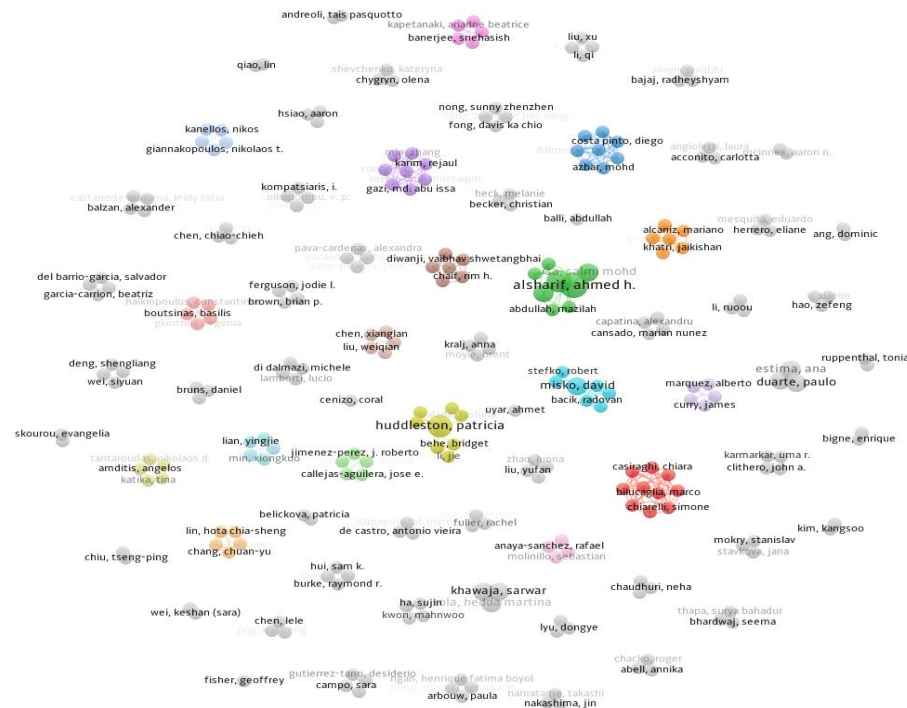


Figure 4. Large-scale author network (VOSviewer)

From the perspective of the study's research questions, the contrast between the dense collaboration core (Figure 3) and the multi-community landscape (Figure 4) underscores why the PRISMA-guided systematic review stage is necessary: the field is sufficiently heterogeneous that harmonising evidence requires structured extraction of stimuli, measures, and outcome linkages across diverse research communities and reporting practices (Krtička & Soukal, 2025).

3.4. Bibliometric Evidence in Relation to the Review Focus

Although the bibliometric stage is primarily intended to address RQ1-RQ2, the resulting maps also provide directional evidence that informs the subsequent systematic synthesis (Ruppenthal & Schweers, 2024). First, the prominence of marketing-communication and decision-process terms (e.g., advertising, purchase intention, and decision-proximity concepts) is consistent with a literature base strongly oriented toward marketing stimuli evaluation in communication-heavy environments (Rohrbach et al., 2024; Biswas et al., 2023; Chaudhuri et al., 2025; Cenizo, 2025; Riswanto et al., 2024). Second, the explicit presence of neuromarketing and EEG within the decision-process cluster indicates that a non-trivial subset of studies frames eye tracking within multi-method cognitive approaches, supporting the review's emphasis on documenting methodological triangulation and on evaluating how gaze measures are linked to downstream consumer outcomes (Clithero et al., 2023; Wang et al., 2024; Alsharif et al., 2023; Alsharif & Isa, 2024; Pšurný et al., 2024; Yfantidou et al., 2024).

In the next stage of the study (systematic review synthesis), these cluster-derived expectations are examined more directly through coded full-text evidence and quantitative summaries (frequencies, proportions, and cross-tabulations), complemented by inferential

association tests where appropriate, as specified in the Methodology section (Krtička & Soukal, 2025).

4. Discussion

This study integrates VOSviewer-based bibliometric clustering with a PRISMA-guided systematic review to map empirical eye-tracking research in consumer behaviour and marketing, focusing on marketing stimulus characteristics and the operationalisation of cognitive responses (Krtička & Soukal, 2025; Ruppenthal & Schweers, 2024; Carter & Luke, 2020). The discussion synthesises patterns from Figures 2-4 in relation to RQ1-RQ5 and situates them within prior methodological and marketing work on translating gaze indicators into interpretable marketing and psychological constructs (Li et al., 2024; Clithero et al., 2023; Alsharif et al., 2023; Nordfält & Ahlbom, 2024).

4.1. Cluster Structure in the Context of Prior Research

The keyword network (Figure 2) suggests two interlinked streams: an attention-focused stream connecting applied eye-tracking terms to outcomes such as purchase intention, and a decision-process stream that includes neuromarketing and EEG, positioning eye tracking within broader cognitive and neuro-oriented programmes (Ruppenthal & Schweers, 2024; Nordfält & Ahlbom, 2024; Yfantidou et al., 2024). Dense cross-links indicate that studies frequently connect “where consumers look” to constructs such as understanding, interest, and choice, reflecting the “black box” motivation in consumer research (Bačák et al., 2023; Carter & Luke, 2020). Across streams, “cognitive responses” are most often operationalised via fixation- and AOI-based measures, while the weaker prominence of pupil-related terms is consistent with pupillometry being less standardised due to stricter validity requirements (McInnes & Sung, 2024). The salience of advertising/communication terms also points to a dominance of digital, screen-based stimuli, while the presence of neuromarketing/EEG indicates growing uptake of triangulation to support interpretation beyond gaze location alone (Nordfält & Ahlbom, 2024; Yfantidou et al., 2024).

4.2. Practical Implications and Future Research

For practice, the two-stream structure implies complementary uses: attention-based diagnostics for stimulus optimization (e.g., layout and information hierarchy) and decision/neuromarketing designs for explanatory modeling of how attention relates to decision processes, as well as proxies of cognitive load or arousal, in some studies. Future research should strengthen (1) construct–metric alignment, (2) more transparent pupillometry under stricter controls, (3) ecological validity via mobile/field studies, and (4) mixed-method investigation of trust and disclosure cues in social media persuasion. Testing individual differences as moderators may further improve predictive value for segmentation and targeting.

4.3. Limitations

Interpretation is constrained by database coverage (Web of Science, Scopus) and English-only inclusion, which may underrepresent regional or non-indexed work. Bibliometric

clustering depends on metadata quality and VOSviewer parameter settings; co-occurrence reflects thematic proximity rather than causality, so mapping should be complemented by full-text synthesis. Finally, time-window effects may reduce the visibility of emerging topics despite practical relevance.

5. Conclusions

This study synthesised empirical eye-tracking research in consumer behaviour and marketing by combining VOSviewer-based bibliometric clustering with a PRISMA-guided systematic review. The evidence supports two tightly connected streams: (1) attention-focused work linking gaze allocation to marketing outcomes (e.g., purchase intention) and (2) decision-making-oriented work embedding eye tracking within neuromarketing and multi-method designs. Across streams, cognitive responses are predominantly operationalised via fixation- and AOI-based metrics, whereas pupil-based measures and other physiological integrations are less consistently applied and more method-sensitive. The dense linkage between streams suggests a shift from descriptive gaze mapping toward explainable accounts connecting attention with comprehension, interest, credibility, and behavioural intentions. Further progress depends on stronger construct–metric alignment, more transparent reporting (e.g., AOI definitions, data-quality thresholds), and stricter control of confounds, particularly in pupillometry. Future research should prioritise higher-ecological-validity designs (mobile/field) and systematic tests of moderators such as stimulus congruence, disclosure cues, and individual differences.

Acknowledgments: The authors acknowledge administrative and technical support related to literature retrieval, document management, and bibliometric processing (VOSviewer). This paper was supported by the University of West Bohemia in Pilsen under the project SGS-2024-031.

Conflict of interest: none

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Evaluating the Usability of Interactive News Maps Using Eye-Tracking

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Abstract: Interactive maps are nowadays routine in data journalism, but their usability depends on whether readers notice and understand interactive controls within busy narrative webpages. This paper reports a formative laboratory evaluation of interactive news maps using screen-based eye-tracking and talk-aloud (concurrent verbalisation). Forty-four participants (22 domain experts; 22 lay readers) completed eight information-extraction tasks across five journalistic articles under standardised time limits. Analysis combined qualitative behavioural diagnosis with quantitative indicators of effectiveness (task success), efficiency (time-on-task), and error-related patterns, supplemented by a composite performance score. Mean task success was 57.67%, with marked task-to-task differences (highest: 79.55% and 77.27%; lowest: 20.45% and 34.09%). The least successful tasks also took the longest, a pattern consistent with breakdowns associated with interaction demands. An analysis of Areas of Interest (AOIs) on article screenshots further shows that, during free exploration, participants allocated substantially more visual attention to article text than to graphical content. Overall, the findings highlight interaction discoverability and transient feedback as recurring bottlenecks, motivating practical design recommendations for making interactive news maps easier to notice, interpret, and use.

Keywords: interactive news maps; data journalism; usability evaluation; eye-tracking; interaction discoverability; formative evaluation

JEL Classification: D83; L86

1. Introduction

Interactive cartographic visualisations are a routine component of contemporary digital communication (Molina Rodríguez-Navas et al., 2021). Beyond “classic” web mapping, interactive maps increasingly appear as embedded artefacts within broader narrative environments. This is especially visible in online journalism, where maps are combined with text, images, and other interactive graphics to support data-driven storytelling and reader exploration (Rafeeq, 2025). Interactive narrative visualisation has been described as an emerging class of presentations that blends a guided story structure with opportunities for user-driven interaction. This pattern is particularly prevalent in online news production (Segel & Heer, 2010). In this setting, maps are not merely decorative. They can serve as

analytical interfaces through which readers interrogate spatial patterns, compare places, and draw conclusions that may influence their attitudes and decisions.

From a data-journalism perspective, interactivity is often viewed as a marker of quality and innovation. Empirical evidence, however, suggests a more nuanced picture. Content-analytic studies indicate that many daily data-driven stories still employ limited interactivity (Karypidou & Veglis, 2019; Zhang et al., 2023). When interactivity is present, maps tend to be among the most interactive visualisation types compared with other chart forms (Stalph, 2018). This creates a design tension. Editorial teams deploy interactive maps to communicate complex socio-demographic phenomena. Yet, the surrounding web context (scrolling articles, competing graphics, advertisements, cookie banners, and heterogeneous layouts) can interfere with map use, reduce the discoverability of interactive controls, and fragment attention. In practice, even well-intended interactive features may become “invisible” (Blascheck et al., 2019). This can happen when users do not notice them, fail to infer interactivity from the visual design, or do not understand how interaction changes the map's message. Recent practitioner-oriented research frames this as a map maker's dilemma: interactive maps promise richer public understanding, but real-world production is constrained by barriers spanning data acquisition and quality, technical implementation, user communication, and organisational context (Zbieczuk Suchá et al., 2026). This perspective underlines that usability problems in journalistic mapping rarely stem from a single interface flaw. They often reflect systemic constraints that limit iteration, testing, and the clarity of interaction cues.

