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1093 Budapest, Fővám tér 8.  
t: +36 1 482 5432  
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A Budapesti Corvinus Egyetem rektora

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FŐSZERKESZTŐ:  
Aranyossy Márta  
vezetestudomany@uni-corvinus.hu

OLVASÓSZERKESZTŐ:  
Nusser Tamás

SZERKESZTŐSÉGI TITKÁR:  
Szabó Krisztofer  
titkarsag.veztud@uni-corvinus.hu

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# VEZETÉSTUDOMÁNY

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## THE ROLE OF DOUBLE AI IN SMART TOURISM – CORPORATE STRATEGIES SERVING RISK RESILIENCE

### A KETTŐS MI SZEREPE AZ OKOS TURIZMUSBAN – VÁLLALATI STRATÉGIÁK A KOCKÁZATI REZILIENCIA SZOLGÁLATÁBAN

The study examines, within the framework of smart tourism, “double AI” (AI-on-AI) systems. The aim is to present how leaders in the tourism sector (SMEs, municipalities, destinations) can use these new frameworks to increase risk resilience. The research is grounded in the theoretical frameworks of resilience and AI technology, utilising both qualitative (case studies) and quantitative (surveys) methods. According to the literature, AI enables personalised services and enhanced efficiency in tourism while also presenting new challenges related to data protection and employment. The study complements this by presenting international and Hungarian examples, as well as three comparative case studies. The results encompass, on the one hand, the primary components and impacts of AI systems on resilience, and, on the other hand, the key quantitative indicators from the surveys. This mixed-method approach supports corporate leaders’ decision-making from several perspectives.

**Keywords:** double AI, resilience, risk management, smart tourism, SME

A tanulmány az intelligens turizmus keretében vizsgálja a „kettős MI” (AI-on-AI) rendszereket. A cél annak bemutatása, hogy a turisztikai ágazat vezetői (KKV-k, önkormányzatok, desztinációk) hogyan használhatják ezeket az új keretrendszerket a kockázatokkal szembeni ellenálló képesség (reziliencia) növelésére. A kutatás az ellenálló képesség és az MI-technológia elméleti keretrendszerére épül, kvalitatív (esettanulmányokat) és kvantitatív módszereket (felméréseket) egyaránt alkalmazva. A szakirodalom szerint az MI személyre szabott szolgáltatásokhoz és a turizmus hatékonyságának javulásához vezet, miközben új kihívásokat is jelent az adatvédelem és a foglalkoztatás terén. A tanulmány ezt kiegészíti nemzetközi és magyar példák és három összehasonlító esettanulmány bemutatásával. Az eredmények egyrészt az MI-rendszerek ellenálló képességre gyakorolt főbb összetevőit és hatásait, másrészt a felmérésekből származó legfontosabb mennyiségi mutatókat foglalják magukban. Ez a vegyes módszerű megközelítés több szempontból is támogatja a vállalati vezetők döntéshozatalát.

**Kulcsszavak:** okos turizmus, kettős MI, reziliencia, kockázatmenedzsment, KKV

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#### **Authors/Szerzők:**

Dr. Etelka Éva Katits<sup>a</sup> (katits.etelka@zek.uni-pannon.hu) academic assistant dean (<https://orcid.org/0000-0003-4108-7459>); Judit Katalin Fejes<sup>a</sup> (fejes.judit@zek.uni-pannon.hu) master teacher (<https://orcid.org/0009-0000-8310-120X>)

<sup>a</sup>University of Pannonia (Pannon Egyetem) Hungary (Magyarország)

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The digital transformation of tourism has ushered in a new era, in which *Artificial Intelligence* (AI) is a strategic tool for risk management. During the transformation of tourism, AI has become an increasingly important factor. AI applications are involved not only in personalising travel experiences (through recommendation systems and chatbots) but also in automating and optimising operational processes (Siddik et al., 2024; OECDa, 2024). However, the degree of adaptation in the sector is uneven: according to OECD data, in 2023, only 11% of tourism intermediaries and 4% of hotels in Europe used some AI solution (OECDa, 2024). In contrast, recent research highlights that AI plays a crucial role in enhancing the efficiency of tourism and achieving sustainability goals (Siddik et al., 2024). Nevertheless, many small businesses, especially Hungarian SMEs, are falling behind in technological developments (OECDa, 2024) – thus, it is essential to develop practical guidelines for them.

In this study, we introduce the concept of „double AI” (AI-on-AI) as a technological framework for smart tourism. We interpret this as a collective term for hierarchically organised AI systems, in which an algorithm functions not only as a data processor but also as the supervisor and optimiser of another AI system. For example, one AI can forecast expected tourist traffic, while another AI continuously evaluates the accuracy of these forecasts and adjusts the strategy accordingly. With such a system, companies can respond more quickly to unexpected events (such as sudden fluctuations in demand or natural disasters), thereby increasing their crisis resilience.

## Research Topic and Relevance

The literature addresses various AI-based applications in tourism (e.g., personalised recommendation systems, chatbots, and demand forecasting). However, it rarely examines the integrated, corporate-level strategic application of AI to strengthen resilience. This knowledge gap forms the basis of the research question: How can the “dual AI” concept be realised in tourism companies to increase their risk resilience?

In terms of realising tourism’s sustainability and social goals, risk management is significant, considering the increasing impact of climate change, economic fluctuations, and other unexpected shocks. Reichstein et al. (2025) emphasise that AI-based, integrated *Early Warning Systems* (EWS) are vital for forecasting and managing climate and natural risks. In this light, the relevance of this research lies in the fact that, with the help of AI, we link the development of innovatstrategy and risk management, thus facilitating the long-term resilience and competitiveness of tourism enterprises.

## Research Objectives

The primary goal of this research is to develop a comprehensive framework and practical guide that supports the

development of dual AI-based solutions applicable in the tourism sector. Specifically, we examine how AI-based predictive models and decision-support simulation models can be integrated into corporate strategy and how they can simultaneously contribute to strengthening corporate resilience.

To achieve this goal, the research

- maps the applicability of AI-based EWS (AI-EWS) for identifying and mitigating tourism risks,
- examines how dual AI systems increase the accuracy of financial and demand forecasts and support strategic decision-making,
- evaluates the socio-economic impacts of the most modern tourism technologies (e.g., AI, *Internet of Things* (IoT), Big Data, digital platforms, smart infrastructure), with special focus on local community involvement and sustainability.

The research also aims to provide practical guidance on how corporate strategies can simultaneously strengthen the digitalization and resilience of the tourism sector.

## Research Questions

To precisely define the focus of the research, we seek answers to the following two research questions:

1. How does the integration of dual AI systems in smart tourism increase the predictive and adaptive capabilities of decision-making?
2. How does dual AI-EWS contribute to aligning corporate resilience and sustainability goals?

The novelty of the research lies in its representation of an integrated, system-based approach, in contrast to existing fragmented AI applications that consider not only technological but also strategic and social aspects. The developed framework can serve as a practical guide for tourism stakeholders, helping organisations connect AI technology and resilience, all in the service of sustainable development goals.

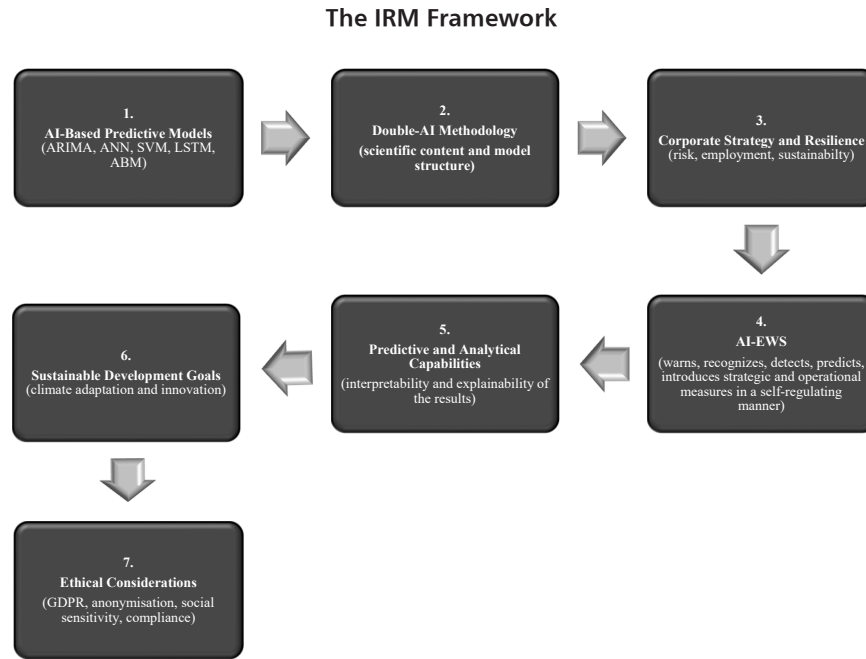
## Historical and Literature Review of Intelligent Resilience Management Framework

The literature review was conducted with PRISMA-like transparency (SPAR-4-SLR protocol) (Wang et al., 2025).

The *Intelligent Resilience Management* (IRM) framework is based on the coordinated integration of several interrelated scientific domains. Here, we explore how the seven components of the IRM framework are reflected in the academic literature (*Figure 1*).

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Figure 1



Source: author's compilation (2025)

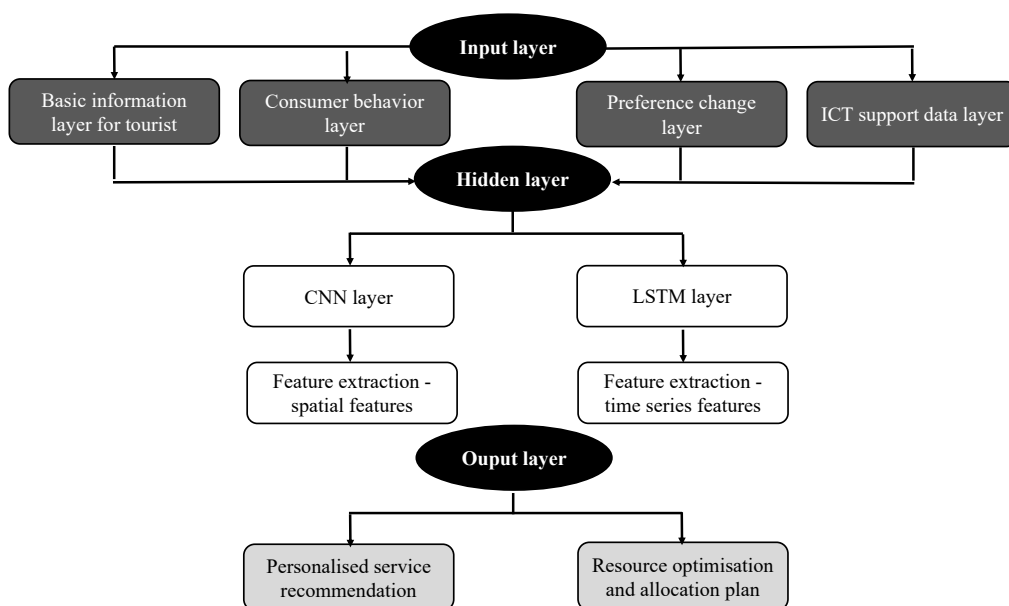
### 1. AI-Based Predictive Models

The history of tourism forecasting and modelling dates back to the 1970s and 1980s, when classic time-series models (e.g., ARIMA = *AutoRegressive Integrated Moving Average*) were used to predict guest flows. In parallel with the development of IT from the 2000s onwards, more and more AI algorithms (*Artificial Neural Networks*=ANN, *Support Vector Machines* (SVM), and deep networks) have been applied to the analysis of tourism data (Song & Zhang, 2025), as reported on frontiersin.org. In the 2010s, neural networks based on long-term

memory (e.g., LSTM=*Long Short-Term Memory*) gained popularity for capturing temporal dependencies (Song & Zhang, 2025) at frontiersin.org. At the same time, in the financial sector, especially in risk analysis and planning, simulation methods (Monte Carlo), as well as *Agent-Based Modelling* (ABM), have been used for a long time. Agent-based simulation has also been applied in tourism for studying visitor behaviour and spatial interactions (Wallinger et al., 2023). The post-COVID-19 recovery demonstrates the robustness of tourist flows: by 2023, global tourism had significantly rebounded to 2019 levels (WTTC, 2024). However, economic and climate crises have brought new,

Figure 2

### Example of a Neural Network Architecture for Tourism Purposes



Source: author's compilation based on Tian & Tang (2025, p. 4)

unforeseen challenges that can be examined using complex AI-based and simulation tools. Recent research, for example, shows that AI-based predictive systems (such as LSTM) are effective for analysing the environmental impacts of tourism and capturing long-term dependencies (Song & Zhang, 2025).