These challenges motivate systematic usability evaluation. Usability is commonly framed as the extent to which specified users can achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use (ISO, 2018). This definition is particularly relevant for interactive news maps because the context of use is close to everyday news consumption rather than to a controlled analysis session. Readers typically skim, scroll, and switch attention between text, graphics, and interface controls. Moreover, journalistic maps often address politically and socially salient topics where misinterpretation can have downstream consequences. Examples include misunderstanding relative versus absolute values, misreading classification, overlooking uncertainty, or conflating correlation with causation. Evaluating usability in this domain is therefore not only a matter of interface convenience. It is also essential for ensuring reliable public communication of spatial data.

In cartography and geovisualisation research, controlled user studies have long been used to assess map design and map use. Eye-tracking, in particular, has been used extensively to study how users allocate visual attention while reading and interacting with maps (Fairbairn & Hepburn, 2023). Overviews of eye-tracking applications in cartography emphasise its value for investigating perceptual and cognitive processes in map use. They also highlight methodological challenges and the need for careful experimental design (Krassanakis & Cybulski, 2021). Eye-tracking captures eye movements (e.g., fixations and saccades). These events are commonly used as proxies for visual attention and allow researchers to link user performance and errors to specific interface elements, spatial regions, and interaction sequences. Practical guidance on transforming raw gaze samples into

analysable events and measures (e.g., using Areas of Interest (AOIs), scanpaths, and aggregated metrics) is well documented in the methodological literature (Holmqvist et al., 2011; Popelka, 2018). Importantly, recent eye-tracking work (Popelka et al., 2025) on journalistic election visualisations shows how attention data can reveal subtle breakdowns. Users may fixate on a control that enables switching to an alternative map view, yet fail to recognise its purpose, resulting in underuse of the intended affordance and potential misinterpretation (Popelka et al., 2025). Such findings support the need to evaluate not only whether users view key elements, but also whether they correctly interpret and act upon them.

In interactive map interfaces, usability evaluation is critical because interactions change the information available to the user. Early eye-tracking work on interactive map interface design proposed combining gaze analysis with traditional usability metrics to understand user strategies better and identify design weaknesses that can remain hidden in log files or questionnaires (Çöltekin et al., 2009). A persistent methodological complication is that interactive exploration produces non-identical stimuli across participants. Pan/zoom, layer switching, pop-ups, and responsive user interface states can vary substantially between users and across time (Vanicek et al., 2024). This reduces straightforward comparability and encourages analysis strategies that can accommodate dynamic interface states, such as dynamic AOIs, event-based segmentation, or hybrid approaches combining gaze with interaction logging.

Because gaze data indicate where users look but not necessarily why, eye-tracking is often complemented by verbal methods (Vanicek & Popelka, 2023). Protocol-based verbalisation techniques treat spoken reports as data that can reveal information accessed in working memory during task performance, when elicitation is appropriately designed and does not unduly alter the cognitive process being studied (Ericsson, 2006). In usability and human–computer interaction practice, talk-aloud (concurrent verbalisation) is often used to expose misunderstandings, expectations, and decision points. These phenomena are central to interactive news maps (e.g., “I assumed the legend was clickable”, “I did not realise the colours changed after filtering”, “I thought this was an advertisement”). Evidence from eye-tracking studies of election news maps further indicates that verbal reports can be essential for diagnosing representational misunderstandings (e.g., confusion about what choropleth units represent). This can occur even when gaze data show that users attended to the relevant on-screen elements (Popelka et al., 2025). In this sense, combining eye-tracking with talk-aloud supports a more defensible interpretation of gaze patterns and enhances the explanatory power of formative evaluation.

Formative evaluation is particularly suitable for data-journalism maps because news interfaces are often released under tight deadlines. Incremental design improvements can still yield substantial gains in comprehension (Soedirdjo et al., 2025). In cartographic research, formative eye-tracking studies have demonstrated their ability to identify interface elements that users overlook or misunderstand. They also show how these findings can be translated into actionable design recommendations (Çöltekin et al., 2009; Krassanakis & Cybulski, 2021). For example, an eye-tracking evaluation of weather web maps found that users often interact

with them in simple, surface-level ways and may not search for hidden functions. This underlines the importance of discoverability and clear visual cues (Popelka et al., 2019). Similar issues are likely in journalistic environments. Readers are typically not trained to explore the map as an analytical tool, and may prioritise finishing the article over experimenting with interface controls.

This paper reports results from a formative laboratory study initially conducted as a bachelor's thesis (Košťál, 2025). It builds on a formative usability evaluation of interactive maps embedded in data-journalism articles, aiming to identify problematic design and interaction patterns and to formulate practical recommendations for improvement. The study combines eye-tracking with talk-aloud to examine attention allocation and user reasoning when interacting with journalistic maps. The remainder of the paper describes the study design and tasks, summarises the key usability issues observed across cases, and derives practical design recommendations for this class of journalistic map interfaces.

2. Methodology

The study was conceived as a formative usability evaluation of interactive maps embedded in data-journalism articles, combining screen-based eye-tracking with talk-aloud and moderator notes. Data collection took place in the eye-tracking laboratory at the Department of Geoinformatics (Palacký University Olomouc) in November 2024. Eye-tracking evidence was interpreted at two complementary levels: a qualitative review of individual gaze recordings and an AOI-based analysis of page screenshots (e.g., fixation-based attention to text versus graphics), supplemented by scarf plots in GazePlotter (Popelka et al., 2024) to compare viewing patterns across participants. The qualitative inspection of user behaviour was complemented by quantitative usability indicators (e.g., success, efficiency, and error-related patterns).

2.1. Participants

A total of 44 Czech participants were recruited and split into two groups of equal size to enable comparison across levels of domain familiarity: experts ($n = 22$) and novices/lay readers ($n = 22$). Experts were defined as participants who work professionally in domains closely related to the communication of socio-demographic data (journalism, sociology, anthropology). Lay participants were defined as typical readers of journalistic articles without specialised expertise in socio-demographic topics. For the sake of anonymity and record traceability, each participant was assigned an internal code (P + ordinal number), which was consistently used in the Tobii Pro Lab recordings and the moderator notes.

2.2. Stimuli and Tasks

Stimuli consisted of five journalistic articles containing interactive map-based (or closely map-related) visualisations, selected after an initial screening and pilot phase. The articles were internally labelled FENTANYL, MIGRATION, UKRAJINA, IROZHLAS, and CNN for analysis and reporting purposes. A preview of the stimuli is clearly shown in Figure 1.



Figure 1. Five journalistic articles for evaluation (three in Czech, two in English)

Each article included 1–2 tasks, operationalised as concrete questions (Q1–Q8 overall), to test whether the interactive element was usable, enabling participants to retrieve the required information through interaction. For two articles (MIGRATION, UKRAJINA), the protocol also included a timed “free exploration” (FE) phase prior to task answering, as shown in Table 1.

Table 1. Overview of tasks for participants (the order of articles was randomised for each participant)

Task ID	Article label	Task	Right answer	Time Limit (s)
Q1	FENTANYL	Which US state has the second-lowest fentanyl mortality rate per 100,000 inhabitants?	Hawaii	120
Q2	FENTANYL	What was the proportion of fentanyl in opioid overdose deaths in 2018?	67%	120
FE1	MIGRATION	Free browsing of the article.	-	240
Q3	MIGRATION	What percentage of the Czech population is immigrants?	5% and 5.1%	120
FE2	UKRAJINA	Free browsing of the article.	-	180
Q4	UKRAJINA	How many inhabitants did the city of Donetsk have before the invasion in 2021?	905,364	120
Q5	IROZHLAS	What was the percentage difference in votes between the most successful and least successful regions in the Karlovy Vary Region for the Five-Party Coalition?	25.3%	120
Q6	IROZHLAS	Which four regions have the highest (worst) destabilising poverty index values in the Karlovy Vary Region?	Aš, Kraslice, Sokolov, Ostrov	120
Q7	CNN	What is the change in percentage points for the Republican Party in Miami-Dade, Florida, in the 2024 presidential election compared to 2020?	18.8 ppt	120
Q8	CNN	Which party won the 2024 presidential election in Los Angeles County (California, on the West Coast) and by how many votes?	The Democrats, with a lead of 1,226,204 votes	120

2.3. Apparatus and Software

Eye movements were recorded using a Tobii Pro Spectrum stationary eye-tracker (sampling rate 300 Hz) controlled in Tobii Pro Lab. Verbal protocols were recorded using an

external microphone (Trust GXT 232, 48 kHz sampling rate). Manual moderator logging was performed on a separate laptop (Lenovo ThinkPad T450S). For post-processing and visual exploration of gaze sequences, the workflow included GazePlotter (v1.6.6) alongside spreadsheet-based analysis.

2.4. Procedure

Firstly, a pilot (n = 3) refined the protocol and timing. In the actual version, participants received standardised instructions and calibration, completed time-limited free exploration (where applicable) and eight information-extraction tasks (120 s each). The talk-aloud approach was also used, including stating participants' answers aloud. A think-aloud protocol was considered but not adopted to keep the procedure lightweight and to preserve a more naturalistic reading and interaction flow. Article order was randomised across participants, and cookie prompts were accepted to preserve realism; moderator intervention was minimal (navigation and technical issues). The complete procedure is shown in Figure 2.