The application of AI in tourism and financial analyses has steadily expanded over the past decades. Initially, traditional tools for temporal forecasting, such as ARIMA models, gained widespread adoption. Zhang et al. (2018) pointed out that ARIMA (and ARCH/GARCH) models are fast, convenient, and relatively accurate for analysing economic time series. However, these are increasingly being supplemented or replaced by *Machine Learning* (ML) solutions. For example, ANN and deep learning methods have become effective forecasting tools. Tian & Tang (2025) developed an ANN model that processes large datasets to predict tourism behavioural patterns, showing a significant increase in accuracy compared to traditional statistical methods (nature.com). The flexibility of ANNs makes them suitable for recognising complex patterns, which is well utilised in forecasting tourist flows.

Figure 2 illustrates the structure of a typical tourism ANN model, where various tourist information (demographics, consumption patterns) enters the input layer. CNN and LSTM units are present in the hidden layer, and the output layer returns personalised service recommendations and optimised resources.

SVMs gained widespread use in the early 2000s for nonlinear time series analysis. Pai et al. (2005) developed a multinational SVM model for forecasting tourism demand and found that their hybrid SVM-neural network solution outperformed previous forecasting methods. This shows that SVMs are also effective in handling complex influencing factors.

LSTM networks are capable of modelling long-range temporal dependencies and have therefore been widely used in recent years for tourism and economic forecasting. Zhang et al. (2025), for example, used a hybrid of BiLSTM (*Bidirectional LSTM*) and Transformer networks to accurately capture both short-term fluctuations and long-term trends, outperforming an ARIMA-based method. This indicates that deep networks are increasingly replacing classical approaches in the era of large databases.

In the field of uncertainty and risk analysis, the Monte Carlo method has long been a fundamental tool. For instance, Zakhary et al. (2009) used a Monte Carlo simulation to model a hotel's booking process, simulating booking events and cancellations for the entire forecasting period. With this method, they obtained survival distributions and modelling densities for the expected number of guest nights. As noted, the Monte Carlo approach methodologically surpasses other techniques, as it can vary all sources of uncertainty simultaneously and does not require parametric assumptions.

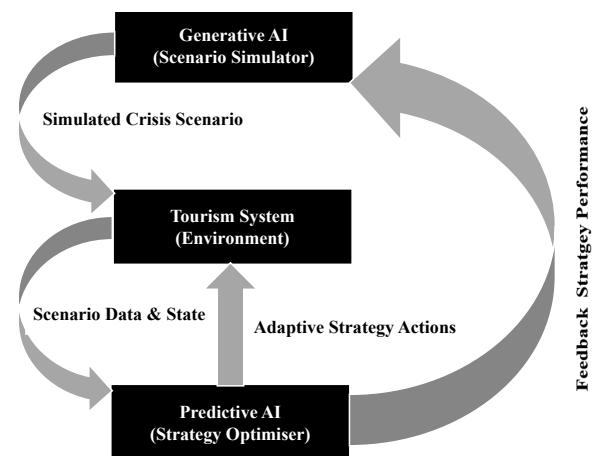
The ABM method simulates the interactions and behaviours of autonomous "agents" (e.g., tourists, residents, entrepreneurs). Agent-based modelling enables the representation of the complex tourism system, where the

heterogeneity of individuals, their interactions, and non-linear processes can be effectively captured. Nicholls et al. (2016) emphasise that ABM can manage the assumptions (homogeneity, linearity, equilibrium, rationality) that traditional models typically require, thus making it particularly useful for simulating complex tourism systems (planning, development, marketing).

## 2. Double-AI Methodology

A dual AI system consists of two AI components (Figure 3 in a tourism decision support system): (1) a generative module that simulates crisis scenarios (on the left), which are tested in a tourism decision environment, and (2) a predictive optimisation module then proposes optimal responses (e.g., strategies) for the given situation (on the right), and applying these makes the effects of the decisions visible in the tourism system. The feedback loop (dashed arrow) indicates that the generative model can learn from the outcome of the strategy – for example, after recognising an effective response strategy, it can generate new, different crises for further testing by the system. The coordinated functioning of these two layers determines the system's effectiveness; therefore, it is necessary to describe their interaction using formal logic.

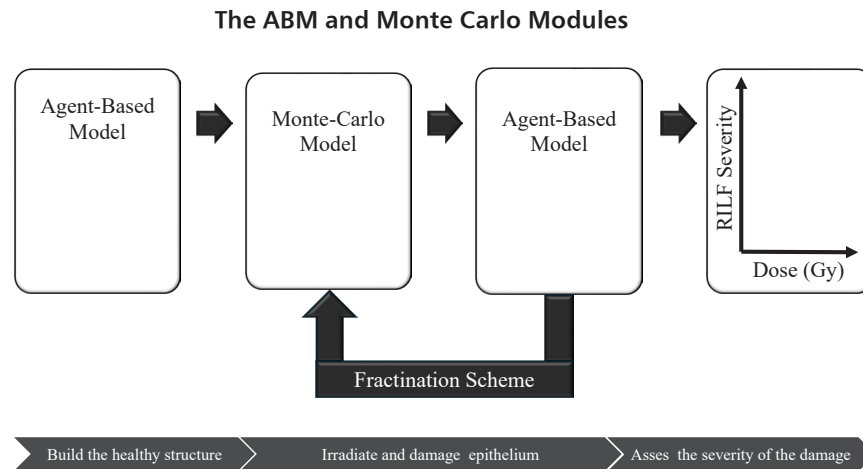
Figure 3  
Schematic Operational Outline of a Dual AI System Based on Synthetic Data



Source: author's compilation (2025)

The dual AI architecture implements a dual AI process: a first, predictive model forecasts tourism indicators (e.g., demand, visitor numbers), and then a second, simulation model examines the dynamics of the region or system based on these forecasts (Cogno et al., 2024). For example, one model (Time Series AI) may use an LSTM or ARIMA network to predict guest traffic based on historical data, after which a so-called Monte Carlo or ABM simulation is fed from these forecasted data.

Figure 4 presents a schematic model showing how the ABM and Monte Carlo modules cycle the system's state: the ABM creates the structure, and after a Monte Carlo irradiation or external-effect simulation, feedback is provided for the system's next step (Cogno et al., 2024).



Source: author's compilation based on Cogno et al. (2024, p. 5)

The essence of the Dual AI approach is that, by combining ML and simulation techniques, we can test complex scenarios and assess risk impacts, increasing the model's flexibility and realism.

In the game-theoretical model, the generative and predictive AI can be seen as two “players” with opposing goals, who together produce an outcome. Generative AI can generate “worst-case” crises – acting as an adversary to the system – while the goal of predictive AI is to minimise such damage, acting as a defender (similar to the minimax optimisation principle). The approach is related to the Stackelberg game concept: the crisis generator, acting as the “leader,” moves first by presenting a scenario, while the “follower” (the response-strategy AI) makes its optimal decision with this knowledge (Kar et al., 2018).

In the Bayesian approach, the generator is modelled less as an adversary and more as a source of uncertainty. Here, the generative AI explores many possible future states, effectively providing a prior distribution over crisis events. The task of predictive AI is to manage this uncertainty: using Bayes' theorem, it updates probabilities as new information arrives (e.g., the first signs of a crisis), or performs stochastic optimisation that accounts for the likelihood of various scenarios. The Bayesian-based dual AI model, therefore, seeks to maximise expected utility.

The methodological elements include the classic ARIMA model, which builds on linear time-series models and works well when the data (or their differenced versions) are stationary. ARIMA components combine past values and random errors. However, ARIMA is only sensitive to linear relationships; it does not handle complex nonlinear trends and long-term dependencies well (Zhang et al., 2025), which can be limiting for tourism data.

In contrast, LSTM networks are suitable for learning complex temporal patterns. They retain important information over time, enabling them to effectively track nonlinear and long-term trends (Song & Zhang, 2025). Recently, more hybrid solutions have emerged: for example, Zheng and Zhang (2023) presented a GM–LSTM

model in which a grey model captures the general trend in the data, while the LSTM learns the nonlinear fluctuations in the residuals.

Monte Carlo simulation uses an entirely different approach: by repeated random sampling, we simulate many “what if...” scenarios (Pavlik & Michalski, 2025). According to Pavlik and Michalski (2025), Monte Carlo simulation is an advanced statistical tool for forecasting risk management, often used to assess the profitability of financial projects and analyse risks. The great advantage of the method is that, when analytical solutions become too complex, Monte Carlo can provide numerical results. For example, Sun et al. (2024) calculated a 99% probability range for global tourism CO<sub>2</sub> emissions using a Monte Carlo simulation, thereby obtaining a quasi-confidence interval for the forecast.

ABM simulates the behaviour and interactions of individual “agents” (tourists, businesses, destination managers, etc.) in complex systems. In tourism, where the heterogeneous preferences and behaviours of individual decision-makers are crucial, ABM is well-suited to analysing what-if scenarios (Wallinger et al., 2023). In the ABM framework, each agent operates according to a set of rules (e.g., budget constraint, risk perception). Thus, complex, emergent system dynamics can develop (tourists' spatial distribution, crowding, demand changes). In tourism, ABM is often used for traffic management and crisis response. Luo et al. (2021) developed a NetLogo-based ABM to examine post-COVID tourism market recovery, modelling the market's restoration by accounting for individual tourist decisions and destination strategies.

### 3. Corporate Strategy and Resilience

Based on a content analysis of definitions of resilience across different disciplines, a common interpretation of the behaviour of resilient systems is presented, which can be described by terms such as adaptation, retrieval, performance, absorption, retention, confrontation, return, response, and resistance (Zahedi et al., 2023).

Building on the General Systems Theory, corporate resilience theory includes inputs of human resources,

socio-cultural values, institutional settings, and social and environmental issues, enabling organisational structure, value and belief subsystem, resilience mindset, sustainability practices, adaptive and buffering capacities, and sustainability performance as the output (Kantabutra & Ketprapakorn, 2021).

Corporate strategy directs attention to what environments to operate in. Part of the corporate strategic management process is ensuring that companies have adequate resilience. According to Zahedi et. al. (2023), three factors contribute to organisational resilience:

1. resilience is the function of an organisation,
2. resilience resulting from organisational operations (namely, an action done by an organisation),
3. resilience is a metric of anomalies that an organisation can tolerate.

Ruiz-Martín (2018) believes that all these definitions have the same meaning and refer to the organisation's survival in the face of shocks and risks. Risk is the threat, and resilience is the response to that threat.

The international standard for risk resilience is ISO 31000, which provides a framework for risk management (financial, operational, strategic, IT risks, cybersecurity, and compliance) that all organisations can adapt. The basic principles of ISO 31000 include the identification, assessment and ongoing management of risks, as well as the integration of risk management at all levels of the organisation. According to the ISO 31000 approach, AI technologies (e.g. dual AI-based predictive models) can play a key role in the continuous cycle of risk management (planning, execution, monitoring, improvement) in predicting threats and automating risk management (TechTarget, 2025).

Here, we mention the RISKRES (*RISK-RESilience*) model, which addresses risk analysis and the development of resilient strategies together (Singh, 2022).

#### 4. AI-EWS

For tourism enterprises, timely risk detection is crucial: pandemics, extreme weather events, and geopolitical crises all require rapid responses. AI-based EWS systems can assist in this by continuously monitoring and analysing large amounts of data (climate data, transport conditions, health statistics, etc.). According to the international organisation WMO (2025), such AI-based EWSs are becoming "life-saving tools" for supporting sustainable development.

In the tourism context, Ghaderi et al. (2024) examined the resilience of smart tourism destinations from a cybersecurity perspective. Their study found that the interconnectivity and decentralised operation of smart destinations enhance defensive capabilities, while also highlighting the importance of risk management measures such as encryption, regular backups, incident management protocols, and awareness-raising programs. Furthermore, the OECD (2024) points out that integrating AI-based warning and decision-support tools can increase the tourism sector's resilience to external shocks (e.g., climate change, pandemics).

In dual AI systems, for example, one AI agent may be responsible for continuously monitoring data and predicting threats (e.g., regulatory models based on climatological or epidemiological data). In contrast, the other model performs strategic simulations, proposing alternative response measures for company management. Such structures aim to ensure that responses to risks are faster, more adaptive, and comprehensive, thereby increasing corporate resilience.

#### 5. Predictive and Analytical Capabilities

The performance of the double AI system can be evaluated by measuring the prediction accuracy and risks. The dual AI system developed in the research contains two modules.

AI1 – predictive module: regression and time series models (XGBoost=*eXtreme Gradient Boosting*, LSTM). The output of the predictive model usually appears as future values or growth paths. It is essential to thoroughly validate models: the available data is divided into training, validation, and test sets, and cross-validation methods are employed to prevent overfitting. The leading indicators characterising model accuracy include *Root Mean Square Error* (RMSE) measures the spread of predictions, *Mean Absolute Error* (MAE) measures the magnitude of error, *Mean Absolute Percentage Error* (MAPE) gives the percentage error of the forecast, and the coefficient of determination, also known as explained variance ( $R^2$ ) indicates how well the model captures the fluctuations of the target variable (Zhang et al., 2025). When assessing a model's acceptability or comparing two models, these indicators are critical: the lower the RMSE/MAE and the higher the  $R^2$ , the more accurate the estimate.