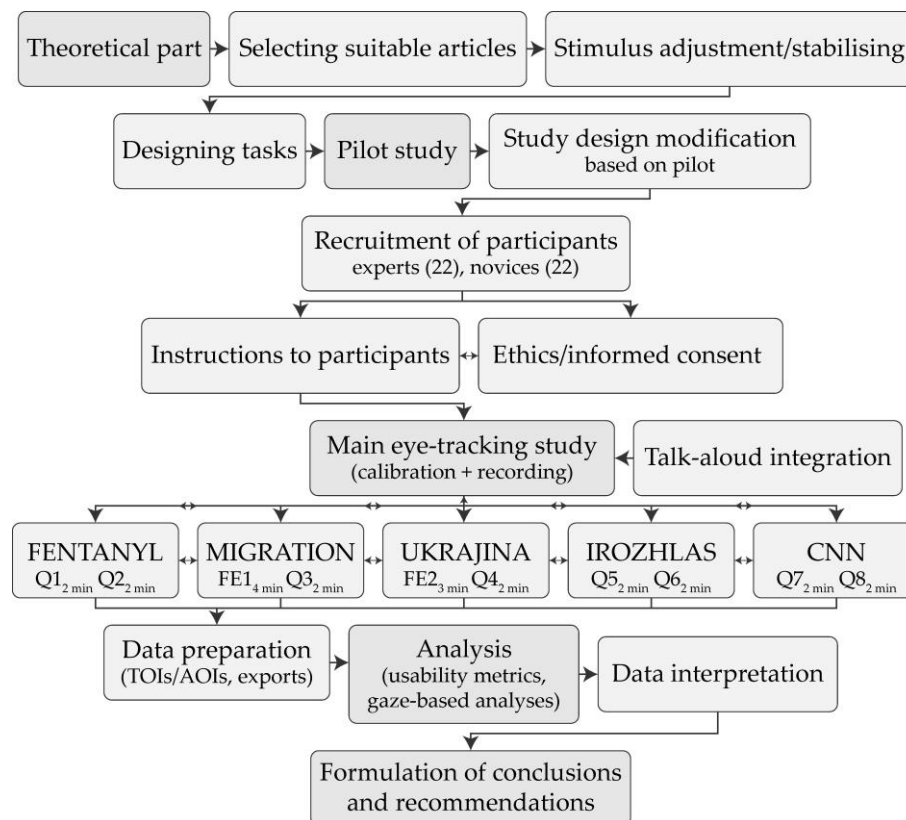


Figure 2. Study the processing procedure

2.5. Measures and Analysis

The analysis combined (1) qualitative behavioural diagnosis (gaze behaviour, interaction strategies inferred from recordings, talk-aloud answers and brief contextual utterances) with (2) quantitative usability indicators. Quantitative indicators were computed at three aggregation levels: task level (Q1–Q8), participant level (performance across all tasks), and group level (experts vs lay users). The expert/lay split was defined a priori (experts:

professionals with a background in socio-demographic data communication; lay users: typical readers without specialised expertise).

Handling of talk-aloud and moderator notes. The talk-aloud approach was used primarily to (i) capture verbal answers for task-success coding and (ii) provide brief contextual cues about the participant's ongoing actions (e.g., intent, uncertainty). The audio was not transcribed, and no formal qualitative codebook, category system, or systematic thematic coding was applied. During each session, the moderator produced brief time-stamped notes (e.g., navigation/technical interruptions and salient behaviours). In post-processing, these notes were used to locate relevant episodes for targeted review alongside screen and gaze recordings in Tobii Pro Lab. Qualitative observations are therefore reported as illustrative, design-relevant examples supporting the behavioural diagnosis rather than as quantified prevalence estimates. The second author (JK) conducted the review of recordings and moderator notes; no independent double-coding or inter-rater reliability assessment was performed.

Task success (effectiveness). For each participant and task, success was coded on a two-point scale: 2 = correct, 1 = incorrect or no answer. Participants who did not provide a verbalised answer within the time limit were treated as having no answer (= 1). Task-level success rates were computed as the percentage of correct responses per task; participant-level success was calculated as the percentage of correctly solved tasks per participant.

Task completion time (efficiency). Each information-extraction task had a fixed time limit of 120 s (Table 1). Time-on-task was measured in Tobii Pro Lab using task-specific TOIs defined from task presentation to the verbalised answer. If a participant did not answer (or did not manage to verbalise an answer) within 120 s, the time-on-task was set to 120 s (i.e., a fixed cap imposed by the protocol time limit).

Empirical task difficulty (D). Because talk-aloud was mainly used as a supplementary interpretive aid and many participants verbalised only minimally, verbal statements were not treated as a reliable basis for estimating task difficulty. Difficulty was therefore derived empirically from mean task success (lower success indicates greater difficulty) and discretised into terciles (D: 1 = most difficult, 3 = most manageable).

Composite respondent score (efficiency beyond correctness). To summarise performance beyond correctness alone, we computed a composite respondent score combining success, empirical difficulty, and time-on-task weighting across Q1–Q8:

$$Score_i = \sum_{j=1}^8 \left(\frac{S_{ij}}{D_j} \times T_{ij} \right) \quad (1)$$

where S_{ij} is task success (2/1), D_j is task difficulty tercile (1–3), and T_{ij} is a within-task speed tercile for participant i on task j (3 = fastest, 1 = slowest), computed separately for each task from the distribution of completion times. This weighting rests on two protocol-driven assumptions: (a) task difficulty can be approximated by empirical success within the present sample, and (b) a uniform time limit (120 s) makes time-on-task comparable across

tasks under a capped measurement scale. The score, therefore, rewards correct answers, assigns greater credit to correctness on empirically more complex tasks (via $1/D_j$), and differentiates efficiency within each task (via terciles), reducing sensitivity to skew and outliers. The maximum attainable score under this scheme is 29 points.

Error-related indicator (repeated-question corrections). As a diagnostic complement, we tracked cases in which a question was repeated after an initial incorrect response, allowing participants to correct their answer. This indicator served to distinguish potential misunderstanding of the question/context from visualisation-driven failure and was summarised descriptively at task, participant, and group levels.

Group comparisons (experts vs lay users) were treated as descriptive and exploratory (e.g., comparing distributions/variability alongside means), because the primary goal was to derive design-focused insights rather than to make strong inferential claims about user-group differences.

Eye-tracking analysis was combined with a qualitative review of recordings, utilising AOI-based metrics computed on page screenshots (including higher-level AOI categories for free exploration). Exported visited AOI sequences were inspected in GazePlotter (Popelka et al., 2024) to compare attention-switching patterns and to guide targeted review of cases with incorrect or missing answers. AOIs were delineated on Tobii Pro Lab-generated page screenshots using an article-specific AOI scheme. They were drawn to cover whole functional elements (e.g., text blocks, graphs, and maps) irrespective of their on-screen size. Fixations were identified in Tobii Pro Lab (v1.241.54542) using the I-VT Gaze Filter with default settings, and AOI metrics were exported as TSV for scarf-plot inspection in GazePlotter.

3. Results

Across all eight tasks (Q1–Q8), the mean task success was 57.67%. Task-level success rates varied substantially, with Q3 (79.55%) and Q6 (77.27%) among the most successful tasks, and Q8 (20.45%) and Q1 (34.09%) among the least successful. At the participant level, P33 (lay user) solved all tasks correctly (100%). The least successful participants were P18 (expert) and P22 (lay user), with the same success rate (12.50%).

Because talk-aloud was used mainly as a supplementary interpretive aid and many participants verbalised only minimally, the study did not treat talk-aloud statements as a reliable basis for estimating task difficulty. Difficulty was instead derived from mean task success and then classified into terciles. Based on the tercile classification, Q1, Q5, and Q8 were identified as the most challenging tasks, whereas Q3, Q4, Q6, and Q7 were the most manageable tasks.

Each task had a fixed time limit of 120 seconds, and time-on-task was measured using TOIs in Tobii Pro Lab (from task presentation to verbalised answer). For participants who did not provide (or did not manage to verbalise) an answer within the 120-second limit, time-on-task was recorded as 120 s, and the task was coded as unsuccessful (success = 1). Mean completion times (seconds) varied notably across tasks, with the overall pattern consistent with the success results (longest: Q8 = 110.99 s, also the least successful task; shortest: Q6 = 56.83 s, among the most successful tasks). This co-occurrence (low success

+ long time) may reflect higher cognitive demands and/or lower comprehensibility of the interactive solution for that task.

To complement success rates, we computed a composite respondent score combining task success, task difficulty, and time-on-task weighting across Q1–Q8. The top performers were P03 (expert) and P33 (lay) (24.33 points each). Notably, P03 ranked only fourth by raw success (7/8 correct) but achieved a top score due to faster performance on more demanding tasks, indicating that efficiency meaningfully differentiated participants beyond correctness.

At the group level, the mean difference between experts and lay users was negligible; however, the distributions differed: experts showed lower variance (greater concentration around the mean), while lay users exhibited higher variability in performance.

We additionally tracked repeated-question corrections to distinguish misunderstandings of the question from visualisation-driven failures. This indicator is compatible with some initial errors being contextual (e.g., article structure or time pressure), while low-performing tasks were frequently associated with weakly discoverable interaction.

For the free-exploration segment, we quantified attention to text versus graphics using AOI-based metrics. After normalising by pixel area, participants still allocated markedly closer relative attention to text than to graphics (lay users: 10.91×; experts: 17.46×), indicating intense competition between narrative content and visual elements in news-page layouts.

Scarf plots in GazePlotter were then used to compare attention-switching patterns among participants (Figure 3) and to identify instances in which users did not reach the intended interactive element within the time limit, which was verified through a targeted review of the corresponding recordings.

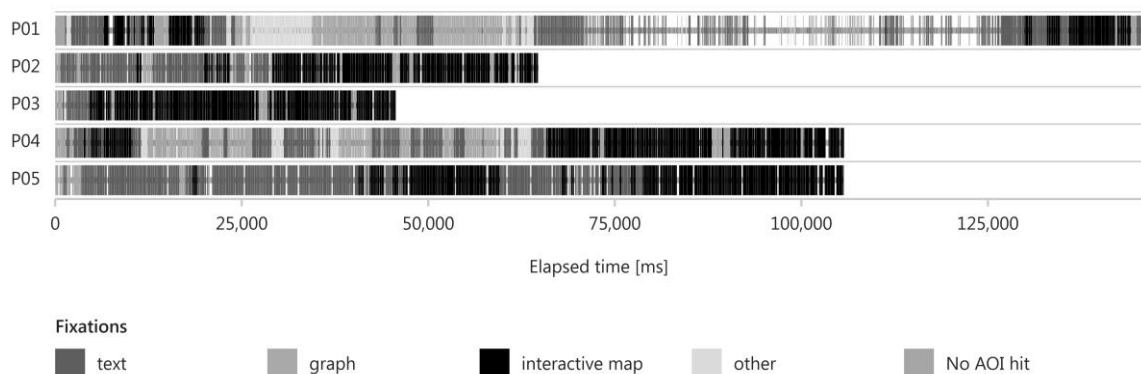


Figure 3. Example of using a scarf plot for Q3 in GazePlotter to compare data from the first five participants (the black-and-white version shown here is provided for illustrative purposes only)

Beyond aggregated metrics, the study highlights several recurring usability issues derived from observed behaviour:

- Interactivity not recognised/insufficient interaction with controls. Some participants did not use the mouse enough, or did not recognise an element as interactive at all.
- Secondary/hidden interaction mechanisms produced major failures (notably Q8). For the problematic Q8 task, most participants did not answer correctly on the first attempt and tended to use only the default map layer; the switching control and the secondary

map accessible via it showed weak interactive potential and limited usability for extracting the required value.