When measuring accuracy, it is worth examining the system's performance separately in calm periods and during crisis scenarios. Ideally, the double AI improves accuracy in both calm periods and crisis scenarios by training on the generated stress-test data. This is supported by the fact that some forecasting models have become more robust and produce less error by incorporating synthetic data (Chatterjee & Byun, 2023). It is also important to measure the actual positive rate and the true negative rate (interventions for minor fluctuations, which are overreactions).

Overall, if the accuracy of forecasts improves, volatility and potential loss decrease, and all this is coupled with greater profitability, then the system is both methodologically sound and commercially justified.

AI2 – generative-simulation module: it uses AI1's predictions to perform scenario analysis, exploring possible outcomes and optimal responses at the system level. The development of this module is supported by the Monte Carlo simulation technique, supplemented as necessary by ABM to illustrate the interactions of tourism actors.

We analyze quantitative data in SPSS and Python, and use the SMESBJ (*Small Medium Enterprises Smart Business Journey*) smart application (Katits, 2024).

The ROC (*Receiver Operating Characteristic*) curve and AUC (*Area Under Curve*) values are reliable and standardised measures of predictive model performance.

The ROC curve plots the relationship between the actual positive rate (sensitivity) and the false positive rate (1-specificity) across different thresholds. The AUC represents the area under the ROC curve and serves as a numerical indicator of the model's overall performance. An AUC value close to 1 indicates excellent predictive ability (Bradley, 1997; Huang et al., 2020; Muschelli, 2019), meaning that double AI predictive algorithms provide significantly reliable decision support in the context of smart tourism and regional employment (Fawcett, 2006).

The interpretability of model results is enabled by the principles of Explainable AI (XAI), thereby increasing transparency for decision-makers. To this end, for the AI1 module, the SHAP (*Shapley Additive exPlanations*) method calculates the contribution of each input feature to each forecast. Each variable is assigned a SHAP value, indicating the extent to which the given feature positively or negatively influenced the model output. This makes it possible to reveal which factors increase the risk the most in a given scenario.

Modelling is often based on limited or incomplete real data. Therefore, tourism research uses synthetic data (typically generated by generative models or theoretical distributions, e.g., simulated traveller demand models) to expand the training dataset. However, synthetic data is most appropriate for preliminary research (e.g., hypothesis testing, model training), while primary studies – if possible – should verify their results with real data. During validation, the distribution of generated data is compared with real data or known standards; for example, agreement is checked in network distributions, medians, or correlation structures. Care is also taken to ensure that AI-generated synthetic training data do not reinforce erroneous patterns, and that the model's generalizability is maintained.

Viglia et al. (2024) note that synthetic data are most useful in preliminary, experimental phases (such as pre-testing for validation). However, using synthetic data requires thorough model validation: predictive accuracy must always be compared with real, international benchmarks.

## 6. Sustainable Development Goals

Several SDGs are directly related to IRM's focus on tourism development, making AI a fundamental role in achieving them. According to the analysis by Vinuesa et al. (2020), AI can contribute to 134 of the 169 targets across the 17 SDGs – although it may also have negative impacts if ethical considerations are not embedded.

The most significant tourist potential lies in the goals of SDG 11 (Sustainable Cities), SDG 13 (Climate Action), and SDG 7 (Affordable and Clean Energy). Accordingly, IRM deploys AI solutions that account for environmental impact, social consequences, and SDG alignment.

## 7. Ethical Considerations

Data collection will be conducted using GDPR-compliant procedures, including anonymisation of personal data, documentation of consent forms, and consideration of social sensitivity considerations in the pilot region. A

separate XAI and ethical compliance protocol will be implemented for AI models.

## Research Plan, Materials, and Methods

The study was divided into theoretical-model development and empirical-data collection phases, thus ensuring both conceptual foundation and practical validation. The project was divided into three stages, during which the individual task blocks were built on each other:

1. Literature foundation and theoretical design of the dual AI framework, including planning the development of the AI1 (predictive) and AI2 (simulation) modules.
2. Empirical data collection (questionnaire survey) and training of the prototypes of the predictive models on real and synthetic data, evaluation of initial results.
3. Fine-tuning and evaluating the models, explaining their outputs (using XAI techniques, e.g. SHAP), and running scenario-based simulations (Monte Carlo) to analyse risks and validate solutions.

One of the quantitative research methodologies was primary data collection; we conducted it using a pre-structured online questionnaire in the fourth quarter of 2024.

The sample size is 1,157 people, who are operational and strategic decision-makers working in various sub-sectors of the national tourism sector (hotel industry, catering, other tourism services).

The sample structure originates from the end of the 2024 survey data. Accordingly, the distribution of companies included in the sample was aimed to reflect the makeup of the entire population. Sample elements were based on the proportions of target audiences (Hungarian tourism enterprise leaders), and, for example, small, medium, and large preparedness were represented in nearly equal proportions. Stratified sampling and purposeful quota representation ensure that the sample reflects actual business structures, thereby increasing the validity of the results. The composition of the analysed sample relative to national proportions is shown in *Table 1*.

Based on geographical, sectoral, and volumetric comparisons, the research sample is demonstrably representative of Hungary's tourism sector. The sample's geographical and corporate structure is proportional to national distributions (across major tourism regions and firm-size breakdowns), and the sample size is statistically significant. The share of digital/AI innovators is slightly higher in the sample, as the study also aimed to analyse advanced solutions.

The variables included in the questionnaire were the following:

- extent of application of AI systems (e.g. financial forecasting, controlling, resource optimisation),
- preventive and proactive management skills,
- challenges of AI implementation,
- awareness and practical use of double AI systems,
- perceptions of (financial, operational, digital) resilience effects generated by AI.

Table 1  
Verification of the Representativeness of the Tested Sample

Characteristics	Research sample	National data	Source
Sample size (count)	1 157	104 600	KSH (2024)
SME share (%)	70% (810 pcs)	73% (42.860 pcs)	KSH (2024)
Large-enterprise share (%)	19.9% (230 pcs)	17% (9 747 pcs)	KSH (2024)
Non-profit/public/other (%)	10.1% (117 pcs)	10% (4 728 pcs + other)	KSH (2024)
AI/digital use (%)	49.9% (self-declaration)	11% (for accommodations)	Statista (2024)
Budapest share (%)	23.3%	25%	KSH, MTÜ (2024)
Lake Balaton share (%)	16%	28%	KSH, MTÜ (2024)
West Transdanubia (%)	9.5%	11%	KSH, MTÜ (2024)
Central Transdanubia (%)	9.5%	~10%	KSH, MTÜ (2024)
Northern Hungary (%)	12.1%	~8%	KSH, MTÜ (2024)
Southern Transdanubia (%)	10.4%	~10%	KSH, MTÜ (2024)
Great Plain & other regions (%)	19.2%	~8%	KSH, MTÜ (2024)

Source: author's compilation (2025)

During the data analysis, we used descriptive statistical indicators and cross-sectional correlation analyses (e.g., AI knowledge × financial resilience). During the analysis, we paid particular attention to the different perceptions of resilience across organisations of different types (SMEs vs. municipalities).

The data were systematically processed using a meta-analysis method – Preferred Reporting Items for Systematic Reviews and Meta-Analysis 2020 (Page, 2021), which enabled a comparative analysis of the benefits of different international and Hungarian AI technologies.

During the meta-analysis, we compared the data in order to examine the extent to which the application of AI technologies has influenced different aspects of tourism. The analysis took into account the specific characteristics and circumstances of the technologies' introduction. We excluded from the analysis studies that were not published in Hungarian or English, were review articles or editorials, had small sample sizes, covered several similar topics, or whose results were too similar, so they do not provide new and valuable information compared to existing knowledge.

## Results: Model Applications and Case Studies

### Hungarian Sample

Regarding the AI1 predictive module's performance, it was trained using the XGBoost regression algorithm to predict resilience and employment life-cycle phases.

For the AI1 predictive module, we also calculated the RMSE, MAE, and  $R^2$  values. When comparing the model variants (ARIMA vs. LSTM), the indicators in *Table 2* illustrate the differences between the neural network and the linear model. Among the predictive models, the LSTM performed best: RMSE = 170, MAE = 13.80,  $R^2 = 0.89$ , while the ARIMA model showed RMSE = 220, MAE = 18.50,  $R^2 = 0.73$ .

Table 2  
Example of Model Fitting Indicators

Model	RMSE	MAE	$R^2$
LSTM	170	13.80	0.89
ARIMA	220	18.50	0.73

Source: author's compilation (2025)

The evaluation of the AI2 module (simulation) required a slightly different approach: here, we primarily examined the plausibility of the generated scenarios and assessed the credibility of the system's reactions, drawing on expert knowledge. We validated whether the simulation output was consistent with real observations: for example, the model should indicate changes in a direction similar to the effects of a given type of shock (be it an economic crisis or a natural disaster), as we saw in historical examples. We also performed a sensitivity analysis, i.e. we examined how much a minor modification of the input conditions (e.g. the extent of the GDP and demand decline, the intensity of the temperature increase) would change the output results, and whether these differences remained within a realistic range. An important requirement was that the predictive and simulation components were consistent: if we ran them with the same input parameters (e.g., a typical business environment), they should produce similar trends; if there was a difference, we performed further fine-tuning of the models. According to the SHAP analysis, the most important explanatory variables of the predictions were seasonality (SHAP=0.41), the most influential predictor, liquidity indicators (SHAP=0.33), an essential predictor of financial sustainability, and booking lead times (SHAP=0.29), which is critical information for tourism decision-makers, also due to the seasonal nature. So, these three factors influenced the forecast the most. These results help decision-makers to identify and manage key factors.

We assessed sustainability performance using a composite ESG index, which yielded an average score of 75/100, indicating that the sector achieves medium sustainability performance and has significant development potential in the environmental and social dimensions.

Based on more than 10000 runs of the Monte Carlo simulation, the expected deviation of tourism revenues was between  $\pm 12$ –18%, while at the P90 risk level, the chance of loss decreased to just under 10%. The average risk exposure index calculated by the RISKRES model was 0.60, while the resilience index was 0.80, indicating that tourism companies can recover relatively quickly after adverse market events. By analysing the characteristics of

each simulation cluster (e.g. mild vs. severe impact cases), we pointed out which system properties are responsible for similar outcomes – for example, it turned out that the scenario groups with the highest losses were characterised by low off-season demand and high labour costs. In contrast, the resilient groups typically had diversified revenue sources and a more flexible labour structure. These insights were part of the XAI approach, increasing the model's business value and acceptance among tourism decision-makers.

The testing of the corporate AI-EWS model was represented by the performance of the four ML models (logistic regression, decision tree, neural network, and random forest) (according to five criteria: accuracy, precision, recall, FI indicator, AUC), which reached or exceed 70%. However, the best result, and thus the highest efficiency, was given by random forest with an accuracy of 85%. So, the dual AI-based EWS system predicted critical financial events with an accuracy of 85%. The random forest model feature importance ranking is: 1. (Tourism) Seasonality index; 2. Liquidity ratio; 3. Booking lead times; 4. Average monthly income; 5. Debt/Total resources ratio; 6. Employee turnover. The SHAP study confirmed that the 1st-3rd magnitude/value is responsible for the explanatory part of the forecast; these are the most significant predictors, which is consistent with the international results of Tanaka et al. (2025).

### Qualitative Results:

#### Targeted Analysis of Case Studies

Within the qualitative methodological framework, a two case study analysis was conducted to compare the operation of the Double AI architecture across different urban environments. The examined cases include two cities: Barcelona and Dubai. The case study approach enables analytical generalisation, as the use of two cases in smart city research yields deeper insights and stronger conclusions than analysis of a single case. In each city, local socio-economic conditions, infrastructural characteristics, and regulatory contexts were taken into account, contributing to a comparative evaluation of Hungarian and European practices (Flyvbjerg, 2011). The processing of the two case studies follows a key characteristic – focus – outcomes logic.

#### Barcelona Case Study

**Key characteristic:** The Catalan example showcases a smart city tourism system in which the city administration utilises AI-powered IoT networks and chatbots.

**Focus:** One AI module is responsible for real-time traffic and crowd management, utilising predictive models based on IoT sensor data and social media data to provide dispatcher-level supervision for traffic management and event planning (e.g., forecasting visitor numbers for festivals and conferences). Another AI network is dedicated to personalising the visitor experience. Local cultural programs and tourist routes serve as a recommendation system, supplemented with real-time event and weather forecasts to shape the itinerary. Although such urban systems are less

common in the current literature, within the framework of the “Smart Tourism” concept, they offer significant advantages for sustainable tourism (Florido-Benítez, 2024).

**Outcome:** In practice, the dual AI algorithm ensures that data-driven prediction (predictive AI) and scenario simulation (decision-support AI) operate in sync: for example, if the number of pedestrians increases in a high-traffic zone, the first AI provides timely alerts, while the second simulates and offers alternative routes to visitors to avoid congestion. In parallel, the city of Barcelona has also provided targeted support for local SMEs to make AI accessible (e.g., a central data platform and pilot projects), thereby improving overall community well-being (Bakıcı et al., 2013; Barcelona Smart City, 2013).

In summary, the European example demonstrates that dual AI systems can be crucial components of urban tourism strategies. The combined use of AI-based customer experience platforms and predictive models can enhance visitor satisfaction and improve the municipality's operational efficiency.

#### Dubai Case Study

**Key characteristic:** Dubai's novel digital twin development is a complex network of virtual city models.

**Focus:** One AI module performs precision crisis simulations, analysing the likelihood of hypothetical emergencies (such as natural disasters and major traffic accidents) using Monte Carlo-based scenarios – an approach applied by Arbulú et al. (2021) to manage extreme uncertainty in the Balearic Islands.

**Outcome:** In the Dubai model, Monte Carlo simulations examined four different tourist return scenarios, considering, for example, travel restrictions and epidemiological measures (MBRSC, 2025ab). Another AI module runs real-time urban simulations: in a specific demo, the system calculated temporary traffic diversion rules in response to the closure of a major road, resulting in a 30% reduction in congestion in the surrounding streets (confirmed during live testing). In parallel, it generated crisis-management advice; for example, in preparation for extreme temperature conditions, the modelling AI developed unified thermodynamic strategies for air-conditioner use, resulting in a reduction of several tons of CO<sub>2</sub> emissions (again validated in real-world trials). The Dubai example also introduces a new platform for tourism services. With city reports accessible through avatars in virtual reality, visitors can extend their experience while the system continuously monitors safety risks. Here, dual AI enhances urban and tourism decision-making in an integrated manner: complementary AI tools facilitate more accurate demand forecasting and expedite crisis response, which is crucial for the sustainable growth and resilience of tourism (Arbulú et al., 2021; Luo et al., 2021).

Overall, the two cases and the Hungarian sample presented demonstrate that “dual AI” systems can enhance decision quality and crisis management effectiveness in the tourism industry, not only in theory, but also in practice.

*Table 3* summarises the main characteristics and KPI indicators of the three case studies.

Table 3

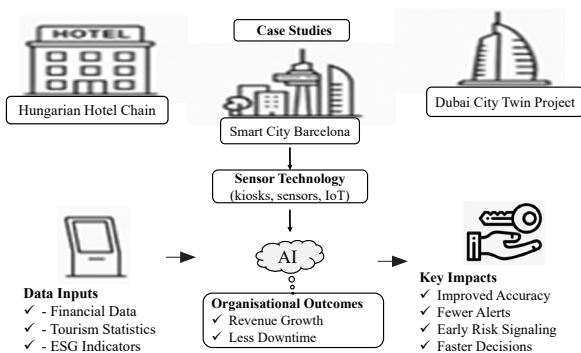
Main Characteristics, KPI Indicators of the Hungarian Sample and Two Case Studies

Case study	Type of AI	Data sources	Methods	Application	Main KPIs
Hungarian sample	Predictive +simulation AI	Booking data, weather, and economic indicators	Time series neural network, regression	Real-time alerts	Occupancy forecast accuracy, revenue, liquidity, and response time
Barcelona (smart city)	Chatbot + predictive analytics	Resident complaints, traffic data	Clustering, predictive models	Tourism service development	Tourist satisfaction, traffic regulation
Dubai (digital twin)	Digital twin + scenario simulation	IoT, public safety and visitor data	Simulation, time series AI	Virtual modeling and response	Emergency response time, tourism experience

Source: author's compilation (2025)

The process behind *Figure 5* is as follows: The kiosk's built-in sensors collect visitor data in real time, which is transmitted to a cloud-based tourism server. The AI module analyses the data using text and image processing, generating personalised dialogue and recommendations for the user. At the same time, the system supports the experience and safety with automatic traffic management and risk alert functions.

Figure 5  
Integrated Application of AI and IoT Technologies as the Architecture of a Smart Kiosk System



Source: author's compilation (2025) based on Suanpang & Pothipassa (2024, p. 13)

Based on the case studies covering three regions (CEE, EU, and global) presented in this study, the dual AI framework can significantly enhance the adaptive and resilient operations of tourism enterprises. In Barcelona, AI-based route planning and traffic regulation reduced tourist congestion by nearly 20%, while in Dubai, Monte Carlo-based simulations shortened infrastructure reaction time by 30%.

We have developed an intelligent risk management framework that includes

- automatic data collection (sensors, digital comments, financial KPIs),
- continuous forecasting (ML models for tourism demand, exchange rates, and liquidity),
- adaptive response actions for a successful turnaround.

A key principle of the framework is that it explicitly links digital business transformation (e.g., online services,

remote work) with strengthening corporate relational capital and resilience. Thus, it interprets digital transformation as a strategic stimulus that only leads to real resilience growth when paired with supporting cultural and organisational elements.

The key findings are as follows:

- Urban services: in the case of Barcelona and Dubai, AI chatbots and digital twin systems brought significant improvements in tourist flow management and visitor satisfaction.
- AI application and resilience: the AI is a catalyst for tourism efficiency and sustainability. However, ethical and transparent practices, FATES (*Fairness, Accountability, Transparency, Ethics, Sustainability*) principles are crucial for building trust.
- Support for SMEs: due to resource challenges among smaller tourism actors, targeted support, training, and financing are necessary for them to benefit from AI technologies.
- Financial resilience refers to a firm's ability to maintain revenues, liquidity and stable financial planning in crises. Modern AI-driven forecasting tools play a critical role here. A Hungarian sample found that an LSTM-based demand-forecast model produced 23–25% more accurate occupancy predictions than a traditional ARIMA model (*Table 2*). This precision directly translated into several million HUF in extra revenue and cost savings. In practice, such improved forecasts allow companies to optimise pricing and inventory, immediately detect shortfalls, and adjust budgets before emergencies hit.
- Operational resilience means keeping day-to-day services and processes running smoothly and reacting quickly when disruptions occur. Dual-AI systems enable this by processing real-time data and running “what-if” simulations of operational stress. For instance, the study found that AI-assisted traffic management in Barcelona cut tourist crowding by ~20%, and a Monte Carlo-based infrastructure model in Dubai improved response time by 30%.
- Digital resilience covers the security and robustness of a company's IT and data systems. How well can an organisation survive and quickly recover from an IT crisis or data security incident? Ghaderi et al. (2024), OECD (2024ab) and the Hungarian questionnaire recommend leveraging AI for early-warning and

decision-support tools in tourism. AI-driven alert systems can flag anomalies (e.g. unusual network activity or weather patterns) and suggest mitigation actions, thereby increasing the sector’s resilience to climate or pandemic shocks.

The synthesis of the literature and the qualitative interpretation of the case studies reinforce the empirical findings. The most advanced tourism technologies – generative AI, IoT, Big Data analytics, and intelligent infrastructure – collectively strengthen the risk resilience and capacity of destinations and companies. The introduction of AI-based systems has significantly catalysed the growth of sustainable tourism in the most important destinations. However, we emphasise that AI alone is not enough: transparent, ethical application and social responsibility are essential. Blunk et al. (2025) emphasise that AI-driven EWS systems must adhere to the FATES principles to deliver fair and reliable solutions for all stakeholders.

Among the qualitative results, the importance of stakeholder cooperation also stands out: in all three cases, business leaders, local governments, tourism clusters, and SMEs needed to collaborate on system development. This approach ensured that AI applications served both business goals and community interests simultaneously. We also observed that smaller tourism players require support. Tourism SMEs struggle to keep up with AI developments due to resource constraints; they require dedicated policy measures, education, and financial support.

Overall, our conclusions suggest that adopting a dual AI strategy simultaneously increases the security of company operations and systemic resilience. While resulting in new, more efficient services and operating models, it also makes risk management more proactive and supports the sustainability of the tourism industry. Nevertheless, challenges remain in forecasting threats, risk communication, and decision-making. For forecasting threats, the

EWS provides appropriate alerts. The accuracy and effectiveness of the EWS depend not only on the quality of data collected by sensors, the understanding of processes, and the ability to forecast hazards and assess their potential impact, but also on the speed and effectiveness of communication, and the ability to make timely and effective decisions.

Figure 6 illustrates the early warning chain from observation to decision and its connection to the framework for “early warnings for all” (Reichstein et al., 2024).

This study contributes to the literature by presenting an integrated methodology that enables the combined application of ARIMA, LSTM, Monte Carlo, and ABM models, thereby establishing enterprise-level, AI-driven EWS in smart tourism.

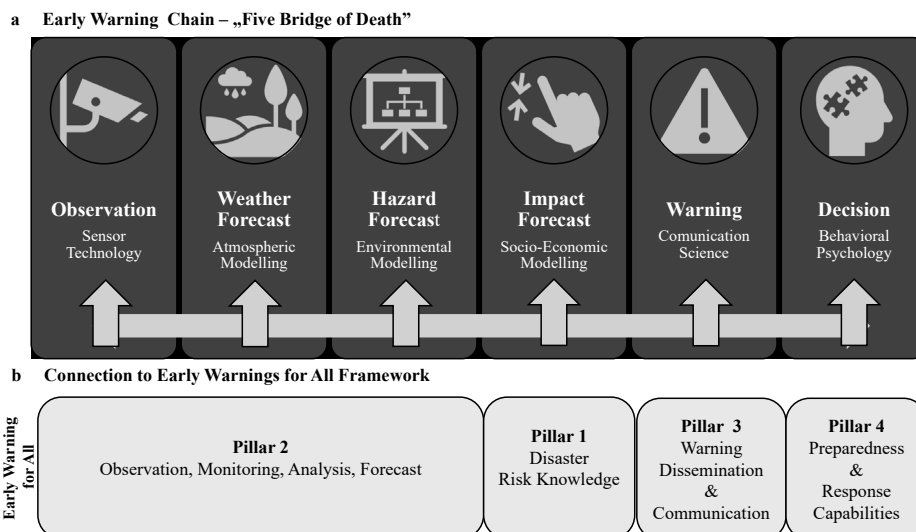
Overall, the scientifically sound combination of models in the dual AI-driven approach enables business decision-makers to increase their risk resilience. Based on historical time-series data, these models adaptively learn from past patterns, while simulation components test hypothetical future scenarios that directly inform crisis management strategies.

**Future Research Directions and Practical Recommendations**

An interesting research direction may be to compare different destination types (e.g., urban vs. rural, developed vs. developing regions) to examine where AI tools have the most significant impact and which local factors influence success. The long-term effects, especially in the context of multiple crises (“polycrisis”), are also worth studying: Are companies becoming dependent on AI forecasts? Can AI adaptively learn from crises and help prepare for future shocks? In addition, the impact on the tourism workforce and the necessary new qualification profiles should also be examined: How AI reshapes labour needs? What new roles emerge (e.g., AI data curator, data economist)? What

Figure 6

**Illustration of the Early Warning Chain from Observation to Decision**



Source: author’s compilation based on Reichstein et al. (2024, p. 2)

training strategies can help workers integrate into the new technology? Examining the legal and ethical frameworks is also important, as it involves implementing the FATES principles in practice, regulating data use, and addressing questions of responsibility (for example, who is liable if the AI recommends a poor crisis-management decision).

The application of synthetic data in tourism also requires further analysis. For example, the use of generative models to produce realistic tourist profiles or simulate rare events (such as festivals or disasters) could enhance the preparedness of predictive systems. Such experiments can reveal the extent to which synthetic data contributes to model performance and, where possible, where deviations occur compared to real data.

Based on the research, we also formulate practical recommendations for actors in the tourism sector. First, it is advisable to launch pilot projects to test AI solutions on a small scale, in a modular development approach, so organisations can gather experience and iteratively refine their systems. Sectoral and cross-sectoral cooperation must be strengthened by involving universities, startups, and competitors in the creation of shared data consortia or platforms, as knowledge and data sharing bring mutual benefits in AI. The human factor should also be a focus, with ongoing staff training, the development of AI skills, and strengthening digital culture being essential to dispel fears and resistance. Introducing technologies to the public is also crucial. For example, if a city installs sensors and uses AI for crowd management, the benefits and the data collected should be communicated to tourists and residents to build public trust.

We formulate three recommendations for enterprises and policymakers

1. for SMEs, it is necessary to support open-source predictive and simulation AI tools,
2. tourism development strategies should place special emphasis on the area of digital twins and AI-based crisis planning,
3. AI-driven platform-based services should be encouraged, especially in tourism, focusing on the involvement of local communities.