- Language and time constraints. In the same scenario, part of the difficulty was attributed to possible misunderstandings of the English text; some participants appeared to locate the correct answer but did not verbalise it before the time limit, leading to no response.

These findings align with the overall quantitative pattern: tasks with poorly discoverable or cognitively demanding interactive mechanisms yielded the lowest success rates and the longest completion times, whereas tasks with clearer interaction affordances (or where the answer could be reliably derived without complex interaction) achieved higher success rates with shorter completion times. Interactive news maps can support targeted information extraction; however, in this study, usability degraded quickly when interactivity was not discoverable, when interactive components were placed low in the narrative, or when interaction feedback was fleeting.

4. Discussion

The results suggest that usability depended primarily on the legibility and placement of interaction mechanisms, not on the mere presence of a map. Failures concentrated in tasks requiring secondary or weakly signposted controls (e.g., layer switching), suggesting that the key barrier was interaction discoverability rather than map reading. Further free exploration reveals intense competition between narrative text and graphics, suggesting that interactive maps may not be used, especially when placed low in the article. When static and interactive maps coexisted, users were often satisfied with the first acceptable (static) representation, underscoring the need to signal why interaction is necessary and to position interactive elements early.

The findings translate into three design implications for data-journalism maps: (1) Make interactivity explicit (e.g., visual cues for clickable/switching controls) so that key mechanisms are noticed in seconds. (2) Place interactive elements early and avoid competing static alternatives or clearly explain why interaction adds value. (3) Support micro-interactions by reducing transient feedback (e.g., longer-lasting pop-ups) and by providing navigational aids (anchors) in longer stories so readers can reach the relevant interactive element efficiently.

At the group level, mean performance was similar for experts and lay users; given the primarily student sample and a potentially weak operationalisation of expertise, the data mainly support design-focused conclusions rather than claims about user-group differences.

The composite respondent score should be interpreted as a relative indicator tailored to this protocol: difficulty is estimated from empirical success in the current sample (terciles), and the 120-second cap bounds completion time. Alternative weightings (e.g., continuous time, external difficulty estimates, or different timeout penalties) may change absolute scores. Still, the metric was introduced to provide a more discriminative view of efficiency than correctness alone for this set of tasks.

Interpretation should consider four constraints: (1) gaze indicates attention, not understood/used interactivity so that interaction logs would improve diagnosis; (2) interactive map states vary across users, limiting cross-participant comparability of gaze metrics; (3) news-web stimuli introduce procedural noise (links, cookies, loading/rendering), motivating stronger stimulus stabilisation (e.g., local hosting and link control), and (4) talk-aloud and moderator notes were collected mainly to capture verbal answers and minimal context, and were not analysed through a formal coding procedure; consequently, the qualitative insights should be interpreted as illustrative.

Future work should (a) triangulate gaze with interaction logs to separate “seen” from “used” controls and (b) stabilise web stimuli (e.g., local hosting/link control), while (c) recruiting more clearly defined expert samples to test group effects with inferential statistics.

5. Conclusions

This study evaluated the usability of interactive news maps embedded in data-journalism articles using laboratory eye-tracking complemented by talk-aloud and moderator observations. Across eight information-extraction tasks, overall effectiveness was moderate (mean success 57.67%) and varied strongly by task. Efficiency measures (time-on-task) aligned with success patterns, indicating that failures were structured and linked to specific interaction demands.

The results point to a central usability bottleneck: the discoverability of interactions and feedback. When tasks required secondary or weakly signposted controls, many participants did not detect the affordance or could not complete the necessary interaction within the time limit. Free-exploration analyses further show that readers devoted substantially more attention to text than to graphics, even after normalising by pixel area, suggesting that interactive maps compete with narrative content and page clutter and cannot be assumed to be used simply because they are present.

Overall, for interactive news maps, usability is primarily a problem of interaction design and narrative integration—not merely a cartographic one.

Conflict of interest: none

Acknowledgements: This work was supported by GAČR – Czech Science Foundation under the “Identification of barriers in the process of communication of spatial socio-demographic information” (23-06187S) project. The work of Tomas Vanicek was supported by the Internal Grant Agency of Palacký University Olomouc (grant number IGA_PrF_2025_002).

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Process and Data-Driven Management of Publicly Funded Organizations through a Shared Services Center

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Abstract: An innovative approach to improving the efficiency of public finance management is the implementation of process- and data-driven service management in publicly funded organizations. These organizations, primarily operating in healthcare, social care, education, culture, and transport, are not profit-oriented but focus on providing quality public services. Decentralized management of such entities often leads to duplicative activities, inconsistent procedures, and limited possibilities for systematic efficiency control. This paper analyzes the introduction of process- and data-driven management through a Shared Services Centre (SSC), defined as a centralized organizational unit providing standardized support services to publicly funded organizations. The study focuses on the application of Business Process Management (BPM) and BPMN notation, as well as on the use of Key Performance Indicators (KPIs) for measuring service efficiency and benefits. Selected areas suitable for centralization include central purchasing, payroll and accounting support, energy management, and IT services. The results suggest that integrating process modeling with performance measurement and data tools enhances transparency, reduces administrative burden, and strengthens adherence to the 3E principles (economy, efficiency, and effectiveness) in public administration.

Keywords: business process management; data portal; key performance indicator; publicly funded organizations

JEL Classification: H83; D73; H61

1. Introduction

The effective functioning of public administration entities, which ensure the development of their territories and services for citizens through publicly funded organizations established by regional or local governments, depends on the responsible management of public funds (Portal VZ, 2019). Public institutions are required to maintain a high level of transparency, ensure high-quality control processes, and adopt a responsible approach to management, especially in reducing operating costs and spending funds (Pollitt & Bouckaert, 2017). These requirements need to be reflected in the individual management processes of publicly funded organizations, which, in addition to their core activities, provide a large range of support and administrative agendas

(OECD, 2025). Practice shows that decentralized provision of these activities often leads to duplication, inconsistent procedures, and limited possibilities for systematic control of cost-effectiveness. One possible response to this situation is the Shared Services Centre (SSC) model, which enables the systematic centralization of selected services and agendas, the standardization and optimization of processes, and their effective management based on process- and data-driven principles (World Bank, 2020). The aim of the paper is to demonstrate that process and data-driven shared services constitute a modern model of corporate management. There is a connection between process management, services, data, and ensuring the principles of economy. The aim of the paper is to analyze SSC as a process- and data-driven model that contributes to more efficient public administration and better management of public finances.

2. Methodology

This paper applies a qualitative analytical approach based on literature synthesis and conceptual modelling of processes using BPMN notation.

2.1. Corporate Governance in Public Administration

Modern corporate governance in public administration is based on the principles of efficiency, economy, and effectiveness, known as the 3E principles (Act No. 320/2001 Coll.). This Act addresses the conditions of financial control while establishing definitions for these basic principles. According to this Act, to ensure the economy, public funds must be used to the minimum extent necessary while maintaining the appropriate quality (Act No. 320/2001 Coll.). Efficiency is determined by achieving the highest possible scope, quality, and benefits relative to the volume of funds allocated for this purpose. (Act No. 320/2001 Coll.). Effectiveness is defined as the optimal level of achievement of objectives in the case of the use of public funds (Act No. 320/2001 Coll.).

These principles highlight the need to control how public funds are spent while also emphasizing the active management of processes to deliver measurable benefits. Publicly funded organizations are managed primarily in accordance with legislative requirements and budgetary rules (Act No. 250/2000 Coll., 2000). Systematic management of performance indicators and financial costs is a current challenge for the application of corporate management tools (Wirtz et al., 2022). The introduction of a SSC represents an innovative solution and a managerial tool that enables the establishment of structured and measurable processes for managing selected agendas (Rosenbloom et al., 2022).

2.2. Shared Services Center and Specific Areas of Shared Agenda

SSC represents an organizational mechanism for implementing the principles of modern management. It may be established within a public administration entity and subsequently provide methodological support and expertise to its publicly funded organizations. These activities provide a wide range of support activities. Among the most common areas that can be shared between organizations is central purchasing for a specific group of goods or services (Lotti et al., 2024). These include the purchase of office

supplies, printers, computers, and mobile phones or inventory readers. This also includes the purchase of electricity or telecommunications services. In case a unified financial or payroll information system is in place, the SSC can provide methodological support in accounting and payroll processes and can also centralize energy management across organizations (IEA, 2022). Legal support is also possible at the central level. For organizations that operate technical equipment, e.g., kitchens, elevators, and central boiler rooms, there is the possibility of offering professional technical support through the SSC. The SSC can coordinate regular service and inspections, provide service contracts, and consult on the renewal or modernization of equipment. In this way, it is possible to reduce the risk of failures, extend equipment life, and better manage operating costs. An interesting area for SSC is shared operational services related to the operational security of buildings and facilities, which are usually handled separately for each publicly funded organization. Sharing these capacities reduces personnel costs and increases flexibility. This makes it possible to solve, for example, repairs to doors, locks, and blinds, minor masonry, painting or electrical work, servicing of windows and blinds, replacement of fluorescent lamps, or minor construction interventions. The advantage of such a service is that the publicly funded organization does not have to maintain its own maintenance schedule; instead, it uses the SSC's capacity as needed, e.g., in the ordering system. There are many areas related to the purchase, installation, and management of HW and SW, including laptops, computers, printers, servers, and routers. This includes information system setup, antivirus, software management, and remote and physical assistance depending on the type of problem (Wirtz et al., 2022). All of this can be implemented provided that individual processes are mapped and responsibilities are determined (Dumas et al., 2018).

Centralization of purchases enables aggregation of demand and savings across consumables, office supplies, energy, and information technology (Lotti et al., 2024). Ensuring payroll and accounting agendas from a methodological perspective reduces error rates, unifies methodologies and data, and improves preparedness for legislative changes (Richter & Brühl, 2016). Based on the settings of these processes, the SSC can systematically monitor consumption within individual organizations, identify deviations, and ensure control processes, including proposals for central savings measures (Pour et al., 2018).

2.3. Data and Information Management Tools in Public Administration

The aim of corporate governance in public administration is to ensure the transparent and efficient operation of organizations managing public funds (Rosenbloom et al., 2022). Unlike the private sector, the aim is not to maximize profit, as the priority is to provide quality services to citizens in accordance with the 3E principles (Act No. 320/2001 Coll.).

The basic tool for effective management is the establishment of a management strategy (Barney & Hesterly, 2018). It is used to define long-term objectives, set priorities, and to identify the benefits of these procedures. From the SSC perspective, it is necessary to translate these strategic objectives into operational measures and measurable indicators.