## Summary

The double AI architecture represents a hierarchically organised system comprising two components: the first AI module (AI1) makes forecasts, and the second AI module (AI2) runs simulations based on them to investigate possible outcomes. The two layers work together continuously and cyclically: the inputs provided by AI1 are processed by AI2, which feeds back into the system, enabling iterative learning and model improvement. The essence of this layered solution is that, by combining ML (data-driven prediction) and simulation (scenario generation) techniques, complex risk scenarios can be tested, thereby increasing the model's flexibility and realism.

The IRM theoretical and methodological framework ensured that the research was grounded in both theory and practice. The dual AI system innovatively combines

predictive analytics and simulation to enable the prediction and management of employment, seasonality, and ESG-based risks in tourism within an integrated model. This framework was supported by a large-scale empirical study of domestic tourist regions, which guarantees that the results are both scientifically sound and practically applicable.

- We have developed an IRM framework that includes
- automatic data collection (sensors, digital comments, financial KPIs),
  - continuous forecasting (ML models for tourism demand, exchange rates, and liquidity),
  - adaptive response actions for a successful turnaround.

A key principle of the framework is that it explicitly links digital business transformation (e.g., online services, remote work) with strengthening corporate relational capital and resilience. Thus, it interprets digital transformation as a strategic stimulus that only leads to real resilience growth when paired with supporting cultural and organisational elements.

We emphasise the special application of data science methods in tourism. We have developed a measurement system that considers not only financial results (such as revenue and occupancy) but also a range of sustainability and customer-loyalty indicators.

It is imperative to emphasise that the integrity of corporate strategy is crucial: a double-AI application requires strong management commitment, effective financial planning, and effective human resource development. Based on the results, we recommend that tourism enterprises always support their AI projects with comprehensive risk and impact assessments. They should consider their partners' needs and the local ecosystem, and adapt their processes to align with broader strategies.

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# MOODLE – AN INFORMATION SYSTEM SUCCESS VIEW

## A MOODLE ÉRTÉKELÉSE INFORMÁCIÓS RENDSZERKÉNT

Digitalisation has become essential for higher education institutions. Sustaining complex information systems must enable faster, more convenient administration while also improving learning outcomes. Understanding the users' opinions can make a relevant contribution to developing these systems. The study focuses on students' opinions of Moodle, a popular virtual learning environment at universities. The framework model is based on the DeLone and McLean Model of Information Systems Success; the analysis used the PLS-SEM method. A non-representative sample of 309 students was available from various universities in Hungary. The results reveal that the benefits of Moodle can be derived from the information provided by the system and the satisfaction of the users. The information success approach to Moodle offers a new perspective on decisions on digitalisation improvements in higher education. Extending the model to other systems may offer a comprehensive evaluation framework.

**Keywords:** Moodle, digitalisation, PLS-SEM, DeLone-McLean IS Success Model

A digitalizáció a felsőoktatási intézmények számára nélkülözhetlenné vált. A komplex információs rendszerek a gyorsabb és kényelmesebb ügyintézésért szolgálnak, valamint hozzájárulnak az tanulási eredmények javításához. A felhasználói véleményének vizsgálata jelentősen hozzájárulhat a rendszerek fejlesztéséhez. A tanulmány a hallgatók véleményét vizsgálja a Moodle rendszerrel kapcsolatban, amely az egyetemeken körében elterjedt virtuális tanulási környezet. A keretmodell a DeLone-McLean információs rendszer sikermodellre épült, az elemzés PLS-SEM-módszert használt. A kutatáshoz 309 hallgatóból álló, nem reprezentatív minta állt rendelkezésre különböző magyarországi egyetemekről. Az eredmények azt mutatják, hogy a Moodle előnyei a rendszer által nyújtott minőségi információkból és a felhasználók elégedettségéből vezethetők le. A Moodle-nak információs rendszerként történő értelmezése és sikerességének vizsgálata új perspektívát kínál a felsőoktatás digitalizációs fejlesztéseivel kapcsolatos döntésekhez, a modell kiterjesztése más rendszerekre pedig átfogó értékelési keretet nyújthat.

**Kulcsszavak:** Moodle, digitalizáció, PLS-SEM, DeLone és McLean IS-sikermodell

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### Authors/Szerzők:

Dr. László Berényi<sup>a</sup> (laszlo.berenyi@uni-miskolc.hu) associate professor (<https://orcid.org/0000-0003-0596-9315>);  
Dr. Nikolett Deutsch<sup>b</sup> (nikolett.deutsch@uni-corvinus.hu) professor (<https://orcid.org/0000-0002-0637-2409>)

<sup>a</sup>University of Miskolc (Miskolci Egyetem) Hungary (Magyarország); <sup>b</sup>Corvinus University of Budapest (Budapesti Corvinus Egyetem) Hungary (Magyarország)

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Digitalization is no longer a vision or the objective of strategies to take the first steps. This phenomenon permeates our everyday activities, including communication, public administration, shopping, and learning. According to the interpretation of quality as achieving customer satisfaction (Berényi, 2023), the challenge lies in the efficient and effective utilization of digitalization. It is a key element of organizational viability and survival (Hess et al., 2020). The rapidly changing world is both a consequence and an engine of digital development: the development of new technologies, procedures, and products has been accelerated. Statistics show that the essential conditions of the digital world are available in the 21<sup>st</sup> century. Access to tools and systems, especially the Internet, does not indicate a barrier; the fact that over 90% of people in the EU used the Internet at least once a week in 2023 (Eurostat, 2024) suggests the availability of the technical background as well.

Nevertheless, the bottleneck of the system is human. Eurostat published that 44% of the EU citizens – within that 41% of Hungarians – lack basic digital skills. It is beyond debate that digital disruption must be managed (Skog et al., 2018). Complex sociotechnical systems are affected by the changes, and the time is limited to analyze the causality and develop appropriate measures because the technologies are rapidly evolving. The sociotechnical network of digital technologies and actors (Kallinikos et al., 2013; Adomavicius et al., 2008) covers different generations, purposes, readiness levels, tools, and software working together.

Still, understanding the relations is an essential information source, but a comprehensive overview goes far beyond one study. Review attempts (Halász, 2024) and local case studies with a narrower scope can contribute to the knowledge base and offer lessons learned to decision-makers, including teachers, instructors, IT staff, and university management at any level.

Digitalization of (higher) education (Bowen, 2015) is a complex task in itself. Controlling and administration systems, mailing or file sharing, have been continuously developed in recent decades, as well as learning administration and the digital support of learning. Adaptability to the accelerated digital world and the growing availability of info-communication tools led to new education models (Cobb, 2013). Recently, there are two issues with an apparent impact on the progress. First, the mainstream is about the emerging role of artificial intelligence in communication, problem-solving, and learning (Crompton & Burke, 2023; Bácsi & Dén-Nagy, 2024). However, the maturity of the solutions and the regulations are in question. Despite the visible impacts, the investigations should not focus only on this topic. Second, the COVID-19 lockdown generated several immediate changes and spectacular impacts on every aspect of life (Szabó et al., 2022). The situation drew attention to the need for rethinking higher education (Ewing, 2021). However, the reordering after the lockdown period (László et al., 2024) confirmed that maybe the virus was not the turning point. Rethinking the ownership and financial background of universities in Hungary

appeared at that time, but its purpose is not investigated in that paper. Silva et al. (2022) noted visible changes in teaching emerging with the lockdown, but there was ambiguity and disagreement about the workload, content, and methods. The digitalization of higher education has a longer and slower history (Benedek, 2008) than the COVID-19 lockdown; there were numerous attempts and sometimes unclear answers. Bygstad et al. (2022) call dual digitalization in higher education digitalization of education and digitalization of subjects.

The study scope is limited to the Moodle (Modular Object-Oriented Dynamic Learning Environment) system, which is a significant ingredient in the digitalization of higher education. It offers an online learning environment that supports renewing the relations between the students, teachers, and learning materials. It can replace or extend the traditional learning methods. Studies are available about the acceptance of Moodle (Sabeh et al., 2021; Mustafa & Ali, 2023), especially focusing on students' personal attitudes and the influencing factors of use. Popular framework models for researchers are the different and modified versions of the Technology Acceptance Model (TAM) by Davis (1989) and the Unified Theory of Acceptance and Use of Technology (UTAUT) model by Venkatesh et al. (2003), but not limited to them (Gamage et al., 2022). In addition to survey attitudes and satisfaction (Berényi et al., 2021; Berényi & László, 2023; Berényi & László, 2024), our study offers a new perspective with an information system approach to Moodle. A pilot survey was performed among students, and we plan to extend it to other domains and stakeholders.

A PLS-SEM model was developed based on the DeLone and McLean Model for Information Systems Success (DeLone & McLean, 2003) to explore the factors that influence Moodle use and satisfaction among students. The results contribute to a better understanding of the driving forces of digitalization and, through this, develop strategies for effective higher education digitalization.

The remaining sections of the paper are organized as follows. Before setting the research goals, a justification is presented for why Moodle can be considered an information system. The description and validation of the research framework model are followed by the results and discussion. The conclusions section includes the methodological and practical implications and the limitations of the study.

## Moodle as an information system

Various computer- and IT-supported solutions have emerged to enhance education and learning over the past 40 years. Among them, not the only one but certainly a widely known tool is Moodle (Modular Object-Oriented Dynamic Learning Environment), introduced in 2002. It is an open-access, multipurpose, and multifaceted Course Management System (CMS). Moodle is ready to run full online courses, but its popularity may be derived from the opportunity that it is a great way to supplement face-to-face teaching in the large and growing higher education market (Bența et al., 2015).

Above all, it must be noted that there is still a huge diversity of terminology in the field. Tóth and Bessenyei (2008) designated platforms in e-learning as Virtual Learning Environments (VLE). The evolution of these environments was a continuous process. The first versions served as static storage places for digital or digitalized learning materials; newer ones included communication forms, tests and surveys, monitoring tools, and customization opportunities utilizing new technologies. The authors pointed to other titles and approaches, such as Learning Management System (LMS), Learning Content Management System (LCMS), Learning Platform (LP), Managed Learning Environment (MLE), and Learning Support System (LSS). These names emphasize different purposes of analysis, which may be essential in some situations, especially in understanding the intentions of how Moodle will be implemented in the university system. Selim (2017) drew instructor, student, information technology, and university support as key factors in the success and acceptance of e-learning systems. The different names of the learning environment essentially reflect the idea of which of these factors are at a greater prominence. At the same time, that is not relevant to our study because the related university systems are out of the study's scope. We consider Moodle an information system that must serve any purpose given to it by the universities, teachers, and students.

Laudon and Laudon (2022, p. 46) defined an information system "as a set of interrelated components that collect (or retrieve), process, store, and distribute information to support decision making and control in an organization. In addition to supporting decision making, coordination, and control, information systems may also help managers and workers analyze problems, visualize complex subjects, and create new products". Moodle meets all requirements of the definition:

- it is software with different modules, functions, and features,
- it collects, stores, and distributes information, however, in an asymmetric way: learning materials from teachers (the main representatives of the manager), and survey responses, using information from students (workers),
- control takes the forms of learning progress, presence, and activities,
- Individual and mass information about using support development actions.

The technology provided by the system helps to organize, manage, and deliver course materials, including creative elements and multimedia tools (Martín-Blas et al., 2009).

The reason for the information system approach to Moodle can be derived from quality assurance. Customer/user satisfaction with the system and attitudes to use intentions are valuable information sources to define goals and expectations, as well as measures of meeting them. The large number of features and the different use levels, even within a given organization, make it difficult to compare the individual evaluations. Although Moodle is free software with a broad and supportive network to assist with

the installation and use, serious efforts are required from the universities to use it effectively. Beyond ensuring the IT background, resources are required for maintenance, system administration, content development, and user training. Assuming that the universities take these efforts to improve the success of the learning process, besides accepting that teachers' skills and approaches may lead to various course structures and toolsets used within Moodle, a higher-level model, such as the information system approach to Moodle, can provide helpful information.

## Research goals and methods

The study aims to support the successful digitalization of higher education through developing a measurement model. An effective learning management system is not exclusive but an important element of this. Understanding the factors that influence effective use and user satisfaction with Moodle can contribute to organizational actions to maximize the benefits. Since information systems play an integrative role in the process, the study accepts this approach. The goal is to learn students' opinions about the quality of Moodle and its usability. There are three research questions formulated:

- RQ1: What is the students' opinion about the Moodle system?
- RQ2: Can the perceived benefits of the Moodle system be explained using a system quality approach?
- RQ3: Are there differences in the perception of the Moodle system by universities, study level, or study form?

An online survey was developed and distributed among higher education students. Grouping factors included gender, university, study level (bachelor or master), and study form (full-time or part-time). Most questions are statements organized in line with the factors of the information system success model by DeLone and McLean (2003). A 7-point scale assessment was used between 'I do not agree at all' and 'I totally agree'. Additionally, open-ended questions were included to ask respondents about what they like and dislike about Moodle.

Beyond the descriptives about the students' opinions (RQ1), the survey was designed to establish a structural equation model (RQ2) with moderating effects (RQ3).