To support effective organizational management, it is necessary to use performance measurement tools. This involves monitoring KPIs (Parmenter, 2010). These indicators can indicate the effectiveness of the services provided, and results can be compared over time. This can also be implemented for comparisons between individual organizations, allowing identification of areas suitable for improvement (Parmenter, 2010). For the management of quality central services, it is proposed to use KPIs to measure costs per unit of service, processing time for agenda items, and compliance with contractually established service levels when resolving operational incidents under the service contract. KPIs can be visualized in data reports and dashboards that support decision-making and control processes (Sherman, 2014). Financial control and management of financial flows are very important for public administration organizations. This includes determining the budgets of publicly funded organizations, preparing financial plans, and setting up an internal control system in accordance with legal regulations (Act No. 250/2000 Coll.). For publicly funded organizations, it is important to include the financing of non-teaching staff and the management of operating costs. Here, the centralization of selected agendas and services through SSC appears to be highly beneficial, as it is in this area that it delivers measurable savings in public finances (Richter & Brühl, 2016). In modern organizational management, data and information tools play a crucial role (Dumas et al., 2018). These are unified information systems, communication portals for publicly funded organizations, and data platforms that ensure the collection, unification, and analysis of data across organizations. An example of a communication portal for publicly funded organizations is shown in Figure 1. These communication portals ensure two-way communication between the founder and the organization and serve as an audit trail (Wirtz et al., 2022). Communication portals ensure the rapid transfer of information and data for multiple organizations, their collection, and subsequent processing. The portals also include data reports that are available to each organization for an overview of their management (Pour et al., 2018).

PORTÁLPO

Přihlašovací jméno
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Heslo
Vložte Vaše heslo

Přihlásit

Aktuality **Seznam organizací**

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Zobrazeno 250 záznamů

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Figure 1. Sample of the home page of the communication portal of publicly funded organizations of the Hradec Králové Region

3. Results

This section presents the main results of the proposed SSC model. It focuses on process management and its role in the standardization of shared services, followed by the analysis of performance measurement through Key Performance Indicators.

3.1. Process Management and BPMN as the Basis for Service Standardization

Quality management and effective provision of shared services for public administration organizations can be achieved by establishing basic principles of process management. This can be achieved by systematically describing, standardizing, and optimizing the processes within the publicly funded organizations (Dumas et al., 2018). These may vary depending on the organization's service focus. The use of Business Process Management (BPM) methodologies, including process modelling in BPMN notation, defines the roles, responsibilities, inputs, and outputs of individual activities within organizations. This sets a clear procedure for both SSC employees and the management of publicly funded organizations, directors, economists, energy managers, and other positions. BPMN diagrams can identify places where time delays and various forms of risk arise (Dumas et al., 2018). Process mapping is very important in the public administration environment, as there is an emphasis on auditability and transparency (Rosenbloom et al., 2022). In addition, these processes create a prerequisite for measuring performance indicators and subsequent economic evaluation of the benefits of the established central services (Parmenter, 2010). For SSCs, this means mapping processes across payroll, accounting, internal control systems, public procurement, contract disclosure, provision of GDPR services, audits, IT support, methodological activities, or energy management. This is a very effective tool for SSCs to set primary processes, ensuring services are not fragmented and maintain their own standards and system performance. The use of process management principles reduces duplication, improves service quality, enhances performance control, and optimizes financial costs (Richter & Brühl, 2016).

An example of BPMN process modelling is shown in Fig. 2. This is a central purchasing process implemented through an SSC for publicly funded organizations. The aim of the process modelled in this way is to ensure standardized, transparent, and economically efficient purchasing of goods and services in public administration. The process captures the interactions among the publicly funded organization, the shared services center, the external supplier, and the information system, including key decision points regarding the standardization of the requirement, the use of framework contracts, or the initiation of a public procurement, and the subsequent control of the delivery's conformity. The example of a central purchasing process shows how process management can standardize procedures across publicly funded organizations, reduce duplication, and increase transparency. The process also establishes a data foundation for updating KPIs and generating management reports that serve as a basis for the founder's decision-making. This demonstrates how process and data tools in public administration form an interconnected whole.

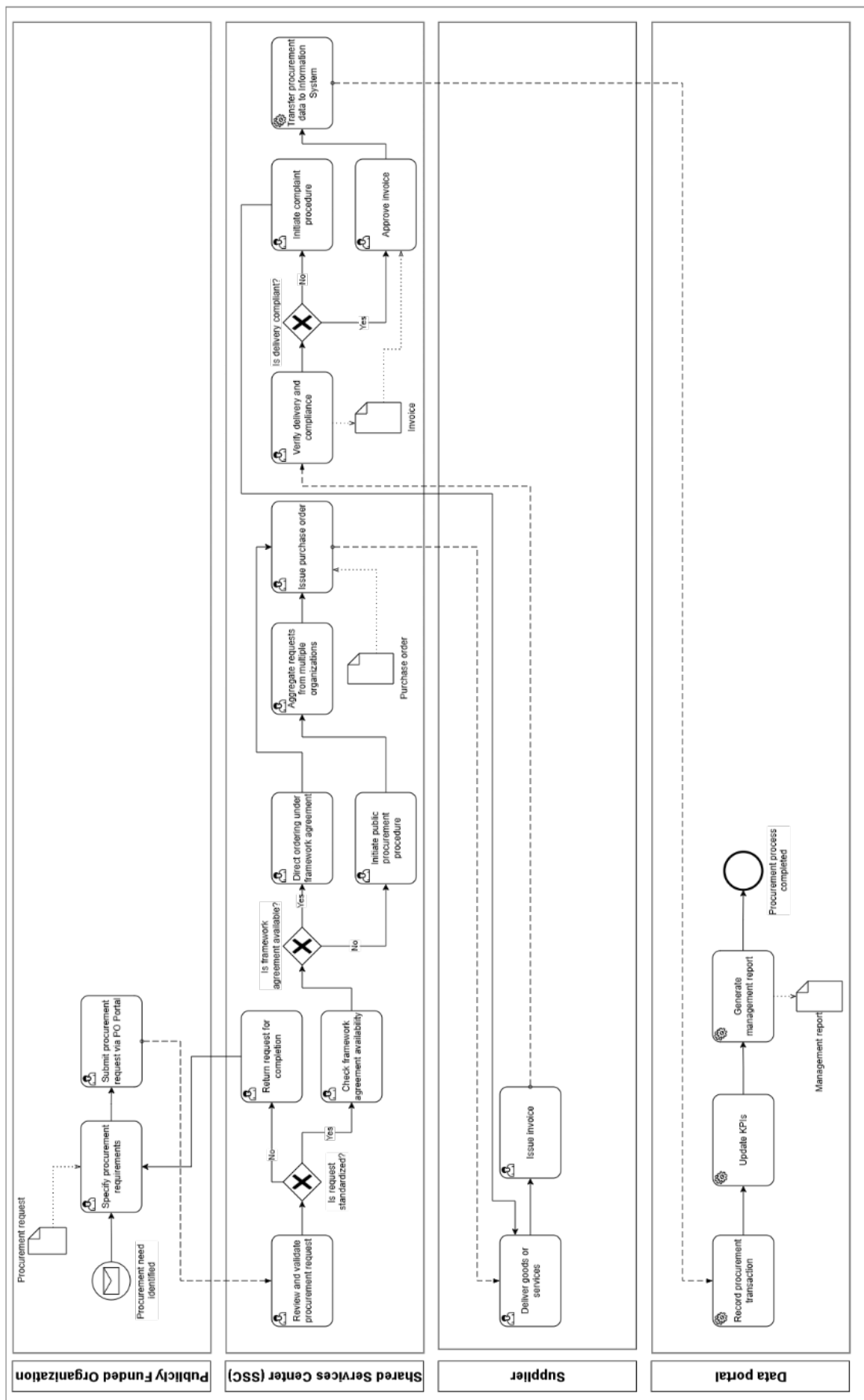


Figure 2. Model of the centralized procurement process within a Shared Services Center

3.2. Key Performance Indicators and Effectiveness Measurement

One of the main benefits of data- and process-oriented management in public administration organizations is the ability to systematically and regularly measure the performance of the services they provide. The established performance indicators serve to evaluate the volume of work performed over a given period and the associated financial costs (Parmenter, 2010). Through these indicators, the quality and economic efficiency of the activities and services performed can be determined.

In the payroll area, it is possible to monitor the number of processed wages per employee per month, or the number of complaints filed. By monitoring these indicators, it is possible to propose more efficient processes for all affected organizations through SSC. In public procurement, it serves to obtain an overview of the average time to implement contracts, the number of contracts implemented within the framework of framework contracts, or the price savings achieved through SSC. In the area of energy management, KPIs can identify year-on-year changes in energy consumption and the number of savings measures implemented. They can also detect inefficient energy use or technical deficiencies that are not obvious at first glance (Parmenter, 2010). These indicators provide specific data to the founder and management of the organization. Based on KPIs, it is possible to evaluate the efficiency of central services and the overall management of publicly funded organizations, and to make qualified decisions to ensure compliance with 3E (Act No. 320/2001 Coll.). An example of KPI proposals from the SSC to improve the management and management of publicly funded organizations is shown in Tab. 1.

Table 1. Proposed Key Performance Indicators for the Management of a Shared Services Centre

SSC Service	KPI	KPI Type	Link to 3E Principles
Training and Methodological Support	Cost per training session (CZK)	Financial	Economy
Training and Methodological Support	Percentage of complaints after methodological support (%)	Qualitative	Effectiveness
IT Support	Average request resolution time (hours)	Process	Efficiency
IT Support	Percentage of recurring incidents (%)	Qualitative	Effectiveness
IT Support	Cost per incident (CZK)	Financial	Economy
Publicly funded Organizations Portal	Percentage of active users (%)	Performance	Effectiveness
Publicly funded Organizations Portal	Average request processing time (days)	Process	Efficiency
Centralized Procurement	Savings compared to individual procurement (%)	Financial	Economy
Centralized Procurement	Percentage of procurements conducted under framework agreements (%)	Process	Efficiency
Centralized Procurement	Average unit price (CZK)	Financial	Economy
Energy Management	Year-on-year change in energy consumption (%)	Outcome	Economy
Energy Management	Cost savings on energy expenditures (CZK)	Financial	Economy
Energy Management	Number of implemented energy-saving measures (units/year)	Performance	Effectiveness

4. Discussion - Impact on Public Finances and the Economy

From the perspective of public finances, the model of data- and process-oriented management of organizations is a highly effective tool for systemic management of publicly funded organizations. Based on the established processes and data models, it is possible to achieve direct and indirect savings, which are particularly important in the public administration environment, especially in maintaining the principles of economy, efficiency, and effectiveness. Direct savings include reducing operating costs, leveraging central purchasing, and optimizing energy consumption based on data and predictions (Lotti et al., 2024). Through them, it is possible to compare costs over time and across individual organizations, thereby optimizing them. Indirect savings can be achieved mainly by reducing the administrative burden and eliminating errors. This is facilitated by the innovative centralization of agendas and services, which are effectively set up based on mapped processes. This contributes to a noticeable reduction in duplicate activities. These savings can also be identified using data, as it is possible to monitor their development over time and propose and implement measures (Pour et al., 2018).