Data processing and analysis were performed with Microsoft Excel, IBM SPSS version 29, and SmartPLS version 4.1.0.9 software based on the guidance of Sajtos and Mitev (2007), Hair et al. (2022), and Ringle et al. (2024). The path model was designed for PLS-SEM analysis with a reflective measurement model. Bootstrapping analysis was performed using 5,000 subsamples with the bias-corrected and accelerated (BCa) method. The significance level is 0.05 for each analysis in the study.

## Research model development

In search of management information system success factors, DeLone and McLean (1992) made a taxonomy review

of former studies. Their recognition that ‘as many measures as studies’ made an urgent need for a comprehensive framework in the age when personal computers and networks were emerging. The synthesis defined system quality, information quality, use, user satisfaction, individual impact, and organizational impact. A benefit of the model is that path analysis is allowed along with the relations between the factors. A ten-year update of the model was published in 2003 (DeLone & McLean, 2003), taking into account the experience gained from validation and the changing environment. The new model uses net benefits instead of individual and organizational impacts and incorporates service quality. Dealing with ‘intention to use’ allows the measurement of voluntariness of use if applicable. The flexibility and diversity in use in the field of e-learning are underlined by Sabeh et al. (2021), who identified several additional success factors added to the DeLone and McLean information system success model; some of these are known from acceptance and behavior models (e.g., ease of use, task-technology fit model elements, self-efficacy), others incorporate learning material content quality, social motivations, communality or evaluation of the teachers.

Our research model is based on the second edition of the model (DeLone & McLean, 2003):

- system quality: usability, reliability, and response time,
- information quality: concise, relevant, and accurate outcomes,

- service quality: quality of support,
- use: frequency of use,
- satisfaction: customers’ opinions,
- benefits: contribution to success.

The ‘intention to use’ is dropped from the model since the use of Moodle is not a choice of the target audience. According to the requirements of PLS-SEM analysis, loops are not allowed in the model (Hair et al., 2022). The original model suggests a bidirectional relation between intention to use/use and satisfaction. The research model selected the path direction from ‘Satisfaction’ to ‘Use’.

Research hypotheses were formulated along the research framework model in Figure 1:

- H1a: Information quality has a positive impact on Moodle use.
- H1b: Information quality has a positive impact on satisfaction with Moodle.
- H2a: System quality has a positive impact on Moodle use.
- H2b: System quality has a positive impact on satisfaction with Moodle.
- H3a: Service quality has a positive impact on Moodle use.
- H3b: Service quality has a positive impact on satisfaction with Moodle.

Table 1

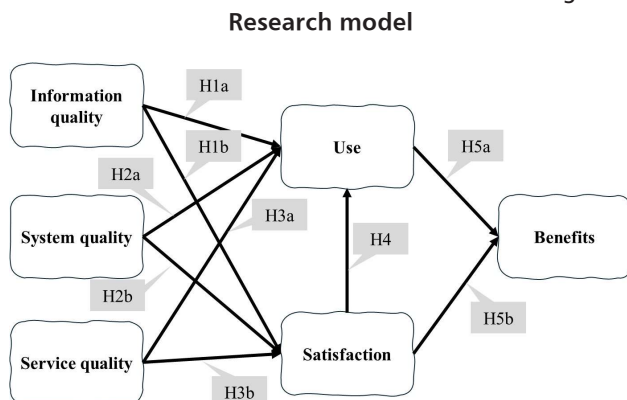
Latent variable constructs and related survey items

Category (Construct)	Question (Item)	Short name
Information quality	The content and information available in Moodle is up-to-date.	IQ1
	The content and information available in Moodle are useful and easy to understand.	IQ2
	Information from Moodle is in a form that is readily useable.	IQ3
	The content and information available in Moodle can be relied upon.	IQ4
System Quality	Moodle is always available for me to perform learning activities. (dropped)	SQ1
	The response time of Moodle is reasonable.	SQ2
	Moodle has attractive features to appeal to the users.	SQ3
	Moodle provides interactive communication between teacher and students. (dropped)	SQ4
	Moodle is user-friendly.	SQ5
Service Quality	The IT services staff understands the specific needs of students.	SeQ1
	I receive a satisfactory and timely response from the IT services staff. (dropped)	SeQ2
	The IT services staff is available and cooperative when facing an error at Moodle.	SeQ3
	Moodle provides proper online assistance and help.	SeQ4
Use	I log into Moodle frequently.	USE1
	I use many functions and features in Moodle.	USE2
	I spend a lot of time in Moodle during study term period.	USE3
	I spend a lot of time in Moodle during exam period.	USE4
Satisfaction	I am satisfied with the content of the Moodle system.	SAT1
	I enjoy using Moodle in my study.	SAT2
	I am satisfied with surface design of the Moodle.	SAT3
	I am satisfied with the instructions on how to use the Moodle e-learning system.	SAT4
	Overall, I am satisfied with Moodle e-learning system.	SAT5
Benefits	Moodle helps me to save time and efforts.	BEN1
	Moodle helps me to follow the course material better.	BEN2
	Using Moodle improves my learning performance.	BEN3
	Using Moodle is a good choice at the university level.	BEN4

Source: own edition

- H4: Satisfaction with Moodle has a positive impact on use.
- H5a: Use has a positive impact on benefits of Moodle.
- H5b: Satisfaction has a positive impact on benefits of Moodle.

Figure 1



Source: own edition

The questions (items) by the categories (constructs, latent variables) are presented in Table 1, including the short names used in the remaining parts of the paper.

To improve the model validity, some items were dropped from the PLS-SEM model due to low and insignificant factor loadings and the negative impacts on model fit.

A critical variable in the measurement is system use for two reasons. Due to the multipurpose application and the broad range of features, no single task can be highlighted in the questionnaire. The frequency of visits, the time spent in the system, and the range of functions used are compromise indicators. Additionally, information about use is based on the user’s self-assessment. Moving beyond the pilot phase, it is worth noting that data deriving from the system log database if its legal conditions can be assured. Another option is to test the correlation between the self-assessment and the log file information in a subset of samples to validate the methodology.

### Research sample

The research sample consists of 309 responses from Hungarian higher education students from different universities. The representativeness of the sample is not assured; we consider the results a pilot study. The research sample is derived from a broader, multipurpose data collection on technology acceptance and digitalization conducted in 2024. 395 responses were collected, but a data cleaning must have been performed to filter for incorrect completions. Cases where the standard deviation of the responses was low have been excluded, as these may indicate the probability of respondent misconduct. The standard deviation of the responses was checked by latent variable constructs, and the case was excluded if the response showed no dispersion in more than two cases. Sample characteristics are summarized in Table 2. It is worth noting that the university names have been replaced with codes in the study to avoid undesirable comparisons based on a non-representative, convenient sample.

Table 2

Sample characteristics

Grouping factor	Option	Frequency	Percent
Gender	female	194	62.8%
	male	115	37.2%
University	A	130	42.1%
	B	85	27.5%
	C	69	22.3%
	D	25	8.1%
Study level	higher vocational training	30	9.7%
	bachelor	180	58.3%
	master	99	32.0%
Study form	full-time	225	72.8%
	part-time	84	27.2%

Source: own edition

### Validation of the research model

The validation of the measurement model followed the guide and threshold values of Hair et al. (2022) for reflective measurement models. The study presents the results of the final model, i.e., after excluding items where the indicator reliability was not met (outer loading < 0.708) and deleting the item improved content validity. The standardized root mean square residual (SRMR) indicators suggest an acceptable model fit for the saturated and the estimated model; the values are 0.078 and 0.080, respectively. Other indices of the saturated model are  $d_{ULS} = 0.661$ ,  $d_G = 0.519$ , and  $\chi^2 = 936.639$ . The indices of the estimated model are  $d_{ULS} = 0.1,759$ ,  $d_G = 0.530$ , and  $\chi^2 = 947.656$ . (NFI) does not meet the minimum threshold value of 0.90; the results are 0.778 for the saturated and 0.775 for the estimated model. However, model fit measures are broadly available for CB-SEM models; these are not transferrable to PLS-SEM models, the statistical approach is validated differently (Hair et al., 2017), more and more solutions are emerging. High  $d_{ULS}$  and low NFI are cautious, but these are due to the relatively low sample size of this pilot study. That assumption can be verified later by extending the investigations.

Internal consistency indices are summarized in Table 3. Cronbach’s alpha values are satisfactory (between 0.7 and 0.90),  $\rho_a$  values are between 0.60 and 0.90, and AVE values are greater than 0.5 for each construct (Hair et al., 2022).

Table 3

Internal consistency indicators

	Cronbach’s alpha	CR ( $\rho_a$ )	CR ( $\rho_c$ )	AVE
IQ	0.811	0.815	0.876	0.640
SQ	0.756	0.767	0.859	0.671
SeQ	0.743	0.884	0.839	0.636
SAT	0.875	0.887	0.909	0.667
USE	0.822	0.827	0.883	0.654
BEN	0.876	0.886	0.915	0.729

Source: based on SmartPLS output

No collinearity issues were found; the variance inflation factor (VIF) values ranged from 1.296 (SeQ4) to 2.588 (SAT1), all of which are below the critical value of 5 (Hair et al., 2022). VIF values are presented in the results section (Table 6), along with the descriptive statistics.

Table 4

## Results of Fornell-Larcker analysis

	BEN	IQ	SAT	SQ	SeQ	USE
BEN	0.854					
IQ	0.617	0.800				
SAT	0.736	0.722	0.817			
SQ	0.580	0.675	0.687	0.819		
SeQ	0.522	0.585	0.564	0.535	0.798	
USE	0.529	0.352	0.504	0.324	0.363	0.809

Source: based on SmartPLS output

Table 5

## Results of HTMT analysis

	BEN	IQ	SAT	SQ	SeQ
IQ	0.727				
SAT	0.818	0.847			
SQ	0.697	0.847	0.832		
SeQ	0.593	0.697	0.625	0.648	
USE	0.618	0.428	0.575	0.408	0.398

Source: based on SmartPLS output

The discriminant validity of the model was tested using the Fornell-Larcker criterion (Fornell & Larcker, 1981). The model is acceptable since the square root of AVE values in the diagonal of Table 4 exceeds the correlations with other constructs for each construct.

Another related test (Table 5) is the heterotrait-monotrait ratio (HTMT). The values are lower than the threshold value of 0.90, which confirms the discriminant validity of the model (Henseler et al., 2015).

## Results

## Descriptive statistics of the measurement model

The mean values of the items in the survey show above medium values, but the standard deviation is high, which suggests a diversity of perception (Table 6). The lowest values belong to 'Service quality' and 'Use'. The students are less satisfied with staff support (SeQ1 and SeQ3) than online assistance and help (SeQ4). However, the mean value (M=4.680) in the case of USE2 item about using many functions and features of Moodle is not an extreme outlier; it is apparently lower than other values within 'Use'.

## Path coefficients and determination

The explanatory power ( $R^2$ ) of the structural model is considered moderate (Hair et al., 2022), the constructs can explain 57.6% of the variation of 'Benefits', 60.8% of 'Satisfaction'. According to 'Use', the  $R^2 = 26.8\%$  value is low. Since the use of the system is not a choice of the

Table 6

## Descriptive statistics and VIF values

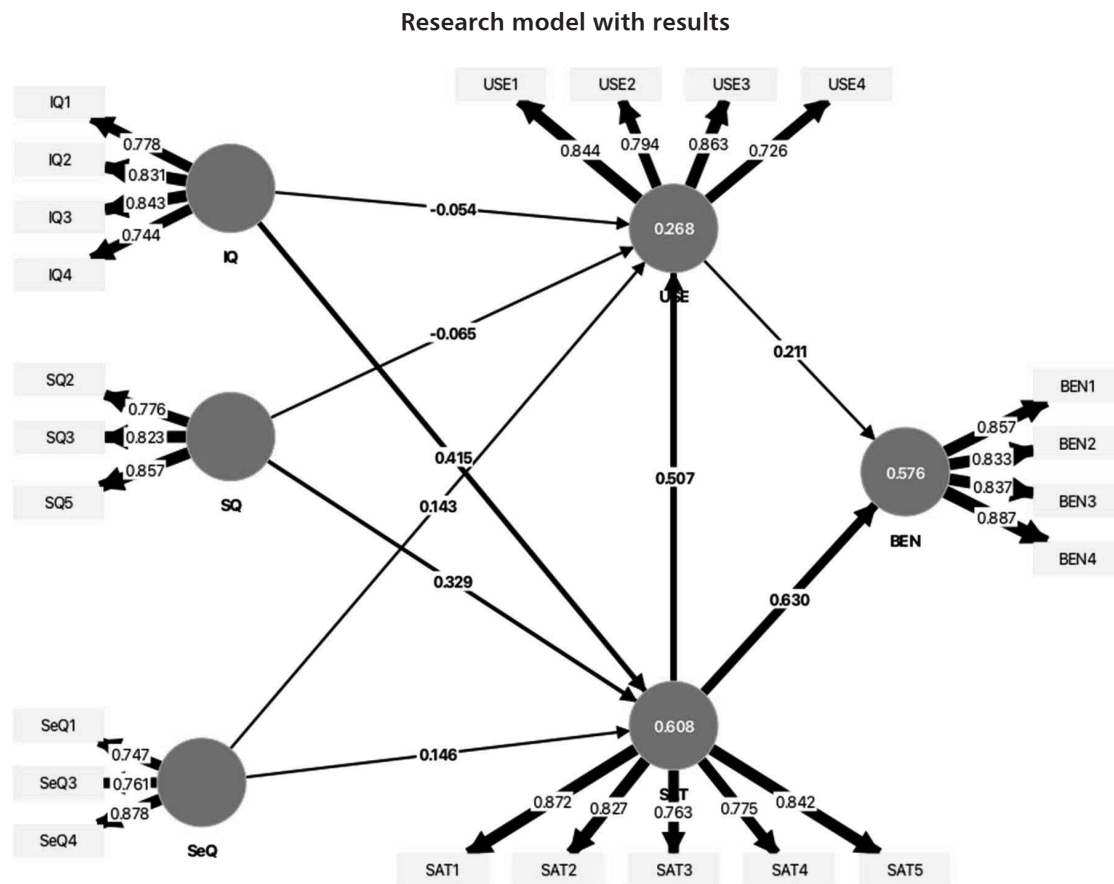
	Mean	Median	Standard deviation	Excess kurtosis	Skewness	VIF
IQ1	5.217	5	1.169	0.254	-0.649	1.550
IQ2	5.689	6	1.002	0.269	-0.684	2.038
IQ3	5.560	6	1.049	1.210	-0.869	2.165
IQ4	5.612	6	1.026	2.202	-1.044	1.481
SQ2	5.424	6	1.246	0.831	-0.855	1.501
SQ3	5.304	5	1.259	1.062	-0.913	1.459
SQ5	5.528	6	1.119	0.362	-0.689	1.697
SeQ1	4.269	4	1.092	0.574	0.005	1.674
SeQ3	4.553	4	1.135	0.561	0.367	1.736
SeQ4	5.049	5	1.118	0.633	-0.459	1.296
USE1	5.631	6	1.396	1.031	-1.137	2.194
USE2	4.680	5	1.409	-0.116	-0.492	1.610
USE3	5.563	6	1.312	0.888	-1.002	2.232
USE4	5.537	6	1.325	0.497	-0.831	1.441
SAT1	5.453	6	1.077	1.554	-0.932	2.588
SAT2	5.592	6	1.197	1.117	-0.936	1.965
SAT3	5.427	6	1.362	1.015	-0.992	1.768
SAT4	5.120	5	1.224	0.389	-0.688	1.883
SAT5	5.712	6	1.051	1.217	-0.932	2.178
BEN1	5.366	5	1.292	0.188	-0.688	2.350
BEN2	5.728	6	1.105	2.238	-1.182	2.008
BEN3	5.388	5	1.256	1.178	-0.863	2.184
BEN4	5.806	6	1.089	2.606	-1.240	2.431

Source: based on SmartPLS output

students, a low value was expected. The results are summarized in Figure 2, including the loadings of the constructs, path coefficients, and R<sup>2</sup> values.

the same time, ‘Service quality’ positively impacts ‘Use’. The most important driver for ‘Satisfaction’ is ‘Information quality’ (β=0.415).

Figure 2



Source: SmartPLS output

Table 7

Path Coefficients and decision on the hypotheses

	Original sample β	Sample mean β	Standard deviation	t	p	Related hypothesis evaluation
IQ -> USE	-0.054	-0.053	0.081	0.668	0.504	H1a rejected
IQ -> SAT	0.415	0.416	0.049	8.414	0.000	H1b supported
SQ -> USE	-0.065	-0.065	0.078	0.831	0.406	H2a rejected
SQ -> SAT	0.329	0.325	0.064	5.157	0.000	H2b supported
SeQ -> USE	0.143	0.144	0.060	2.363	0.018	H3a supported
SeQ -> SAT	0.146	0.151	0.052	2.802	0.005	H3b supported
SAT -> USE	0.507	0.507	0.081	6.265	0.000	H4 supported
SAT -> BEN	0.630	0.630	0.035	18.124	0.000	H5b supported
USE -> BEN	0.211	0.212	0.044	4.754	0.000	H5a supported

Source: based on SmartPLS output

The hypotheses of the study are related to the path coefficients of the PLS-SEM model. The bootstrapping analysis results are presented in Table 7. The result revealed exogenous constructs of the DeLone and McLean Model of Information Systems Success as ‘Information quality’, ‘System quality’, and ‘Service quality’ have a significant positive impact on ‘Satisfaction’, while ‘Information quality’ and ‘System quality’ do not have an impact on ‘Use’. At

Satisfaction is the most important driver for ‘Use’ (β=0.507) and ‘Benefits’ (β=0.630). ‘Benefits’ are retrieved to a lower extent from ‘Use’ (β=0.211). The path coefficient value of 0.507 between ‘Satisfaction’ and ‘Use’ is significant and among the higher ones in the model. We made a model run with an inverse link to test the relations. In that model, the path coefficient from ‘Use’ to ‘Satisfaction’ was 0.380 (t=5.767, p=0.000). That confirms that ‘Satisfaction’ impacts ‘Use’ more than the other way.

The total effects (Table 8) are significant, except for the case between ‘System Quality’ and ‘Use’, and most of the indirect effects (Table 9) are also significant.

### Moderating effects

The distributions of responses to survey questions are typically right-skewed, which suggests high confidence and

Table 8

#### Total effects

	Original sample	Sample mean	Standard deviation	t	p
IQ -> BEN	0.294	0.295	0.043	6.837	0.000
IQ -> SAT	0.415	0.416	0.049	8.414	0.000
IQ -> USE	0.156	0.158	0.077	2.028	0.043
SAT -> BEN	0.737	0.737	0.031	23.939	0.000
SAT -> USE	0.507	0.507	0.081	6.265	0.000
SQ -> BEN	0.229	0.227	0.049	4.644	0.000
SQ -> SAT	0.329	0.325	0.064	5.157	0.000
SQ -> USE	0.102	0.100	0.077	1.323	0.186
SeQ -> BEN	0.138	0.141	0.039	3.573	0.000
SeQ -> SAT	0.146	0.151	0.052	2.802	0.005
SeQ -> USE	0.217	0.220	0.062	3.494	0.000
USE -> BEN	0.211	0.212	0.044	4.754	0.000

Source: based on SmartPLS output

Table 9

#### Indirect effects

	Original sample	Sample mean	Standard deviation	t	p
SQ -> SAT -> BEN	0.207	0.205	0.040	5.173	0.000
SeQ -> SAT -> BEN	0.092	0.095	0.034	2.706	0.007
IQ -> SAT -> USE	0.211	0.210	0.040	5.253	0.000
SQ -> SAT -> USE	0.167	0.165	0.044	3.819	0.000
SeQ -> SAT -> USE	0.074	0.076	0.029	2.536	0.011
IQ -> SAT -> USE -> BEN	0.044	0.044	0.012	3.699	0.000
SQ -> SAT -> USE -> BEN	0.035	0.035	0.012	2.853	0.004
SeQ -> SAT -> USE -> BEN	0.016	0.016	0.006	2.408	0.016
IQ -> USE -> BEN	-0.011	-0.011	0.018	0.649	0.517
SAT -> USE -> BEN	0.107	0.107	0.027	3.994	0.000
SQ -> USE -> BEN	-0.014	-0.013	0.017	0.823	0.411
IQ -> SAT -> BEN	0.261	0.262	0.036	7.321	0.000
SeQ -> USE -> BEN	0.030	0.030	0.014	2.113	0.035

Source: based on SmartPLS output

The direct, indirect, and total effects between the constructs (Tables 7-9) emphasize the primary role of information quality, and also the important role of system quality in the model on satisfaction. The direct effects between the factors and use are not significant. Indirect effects confirm that information and system quality affect Moodle use through the user's satisfaction. The impact of service quality on the results is statistically significant but only of secondary importance. Based on the total effects, benefits are significantly affected by all constructs of the model, allowing the conclusion that the model is comprehensive and applicable to Moodle evaluation. The non-voluntary use of Moodle by students is mirrored in the not significant total effects between ‘System quality’ and ‘Use’ ( $\beta=0.102$ ,  $t=1.323$ ,  $p=0.186$ ), and the related indirect effects between ‘Information quality’ to ‘Benefits’ through ‘Use’ ( $\beta=-0.011$ ,  $t=0.649$ ,  $p=0.517$ ) and ‘System quality’ to ‘Benefits’ through ‘Use’ ( $\beta=-0.014$ ,  $t=0.823$ ,  $p=0.411$ ).

satisfaction with Moodle. However, due to the high standard deviation values, the question logically arises whether the students' opinions show patterns. The study employed moderation analysis in SmartPLS software, using institution, gender, study level, and study form as grouping factors.

The research model was supplemented with moderating factors for all significant paths. Table 10 highlights the significant findings. The bootstrapping options used 5000 samples and the bias-corrected and accelerated (BCa) method. No significant moderating effects were found by gender or the full-time or part-time nature of the studies. Study level moderates the path between ‘Use’ and ‘Benefits’; the positive coefficient ( $\beta=0.129$ ) suggests that satisfied master-level students can take better advantage of the system. University differences were caught in the impact of ‘System quality’ and ‘Service quality’ on ‘Use’. These paths are not significant, but the results have

a remarkable message on the role of institutional differences.

According to RQ1, the survey shows that the students like the Moodle system. They found it easy-to-use,

Table 10

Summary of significant moderating effects

		Original sample $\beta$	Sample mean $\beta$	Standard deviation	t	p
Study level	USE -> BEN	0.129	0.125	0.049	2.630	0.009
Study level	SAT -> BEN	-0.134	-0.134	0.049	2.739	0.006
University	SQ -> USE	0.183	0.189	0.074	2.466	0.014
University	SeQ -> USE	-0.158	-0.158	0.051	3.115	0.002

Source: based on SmartPLS output

## Discussion and conclusion

It is not a new finding, but it has become a universal truth that investment in information technology contributes to value creation (Nemeslaki & Aranyossy, 2005). Since Moodle is a remarkable platform for the digitalization of higher education, careful management and development of the system are essential. Gamage et al. (2022) noted strong evidence that Moodle increases student engagement, performance, and satisfaction. Taking the views of students as the main beneficiaries into account is worthwhile.

The explanatory power of the model is rated as moderate, according to Hair et al. (2022), as it does not exceed 75%, but this level is acceptable. Among studies that use a technology acceptance approach with the TAM model (Davis, 1989) or its extensions (Venkatesh & Davis, 2000; Venkatesh & Bala, 2008), Saqr et al. (2024) or Sánchez and Hueros (2010) found that perceived usefulness and ease of use influence satisfaction and students' attitudes toward e-learning. Saqr et al. (2024) found that there is no impact on their intention to use it, and Sánchez and Hueros (2010) found a low  $R^2 = 0.41$  explanation on system usage. These two papers show similar conclusions before and after the COVID-19 lockdowns.

Nasution (2024) highlighted the positive impact of prior experience on perceived ease of use. In their review paper, Mustafa and Ali (2023) confirmed the usability of such models and the positive impact chains from the influencing factors and the results. At the same time, the authors present the limitations of such studies, including the lack of generalizability and the missing measurement of actual use. Most studies in the field have found low explanatory power regarding use, regardless of the system used by the university. The intention to use Moodle is not in question, as students cannot choose whether they want to use it. The experience with behavioral and technology acceptance models has appeared in our information system approach as well. The high consistency of the results by framework models and the locality of the research confirm the usability of different models, including the information system success approach.

Since students and teachers have different motivations and expectations derived from their different tasks according to using the same system, a common assessment model can be found in the DeLone and McLean IS Success Model.

up-to-date, and helpful in following the course materials. The main finding of our study is that satisfaction plays a key role in achieving the benefits of the Moodle system. Through this, the total effect is 0.737, which is considered high. The indirect effect of the 'Satisfaction', 'Use', and 'Benefits' path is 0.107. Exogenous constructs explain 60.8% of the standard deviation in satisfaction. That means the individual and organizational benefits can be achieved through investments in improving satisfaction. 'Satisfaction' is primarily achieved through 'Information quality' ( $\beta=0.415$ ,  $t=8.414$ ,  $p=0.000$ ), followed by 'System quality' ( $\beta=0.329$ ,  $t=5.157$ ,  $p=0.000$ ). The low path coefficients from 'Information quality' to 'Use' ( $\beta=-0.054$ ,  $t=0.668$ ,  $p=0.500$ ) and from 'System quality' to 'Use' ( $\beta=-0.065$ ,  $t=0.831$ ,  $p=0.406$ ), while the paths to 'Satisfaction' are more significant, warn policymakers that increase in use is not directly available, the measures must incorporate the user satisfaction. Furthermore, related measurements must be designed accordingly, which clearly indicates the need for quality management experts. They can survey the factors contributing to satisfaction and help define whether information, system, or service development is required for success.