This model of a process- and data-driven shared services center enhances transparency in management and can deliver significant benefits. However, the success of this approach is not automatic. The basic factors are the mapping and setting of processes, the availability of high-quality data, and the ability to manage change (Dumas et al., 2018). The prerequisites are the definition of KPIs, their evaluation, and the adoption of measures. Communication with the organizations involved plays a significant role, as well as their perception of the SSC as a partner. If these conditions are met, this model can be sustained in the long term and further developed as a supporting tool for effective management of public finances.

5. Conclusions

The paper highlights the importance of integrating process and data-driven management in the public administration environment, especially in the context of managing publicly funded organizations through a SSC. The presented model shows that systematically mapping processes in BPMN notation, standardizing them, and connecting them to measurable performance indicators creates a prerequisite for transparent and economically responsible management of public finances.

The proposed central purchasing process demonstrates how, through standardized procedures, clearly defined responsibilities and control mechanisms, duplication can be reduced, transparency increased, and a data foundation for managerial decision-making created. The integration of process modelling with data infrastructure enables not only the monitoring of service performance, but also its systematic evaluation in line with the principles of 3E.

The results suggest that implementing a process- and data-driven SSC model can reduce administrative burdens, better coordinate support agendas, and identify savings in operating costs. However, the success of this model depends on the quality of process design, the availability of relevant data, the willingness of organizations to cooperate, and the capacity to manage change within the institutional environment of public administration. Further

research should focus on empirically verifying the benefits of this model in specific conditions within public institutions, including quantifying the achieved savings and analyzing the impacts on service quality. The development of data analytical tools and their integration with process models to support strategic decision-making is also promising. In the context of increasing demands for the quality of public services and the optimization of public finances, this model represents an innovative direction for the further development of public administration.

Acknowledgments: The research has been supported by the Specific Research Project of the Faculty of Informatics and Management UHK “Digital Transformation of Organization Control Through Data, Processes, and AI”.

Conflict of interest: none

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Leadership Dynamics and Success of Czech Healthcare Startups: A Pilot Quantitative Analysis

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Abstract: This pilot study examines whether leadership composition and leadership change are associated with early signals of success among Czech healthcare startups. A hand-curated sample of 87 companies founded within the last 15 years was compiled from Dealroom and Czech Founders data and complemented with publicly available information on statutory leadership. Startup “success” was operationalized as a binary outcome, equal to 1 if a firm exceeded at least one threshold in valuation (> EUR 1,000,000), cumulative funding (> EUR 300,000), or revenue (> EUR 300,000). Two leadership indicators were constructed: (i) mixed-gender leadership (at least one woman in statutory bodies) versus male-only leadership, and (ii) at least one leadership change in statutory bodies versus no change. Descriptive comparisons indicate a positive direction for mixed-gender leadership, though evidence remains inconclusive in this pilot sample. In contrast, leadership change shows a clear positive association with early success signals. The results suggest that managed leadership transitions may reflect adaptive capacity in regulation- and capital-intensive startup contexts, warranting further research on the timing and types of leadership change in larger international samples.

Keywords: startup; healthcare; leadership change; gender diversity; Czech Republic; Dealroom

JEL Classification: L26; O32; G24

1. Introduction

Healthcare, medtech, biotech and digital health startups have become important vehicles for translating research and engineering advances into societal and economic value, with a growing relevance also in smaller innovation ecosystems such as the Czech Republic and the broader Central and Eastern Europe (CEE) region (Cohen & Hochberg, 2014; DEALROOM, 2023). In contrast to many purely software-based ventures, healthcare-oriented startups typically face longer innovation cycles, capital intensity, and strict regulatory requirements, which increase the strategic importance of governance, statutory leadership, and the ability to adapt organizationally during scaling.

Leadership is increasingly discussed as a performance-relevant mechanism not only through individual founder capabilities, but also through the composition of leadership teams and the dynamics of leadership change over time. Prior work has emphasized that

early-stage ventures benefit from leadership that can integrate scientific depth with market-facing execution, while building organizational routines under uncertainty (McKinsey & company, 2024). In the CEE context, these challenges are amplified by thinner pools of experienced scale-up managers and by a stronger dependence on external investors and public support instruments (Zahradka Zajfrtova & Marešová, 2025).

Recent studies and practitioner evidence highlight two leadership-related dimensions with potential links to startup outcomes. First, leadership diversity (including gender diversity) is often associated with broader perspectives and decision quality, and is increasingly embedded in European innovation policy and funding frameworks (European Commission, 2023; European Innovation Council, 2024; Hughes, 2024). Second, leadership dynamics, including managed changes in statutory bodies during growth phases, can reflect governance professionalization and the ability to respond to scaling requirements and investor monitoring (Chahine & Zhang, 2020).

Within this research stream, earlier work by the authors mapped human resource management challenges in Biotech and DeepTech startups and pointed to leadership and capability gaps as practical bottlenecks that are frequently addressed through external mentoring, investor involvement, and interim management solutions (Zahradka Zajfrtova & Marešová, 2025). However, empirical evidence from Czech healthcare startups that links observable leadership characteristics to early success signals remains limited and fragmented.

To help address this gap, the present article reports a pilot quantitative analysis of Czech healthcare startups based on two complementary data sources: the Czechia Dealroom platform (developed together with CzechInvest) and a community-maintained dataset Czech Founders (Dealroom, 2026; Czech Founders, 2026). The study focuses on statutory leadership because it is observable from public records and is directly relevant for governance in ventures.

The analysis is guided by two research questions: (RQ1) Do early success rates differ between startups with mixed-gender statutory leadership and those with male-only statutory leadership? (RQ2) Do early success rates differ between startups that experienced at least one leadership change in statutory bodies and those that did not? The pilot design is intended to generate testable hypotheses and refine measurement choices for a larger, international follow-up study.

2. Methodology

The empirical dataset was built from an export of the Dealroom (2026) database and complemented with the community database Czech Founders (2026). From the broader pool of Czech healthcare-related companies, a targeted sample was created using the following inclusion criteria: (i) healthcare/healthtech (including medtech, biotech and digital health tags), (ii) company age under 15 years as of 2025, and (iii) Czech nexus (headquarters and/or core technology originating in the Czech Republic).

The final sample includes 87 startups. Information missing from structured databases, namely gender composition of statutory leadership and whether a leadership change

occurred, was manually added based on public sources (commercial register records and company websites).

Outcome variable (SUCCESS) is binary and equals 1 if at least one of the following thresholds is met: valuation > EUR 1,000,000; cumulative funding > EUR 300,000; or revenue > EUR 300,000. Key explanatory variables are MALE-ONLY (1 if male-only statutory leadership; 0 if at least one woman has held a statutory role) and CHANGE (1 if at least one change in statutory leadership was identified; 0 otherwise).

Descriptive statistics are provided for all key variables. Associations between SUCCESS and the two leadership indicators were assessed using 2×2 contingency tables and standard tests of association for categorical variables. The analysis is intended as an exploratory pilot to inform the next research stage.

3. Results

Table 1 summarizes the main characteristics of the sample. Overall, 25 of 87 firms (28.7%) meet the study's success definition. Approximately 37.9% of startups have mixed-gender statutory leadership, and 44.8% show at least one identified leadership change.

Table 1. Descriptive characteristics of the analyzed sample (N = 87)

Characteristic	Category / statistic	Value
Sample size	Number of firms	87
Founding year	Median	2019
	Min–max	2013–2025
Age in 2025	Mean ± SD	6.1 ± 3.1 years
	Median	6 years
	Min–max	0–12 years
Success (SUCCESS)	SUCCESS = 1	25 firms (28.7%)
	SUCCESS = 0	62 firms (71.3%)
Leadership gender (MALE-ONLY)	Male-only leadership (1)	54 firms (62.1%)
	Mixed-gender / ≥1 woman (0)	33 firms (37.9%)
Leadership change (CHANGE)	With leadership change (1)	39 firms (44.8%)
	No leadership change (0)	48 firms (55.2%)
Growth stage	Seed	50 firms (57.5%)
	Early growth	26 firms (29.9%)
	Late growth	4 firms (4.6%)
	Unspecified / missing	7 firms (8.0%)

3.1. Success by Leadership Gender Composition

Mixed-gender leadership is associated with a higher share of successful firms (13/33, 39.4%) than male-only leadership (12/54, 22.2%). This indicates a visible difference in observed success rates between the two groups in the sample. However, the statistical test did not confirm significance for this association ($\chi^2(1)=2.17$, $p=0.141$), so the result should be interpreted as an observed pattern rather than a statistically supported effect in this dataset (Table 2).

3.2. Success by Leadership Change

Startups with at least one identified leadership change show a substantially higher success rate (17/39, 43.6%) than those without a recorded change (8/48, 16.7%). In other words, successful outcomes are observed more frequently among firms that experienced a change in top leadership during the period studied. This difference is consistent across the sample in the dataset. The association is statistically significant ($\chi^2(1)=6.36$, $p=0.012$), supporting the presence of a measurable relationship between leadership change and success (Tab. 2).

Table 2. Contingency results for SUCCESS and leadership indicators.

Comparison	Group	SUCCESS=1	SUCCESS=0	Success rate	$\chi^2(1)$	p-value
SUCCESS × MALE-ONLY	Mixed-gender leadership	13	20	39.4%	2.17	0.141
	Male-only leadership	12	42	22.2%		
SUCCESS × CHANGE	Leadership change	17	22	43.6%	6.36	0.012
	No leadership change	8	40	16.7%		

4. Discussion

This pilot study examined whether (i) statutory leadership gender composition and (ii) leadership change dynamics are associated with the likelihood of early startup success in healthcare, operationalized through threshold-based signals of valuation, funding, and revenues. The findings point to three complementary lines. First, mixed-gender statutory leadership shows a *positive direction* relative to male-only leadership, consistent with arguments that diversity can strengthen decision quality, broaden perspectives, and support innovation under uncertainty (Hughes, 2024; Mahadevia, 2014). However, in this dataset the relationship is not statistically conclusive, which is likely influenced by the limited sample size and a coarse operationalization of diversity (≥ 1 woman). Future research should therefore apply richer measures such as the share of women in executive roles, functional diversity, board composition, and the timing of women’s entry into leadership positions (Hughes, 2024).

Second, leadership change appears more strongly related to success than gender composition alone. In capital- and regulation-intensive healthcare domains, leadership transitions may reflect an adaptive response to scaling demands, investor monitoring, and governance professionalization rather than a simple “founder failure” narrative (Chahine & Zhang, 2020). This interpretation aligns with evidence and practice-oriented insights emphasizing the role of interim leadership, external experienced executives, and board strengthening during critical growth phases in deeptech and biotech contexts (Mochnac, 2022; Mochnac, 2023; Mulder, 2020; Van Rooij, 2023). A key next step is to distinguish types of change: founder-to-professional CEO transitions, interim appointments, or investor entry

into boards, and to model their timing relative to funding rounds and strategic pivots (Chahine & Zhang, 2020).

In practice, accelerators, investors, and ecosystem intermediaries provide not only capital but also governance know-how, mentoring, and occasionally direct leadership reinforcement, which may partially explain why leadership change correlates with stronger milestone attainment (Cohen & Hochberg, 2014; Lange et al., 2024), however, further research needs to be done to confirm this.

From a policy perspective, the directional advantage observed for mixed-gender teams and the relevance of leadership dynamics are consistent with EU frameworks that treat diversity and HR capacities as components of innovation performance. Horizon Europe embeds Gender Equality Plan requirements for eligible institutions, and the EIC explicitly promotes gender diversity and support for women-led deeptech ventures (European Commission, 2023; EIC, 2024). This pilot therefore adds initial quantitative indications from a Czech/CEE setting that leadership composition and leadership adaptation may relate to reaching investment and market thresholds, while also demonstrating the need for larger and more granular datasets before drawing definitive conclusions.

The study is limited by its cross-sectional design, reliance on database-derived financial proxies, and limitation in data on leadership change. Nevertheless, it provides an empirical starting point for a broader CEE-focused research agenda: expanding the sample internationally, introducing time-resolved measures of leadership change, and combining quantitative analysis with qualitative case studies to uncover mechanisms (governance, fundraising capability, regulatory strategy, internationalization, and ecosystem support) (Mochnac, 2022; Van Rooij, 2023; Lange et al., 2024). Despite the limitations, the results appear practically relevant for investors and ecosystem builders who often influence governance arrangements and leadership transitions in the scaling journey (Chahine & Zhang, 2020; Van Rooij, 2023).

5. Conclusions

Using a hand-curated sample of 87 Czech healthcare startups founded within the last 15 years, this pilot study explored whether two observable governance-related indicators - gender composition of statutory leadership and the occurrence of leadership change in statutory bodies - are associated with early success signals captured by valuation, cumulative funding, or revenue thresholds.

The pilot evidence suggests two distinct patterns. Mixed-gender statutory leadership shows a positive direction in relation to early success signals, but the current sample and the coarse diversity measure (presence of at least one woman) do not allow for firm conclusions. In contrast, leadership change is consistently associated with higher success rates, which supports the interpretation that managed leadership transitions may represent adaptive capacity and governance professionalization during scaling in capital- and regulation-intensive domains.

These findings have practical implications for founders, investors, and ecosystem builders in the Czech Republic and CEE. Rather than viewing leadership change purely as

a failure of founding teams, the results are consistent with a more nuanced view in which leadership transitions can be part of a growth and scaling strategy aligned with investor requirements and operational complexity.

The study is limited by its pilot design, cross-sectional nature, and reliance on database-derived financial proxies and manual coding of leadership indicators. Future research should extend the dataset internationally, refine leadership measures (e.g., functional diversity, share of women, role types), and apply multivariable models controlling for age, growth stage, and traction metrics.

Acknowledgments: The research/work was supported by the internal project "SPEV - Economic Challenges and Opportunities within Industry 4.0 and the Societal Concepts of 5.0 and 6.0", 2025, University of Hradec Králové, Faculty of Informatics and Management, Czech Republic. I would like to express my sincere gratitude to Prof. Petra Marešová, Ph.D., MBA for her expert supervision, valuable guidance, and continuous support throughout the preparation of this thesis. I also thank the University of Hradec Králové for providing an academic environment that enabled this research. Additionally, I acknowledge the use of AI-based tools (ChatGPT by OpenAI) for selected language editing and stylistic corrections of the English version of the text. All content, structure, and conclusions presented in this work remain the responsibility of the author.

Conflict of interest: none

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Behavioral and Institutional Approaches to Optimizing the Battery Take-Back System in the Czech Republic

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Abstract: Optimizing battery take-back systems is a critical component of the circular economy, yet efficiency remains limited by various systemic barriers. This paper identifies these barriers in the Czech Republic through the lens of behavioral and institutional economics. The main objective is to propose theoretically grounded measures to increase the overall efficiency of the collection system. The research framework integrates concepts from behavioral economics—specifically heuristics and choice architecture—and institutional economics, focusing on transaction costs and the role of formal and informal rules. Utilizing a systematic literature review and a comparative case study analysis involving the Czech Republic, Germany, and Sweden, the study identifies a significant "saturation paradox" where infrastructural growth does not yield proportional increases in collection rates. The findings suggest that focusing on behavioral nudges and reducing non-monetary transaction costs, such as information search costs, is more effective than mere physical expansion of the network. The results offer a strategic basis for policymakers to design more effective environmental regulations and collection systems tailored to the specific institutional context of post-communist economies.

Keywords: battery recycling; behavioral economics; institutional economics; nudge; Czech Republic; circular economy

JEL Classification: Q53; D91; D23

1. Introduction

The transition toward a circular economy has become a fundamental pillar of sustainable development, necessitating efficient systems for resource recovery and waste management (Zhan et al., 2024). Within this framework, the management of hazardous waste, particularly used batteries, represents a critical challenge due to its environmental risks and the strategic value of recovered materials (Zanoletti et al., 2024).

This issue is particularly pressing in light of the evolving legislative landscape of the European Union. The European Green Deal and the subsequent Circular Economy Action Plan (European Commission, 2020) have set ambitious targets for waste reduction and material recovery. Most notably, the recently adopted Regulation (EU) 2023/1542 concerning batteries and waste batteries introduces stricter collection targets (45% by 2023, rising to 63% by 2027) and mandates the implementation of a 'battery passport' to ensure traceability. This

regulation represents a paradigm shift from voluntary compliance to mandatory life-cycle management. However, as noted by Ghisellini et al. (2016), top-down legislative measures often fail if they do not account for the local institutional and behavioral realities of the implementation phase.

Despite the existence of robust legislative frameworks established by the European Union, empirical evidence suggests that the actual efficiency of take-back systems often falls short of theoretical expectations (Schultz, 2014). In the Czech Republic, this discrepancy points to the existence of systemic barriers that traditional economic models may fail to fully capture.

Current research in environmental economics increasingly emphasizes the necessity of integrating behavioral and institutional perspectives to understand these inefficiencies. As identified by Shogren et al. (2021), the success of environmental policy is heavily dependent on the alignment of institutional rules with human psychology. This study builds upon the foundational concepts of behavioral economics, specifically the role of "nudging" and cognitive biases in consumer decision-making (Thaler & Sunstein, 2021). Simultaneously, it draws on New Institutional Economics to analyze how transaction costs and formal rules shape the incentives within the collection system (North, 1990). Recent studies demonstrate that even minor increases in information search costs can significantly deter recycling participation (Wang et al., 2019).

The objective of this paper is to identify the primary behavioral and institutional barriers affecting the battery take-back system in the Czech Republic and to propose optimization measures. Specifically, the research addresses the following question: How do institutional constraints, particularly transaction costs, and behavioral factors, such as cognitive heuristics, influence the effectiveness of waste collection from the perspective of Czech consumers? By synthesizing these two theoretical streams—institutional and behavioral economics, the paper aims to provide actionable insights for both policymakers and collection scheme operators to enhance the efficiency of the circular economy.

2. Methodology

The methodological approach was designed to ensure rigor and replicability. The first phase consisted of a systematic literature review conducted in accordance with the guidelines proposed by Snyder (2019) for integrative reviews. This approach allows for the synthesis of literature on mature topics (transaction costs) with emerging fields (behavioral nudging). The review covered peer-reviewed articles from the Web of Science and Scopus databases published between 2010 and 2024, selected based on their applicability to the specific institutional context of the Czech Republic.

The second phase employed a qualitative case study design, focusing on the Czech Republic as a critical case (Yin, 2018). This method is particularly suitable for investigating contemporary phenomena within their real-life context, specifically when the boundaries between the phenomenon (recycling behavior) and context (institutional rules) are not clearly evident. The empirical analysis synthesized secondary data from the ECOBAT annual reports and the Ministry of the Environment with a legislative analysis of Act No. 542/2020 Coll., on

End-of-Life Products, and the strategic framework of the Regulation (EU) 2023/1542 concerning batteries and waste batteries. Furthermore, a comparative analysis of international best practices from Germany, Sweden, and the Netherlands was conducted to benchmark the Czech system against high-performing European models.

To guide the research and address the identified efficiency gap, two central hypotheses were formulated:

Hypothesis 1 (H1): The current inefficiency of the battery take-back system in the Czech Republic is primarily caused by high non-monetary transaction costs (specifically information search costs), rather than a lack of physical infrastructure.

Hypothesis 2 (H2): Behavioral biases, specifically the status quo bias and the availability heuristic, significantly reduce consumer participation in recycling, regardless of the density of the collection network.

3. Results

The analysis of the battery take-back system in the Czech Republic reveals a significant structural paradox. While the infrastructure for collection has seen extensive growth, the actual performance metrics indicate a period of prolonged stagnation.

3.1. Infrastructure Saturation and Performance Gap

Quantitative assessment of the collection network confirms that physical availability has reached a saturation point. As of 2023, the Czech Republic maintains over 20,500 collection points (ECOBAT, 2024), theoretically providing access to 90% of the population within a short walking distance. However, a longitudinal comparison reveals that the collection rate has fluctuated between 45% and 48% over the last five years. The development of collection rates in relation to the expanding infrastructure, as well as the increasing gap towards the mandatory EU targets, is illustrated in Figure 1.

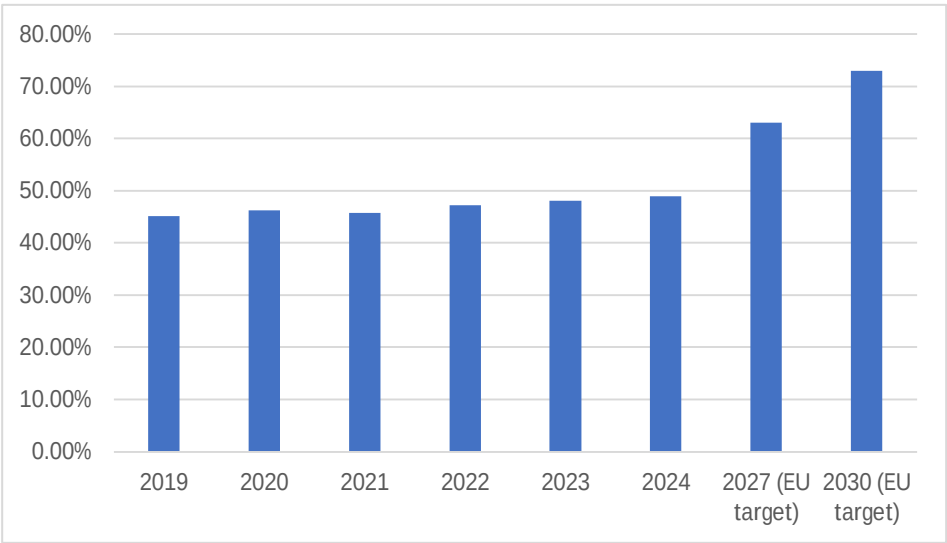


Figure 1. Collection rates of portable batteries in the Czech Republic (2019–2024) and future EU targets for 2027 and 2030

This statistical discrepancy provides the primary empirical evidence for Hypothesis 1 (H1). Since a 15% increase in the density of collection points did not yield a proportional increase in efficiency, it is evident that physical distance is no longer the primary limiting factor. The barrier has shifted from physical access to information search costs. Applying North's (1990) institutional framework, we identify that the "cost" of participation is not defined by meters to the bin, but by the cognitive effort required to identify the correct disposal method and verify sorting rules under the Act No. 542/2020 Coll., on End-of-Life Products.

3.2. Comparative Analysis of International Models

To contextualize the Czech results, the study benchmarked the local system against high-performing European models (Germany and Sweden). This comparison highlights the role of informal institutions and different regulatory approaches. The institutional configurations and behavioral drivers vary significantly across the examined countries, as summarized in Table 1.

Table 1. Institutional comparison of battery take-back systems

Country	Key Mechanism	Performance Level	Primary Driver
Czech Republic	Physical Infrastructure	Stagnating (~49%)	Information search costs
Germany	Retail Integration	High (>50%)	Institutional convenience
Sweden	Normative Influence	High (>55%)	Social trust & moral duty

The comparison illustrates that while the Czech Republic relies primarily on the density of its physical infrastructure, the higher efficiency in the benchmarked countries is driven by lower transaction costs or stronger social norms.

The German Model (Institutional Efficiency): Germany achieves superior collection rates by integrating collection points directly into the "natural pathways" of consumers (OECD, 2018). By placing highly visible bins at retail exits and high-traffic areas, the system reduces transaction costs to near-zero. This minimizes the cognitive load on the consumer, as the act of disposal is integrated into the act of daily shopping, a strategy consistent with the principles of choice architecture (Thaler & Sunstein, 2021).

The Swedish Model (Normative Influence): Sweden demonstrates that high social trust and established environmental norms can effectively compensate for logistical complexity (Lundgren, 2020; Naturvårdsverket, 2023). In this model, recycling is internalized as a social duty. This normative pressure serves as an informal institution that reduces the need for external behavioral nudges, as the population exhibits high intrinsic motivation to comply with environmental regulations (Schultz, 2014).

In contrast, the Czech Republic is currently situated in an 'institutional trap' (North, 1990). It lacks the extreme retail visibility and logistical convenience of the German model, while also lacking the deeply rooted normative pressure found in Sweden. Consequently, further expansion of the physical network in the Czech Republic may yield diminishing returns (ECOBAT, 2024), unless fundamental behavioral and institutional frictions—specifically search costs and habit persistence—are addressed.

3.3. Identification of Behavioral Barriers

The persistence of batteries in municipal solid waste (approx. 50% of sold volume) confirms the dominance of cognitive biases, validating Hypothesis 2 (H2). Two specific biases were identified as critical:

Status Quo Bias: Consumers default to the easiest available option, due to habit persistence. Without a disruptive trigger, the intention to recycle is overridden by routine.

Availability Heuristic: Because collection containers in the Czech Republic are often placed in low-visibility zones (e.g., inside administrative buildings or behind store counters), they do not trigger the mental "reminder" at the moment of disposal.

The analysis suggests that current information campaigns are often ineffective because they appeal to conscious, rational decision-making. However, the act of disposal is largely governed by automatic habits and routine. As described by Kahneman (2011), without a disruptive cue to break this routine, the cognitive effort required to recycle overrides the intention to do so.

4. Discussion

The findings of this research reveal a fundamental discrepancy between infrastructural supply and behavioral response within the Czech battery take-back system. While the collection network has expanded to over 20,500 points (ECOBAT, 2024), the stagnation of collection rates at approximately 45–48% suggests that the system has reached its marginal utility in terms of physical expansion. This aligns with the "saturation paradox" observed by Wang et al. (2019), indicating that the limiting factor is no longer the "hardware" (infrastructure) but the "software" (institutional rules and consumer psychology).

4.1. The Institutional Efficiency Gap and Transaction Costs

The validation of Hypothesis 1 (H1) demonstrates that the Czech system is currently hindered by high non-monetary transaction costs. Although Act No. 542/2020 Coll. provided a solid legal foundation for Extended Producer Responsibility (EPR), it inadvertently placed a significant cognitive burden on the end-user. As theorized by North (1990), if the information search costs (identifying where and how to sort) exceed the perceived utility of the action, rational actors will default to non-participation. In the Czech Republic, the lack of a unified digital interface and the low visual prominence of collection points in retail spaces maintain these transaction costs at an inhibitive level.

From an economic perspective, this study demonstrates that further extensive expansion of the physical network exhibits diminishing marginal utility. For both firms and the state, it is financially more efficient to allocate resources toward digital integration and unified information platforms that reduce information search costs, rather than investing in further densification of a network that has already reached its saturation point. This shift from quantitative to qualitative optimization can lead to significant savings in the total logistics costs of the take-back system.

4.2. Behavioral Inertia: Habit vs. Conscious Deliberation

The persistent presence of batteries in municipal solid waste provides strong evidence for Hypothesis 2 (H2) regarding behavioral biases. The core failure of current communication strategies is their reliance on conscious, rational decision-making. Educational campaigns assume that consumers make an active choice to recycle. However, as Kahneman (2011) points out, routine waste disposal is largely an automatic, habitual activity. The status quo bias acts as a powerful deterrent; without a disruptive "nudge" in the physical environment, the consumer defaults to the easiest path—the general waste bin. The Czech system currently lacks effective "choice architecture" to trigger an impulse at the moment of disposal. Our findings suggest that unless collection bins are moved from hidden corners to "natural decision pathways" (e.g., apartment exits), the gap between the intention to recycle and the actual behavior will remain.

Instead of costly rational educational campaigns, operators should focus on 'visual disruption' of consumer routines. Implementing aesthetically distinct and visually prominent containers in residential zones serves as a low-cost behavioral trigger that effectively overcomes the status quo bias more efficiently than traditional information appeals.

4.3. Cultural Context and Social Norms

A critical nuance is the role of cultural friction. Comparing the Czech Republic to the Swedish model highlights a difference in informal institutions. Sweden's success is built on high social trust where recycling is a moral obligation. As noted by Kaasa et al. (2014), post-communist societies often exhibit lower levels of institutional trust, meaning consumers are less likely to respond to "moral suasion" alone. This implies that for the Czech Republic to meet the ambitious targets of Regulation (EU) 2023/1542 (63% by 2027), it must focus more on environmental design and digital convenience than on traditional normative appeals.

4.4. Practical Implications and Future Research

From the perspective of the Circular Economy, the current focus is disproportionately shifted toward end-of-pipe collection. As argued by Kirchherr et al. (2017), a true circular transition requires higher-order strategies (Reduce, Reuse). While the new Battery Passport will reduce information asymmetry, the physical "last mile" of collection will still fail if behavioral triggers are missing. Future research should employ field experiments (A/B testing) to quantify the exact impact of visual nudges and social feedback on actual collection volumes in Czech residential areas.

For collective system operators and retailers, the research suggests that success lies not in merely increasing the number of collection points, but in their strategic placement within the consumer's 'natural decision-making paths. A key managerial recommendation is to relocate collection boxes from less visible areas—such as behind counters or in administrative zones—directly to store exits or near parking payment machines, thereby reducing non-monetary transaction costs for consumers to near zero.

5. Conclusions

The objective of this paper was to identify the primary institutional and behavioral barriers hindering the efficiency of the battery take-back system in the Czech Republic. The research demonstrates that the current stagnation in collection rates is not a result of infrastructural deficiency, but rather a consequence of high transaction costs and cognitive biases. Based on the synthesis of empirical data and theoretical frameworks, the study confirms that the high density of the collection network has reached a point of diminishing returns. The primary barrier has shifted to information search costs (validating H1), where consumers face significant ambiguity regarding disposal rules under Act No. 542/2020 Coll. Simultaneously, consumer behavior is inhibited by the status quo bias (validating H2), as the lack of visual cues and environmental nudges in the physical decision-making pathway leads individuals to default to automatic habits of disposing of batteries in general waste.

To overcome these barriers and meet the ambitious targets of Regulation (EU) 2023/1542, a strategic shift from quantitative expansion to qualitative optimization is required. This paper proposes a hybrid intervention strategy that addresses both institutional and behavioral constraints. From an institutional perspective, digital integration through unified interactive platforms is essential to minimize search costs. Complementing this, the redesign of the choice architecture through highly visible, aesthetically distinct collection containers in residential common areas is necessary to break behavioral inertia.

The study provides three main practical contributions. First, for operators, it identifies the necessity of re-designing choice architecture within retail environments. Second, for policymakers, it provides evidence of the inefficiency of further physical network expansion and recommends a strategic focus on digital tools to reduce transaction costs. Third, regarding economic benefits, it proposes cost optimization through behavioral interventions, which are financially less demanding than large-scale infrastructural changes.

Future research should focus on the experimental verification of specific behavioral nudges in the Czech retail context, prioritizing field-based A/B testing to quantify the effectiveness of these interventions in real-world settings. Additionally, investigating the long-term sustainability of these behavioral changes compared to traditional awareness campaigns remains a key challenge for further study.

Acknowledgments: The authors state that no external funding was received for the preparation of this manuscript.

Conflict of Interest: none

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Hradec Economic Days

Volume 16

Issue 1

Proceedings of the International Scientific Conference

Hradec Economic Days 2026

April 9–10, 2026.

Editors: Martin KRÁL, Petra MAREŠOVÁ, Krzysztof FIRLEJ, Ivan SOUKAL.

Hradec Economic Days are published annually.

Edition size: electronic edition only.

Published: April 1, 2026.

Publisher: University of Hradec Králové.

Publisher's office: Rokitanského 62, Hradec Králové 3, 500 03, Czech Republic.

VAT ID: CZ62690094.

ISSN 2464-6067 (Online)

ISBN 978-80-7435-966-8

DOI: 10.36689/uhk/hed/2026-01-000



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