'Service quality' significantly and positively impacts both 'Use' ( $\beta=0.143$ ,  $t=2.363$ ,  $p=0.018$ ) and 'Satisfaction' ( $\beta=0.146$ ,  $t=2.802$ ,  $p=0.005$ ), but the path coefficients are lower than the other constructs. That suggests that service quality must be considered a hygiene factor, i.e., required for effective operation, but it is a kind of default assumption. Indeed, in the case of regular operation, the service can remain in the background. The results reveal that the universities have dual responsibility for information quality and system quality. Information quality depends on the teachers and instructors, while system quality depends on managerial decisions regarding which features will be developed and utilized. These responsibilities should not be mixed or joined.

The DeLone and McLean Model of Information Systems Success (DeLone & McLean, 2003) is an appropriate selection for the analysis. The convergent and discriminant validity analysis confirms that Moodle can be analyzed as an information system (RQ2). Since universities run different software within their information systems, the implication of the study is to extend the scope of investigations to those. That requires mapping

the stakeholders and the system in use, as well as the refinement of the questions in the survey. As a result, a comprehensive instrument can be established to support management decisions.

According to RQ3, the study found that there are few moderating effects in the judgments on the Moodle system, and it is generally accepted. The differences by study level suggest the need for user training and education. More experience in system use saves time and effort for the students; the confident use contributes to successful utilization. The differences in system quality and service quality among universities may be based on the varying maturity of institutions, which highlights the importance of knowledge sharing and adopting best practices.

## Limitations

The study has some limitations. First, the data collection was not representative of the population. Although more universities were included, and the results do not show many differences by that grouping factor, a broader data collection is needed for policy-making. The study is considered a pilot study and aims to develop a measuring tool. A comprehensive survey among universities enables general conclusions and informed system development actions. The results will hopefully raise interest in the topic among universities, and a representative sample can be obtained through their collaboration. Second, the analysis is based on the self-assessment of the students as users of the Moodle system. Alternative measurement methods of use may improve the explanatory power of the model. Third, the study was not longitudinal. Due to the fast technological development, repeated data collection could justify the timeliness of the results. Fourth, the database was filtered for incorrect completions, but the bias of self-managed, voluntary online data collection cannot exclude all errors.

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BEWAR HAJI – AWAZ SHUKRI ISMAEL

# ADVANCING SUSTAINABILITY IN ORGANIC FOOD SMES THROUGH GREEN ENTREPRENEURSHIP – A BIBLIOMETRIC ANALYSIS OF THE PAST DECADE OF RESEARCH

## A FENNTARTHATÓSÁG ELŐMOZDÍTÁSA A BIOÉLELMISZER-IPARI KIS- ÉS KÖZÉPVÁLLALKOZÁSOKBAN A ZÖLD VÁLLALKOZÁS RÉVÉN – AZ ELMÚLT ÉVTIZED KUTATÁSAINAK BIBLIOMETRIAI ELEMZÉSE

This bibliometric study analyses 157 publications (between 2015 and March 2025) mapping research at the intersection of green entrepreneurship, sustainability, and organic food SMEs. Citation network analysis identified six thematic clusters: sustainable business model innovation, financing mechanisms for green innovation, transformative entrepreneurship, circular economy strategies, institutional support systems, and hybrid business models in organic food. Performance analysis reveals that systematic reviews and conceptual frameworks predominate in high-impact research (GCS: 1.6-8.8). Temporal evolution shows a transition from broad sustainability frameworks pre-2020 to focused innovation strategies post-2020, driven by the European Green Deal and UN Sustainable Development Goals. Geographic concentration in Western Europe and Asia limits cross-contextual applicability. Critical gaps include longitudinal validation of sustainable business models, gender-inclusive entrepreneurship research, and digital transformation pathways in developing economies. This study advances bibliometric methods in entrepreneurship research while providing evidence-based priorities for scholars, policymakers, and practitioners in organic food sustainability.

**Keywords:** green entrepreneurship, organic food SMEs, sustainable business models, circular economy, bibliometric analysis

Ez a bibliometriai tanulmány 157 publikációt elemez (2015–2025 március között), feltérképezve a zöld vállalkozás, fenntarthatóság és organikus élelmiszer KKV-k metszéspontjában zajló kutatásokat. Az elemzés során citációs hálózatelemzéssel hat tematikus klasztert azonosítottak a szerzők: fenntartható üzletimodell-innováció, zöld innovációk finanszírozási mechanizmusai, transzformatív vállalkozás, körforgásos gazdasági stratégiák, intézményi támogatási rendszerek, valamint hibrid üzleti modellek az organikus szektorban. Emellett a teljesítményelemzési módszer kimutatta, hogy a szisztematikus áttekintések és a koncepcionális keretrendszerek dominálnak a nagy hatású kutatásokban (GCS: 1,6-8,8). Az időbeli változás elemzése a 2020 előtti széles fenntarthatósági keretrendszerektől a 2020 utáni célzott innovációs stratégiák felé mutat elmozdulást, amelyet az európai zöld megállapodás és az ENSZ fenntartható fejlődési céljai katalizáltak. A cikkek nyugat-európai és ázsiai koncentrációja korlátozza a kontextusok közötti átjárhatóságot. Kritikus hiányosságként a fenntartható üzleti modellek longitudinális validálása, a nemek közötti inkluzív vállalkozáskutatás a feltörekvő gazdaságok digitális transzformációja azonosíthatók. A tanulmány a bibliometriai módszertan fejlesztése mellett megalapozott fejlesztési irányokat mutat kutatóknak, döntéshozóknak és gyakorlati szakembereknek.

**Kulcsszavak:** zöld vállalkozás, organikus élelmiszer KKV-k, fenntartható üzleti modellek, körforgásos gazdaság, bibliometriai elemzés

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### Authors/Szerzők:

Bewar Haji<sup>a,c</sup> (haji.bewarsulaiman.70@unibge.hu, bewar.sulaiman@dpu.edu.krd) PhD student (<https://orcid.org/0009-0009-1280-8692>); Awaz Shukri Ismael<sup>b,c</sup> (awazshukri@mailbox.unideb.hu, awaz.shukri@dpu.edu.krd) PhD student (<https://orcid.org/0000-0003-0853-0658>)

<sup>a</sup>Budapest University of Economics and Business (Budapesti Gazdaságtudományi Egyetem) Hungary (Magyarország); <sup>b</sup>University of Debrecen (Debreceni Egyetem) Hungary (Magyarország); <sup>c</sup>Duhok Polytechnic University (Duhoki Műszaki Egyetem) Iraq (Irak)

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Green Entrepreneurship, particularly among Small and Medium-Sized Enterprises (SMEs), has become an important driver of sustainability in environmentally conscious markets. By integrating ecological considerations into their core strategy, green entrepreneurs create innovative business models that aim to succeed in both economic and ecological terms (Schaltegger et al., 2016; Rodríguez-García et al., 2019; Rok & Kulik, 2021). The organic food industry serves as a unique example of green entrepreneurship. Here, the increasing consumer demand for sustainable products creates significant opportunities for small and medium-sized enterprises (SMEs) to innovate and expand. By incorporating eco-innovative methods into their business models, these businesses can improve their environmental performance and enhance their competitive advantages (Ersoy et al., 2022; Bossle et al., 2016). However, despite the growing number of studies on green entrepreneurship and sustainable practices, there remains a lack of systematization of research at the interface of green entrepreneurship, sustainability, and organic food SMEs.

While bibliometric studies have addressed associated areas including agriculture, food entrepreneurship broadly (Petrolo et al., 2022), sustainability strategies in agribusiness (Alvarez-Ochoa et al., 2024), and green marketing trends (Bhardwaj et al., 2023). To the best of our knowledge, no prior study has systematically mapped the intellectual structure of the research at the specific interface of green entrepreneurship, sustainability practices, and organic food SMEs. Given the sector's high-growth profile and its contribution to the Sustainable Development Goals (SDGs), this gap is especially relevant. Furthermore, the lack of citation-based synthesis also limits researchers' understanding of how research topics develop over time, how they connect across different knowledge domains, and what new research frontiers emerge in this area.

To address this gap, this study aims to map and synthesize the scholarly literature on sustainable business model innovation, circular economy strategies, hybrid entrepreneurship, and alternative funding models in the context of organic food small and medium-sized enterprises (SMEs) using bibliometric analysis. In doing so, the study aims to inform entrepreneurs, policymakers, and researchers about how this research stream has evolved and where it is heading. Specifically, this bibliometric study systematically evaluates the field's intellectual structure, thematic development, and research trends at the intersection of green entrepreneurship, sustainability, and organic food SMEs over the last decade (2015-2025). To achieve this, this study has four research objectives. First, identify and describe the leading publications, authors, and journals that have contributed to the understanding of green entrepreneurship in organic food SMEs through Global Citation Score (GCS) analysis and temporal publication trend analysis. Second, map the intellectual structure of research on green entrepreneurship in organic food SMEs by identifying thematic areas and their relationships with other areas of research using Citation Network Analysis (CAN) and keyword co-occurrence mapping to reveal the research

knowledge base. Third, analyze the temporal development of thematic areas of research using Thematic Evolution Structure Analysis (TESA) and Thematic Mapping (TM) to determine how the research area is evolving and where it may develop in the future. Finally, synthesize the theoretical, practical, and policy implications of the bibliographic analysis findings to identify critical research gaps and provide action-oriented recommendations to help the application of sustainable entrepreneurship theory and practice in the organic food industry.

The following section outlines the literature review on green entrepreneurship, covering its definitions, frameworks, and historical development. It also examines sustainability practices and the circular economy from the perspective of SMEs, along with organic food as an under-explored nexus. Next, the materials and methods section describes the approaches for collecting and analyzing bibliometric data. Following this, the results section presents performance analysis, thematic clusters, keyword trends, and temporal patterns. The discussion then interprets the findings, focusing on theoretical, practical, and policy implications, along with future research directions and limitations. Finally, the conclusion summarizes thematic areas and provides recommendations for key stakeholders.

## Literature Review

### Green Entrepreneurship: Definitions, Frameworks, and Evolution

Green entrepreneurship has shifted from being a niche idea to a key concept in sustainability studies over the last twenty years. Initial definitional efforts identified ecopreneurs as individuals who create businesses primarily driven by environmental goals, seeing environmental issues as opportunities for business (Kirkwood & Walton, 2010). Gibbs (2006) described ecopreneurs as vital players in a sustainable economy, who incorporate environmental values into the core of their business operations rather than viewing sustainability merely as an aspect of corporate social responsibility. In addition, Santini (2017) combined various definitions, suggesting that ecopreneurship ranges from companies that produce eco-friendly products to those that fundamentally overhaul production systems for ecological restoration, while also recognizing ongoing conceptual confusion about the distinctions among green, ecological (eco-), and sustainable entrepreneurship.

Current theoretical models stress the interdependent dynamics between entrepreneurial actions and institutional contexts. Schaltegger et al. (2016) developed a foundational framework that portrays green entrepreneurs as agents of sustainability who navigate multi-stakeholder ecosystems through adaptable strategies. This framework was expanded through collaborative entrepreneurship models aligned with the UN Sustainable Development Goals (Schaltegger et al., 2018), thereby establishing normative policy foundations. Olteanu and Fichter (2022) translated these theoretical frameworks into practical applications by categorizing transformation-focused startups, highlighting the variety of sustainability approaches.

Additionally, recent focus on institutional support structures illustrates how university ecosystems and external entities influence the conversion of green entrepreneurial intentions into actionable behaviors (Alshebami, 2023; Yi, 2021), although the concentration of research in academic settings limits its applicability to larger entrepreneurial ecosystems. Nonetheless, despite theoretical advances, empirical gaps remain in understanding the long-term development paths of ventures, failure factors in sustainable startups, and contextual differences across institutional settings.

### Sustainability Practices and Circular Economy in SME Contexts

Implementing sustainability in small and medium-sized enterprises (SMEs) presents unique challenges compared to larger companies, primarily due to limited resources, a lack of formal processes, and greater entrepreneurial flexibility. Research indicates strong positive correlations between green and sustainable business models and various developmental outcomes across economic, social, strategic, and environmental areas (Mondal et al., 2022). However, the implementation paths differ significantly by organizational size and sector. For example, Rodríguez-Espíndola et al. (2022) stated that circular economy principles have emerged as frameworks for enacting sustainability, focusing on closed-loop systems, efficient resource use, and the transformation of waste into valuable resources. Furthermore, Briguglio et al. (2021) highlighted important differences between companies that are inherently circular and those that are working to adopt circularity, noting that startups typically face fewer obstacles due to the lack of legacy systems but struggle with limited resources. Moreover, Rodríguez-Espíndola et al. (2022) found in their analysis of Mexican SMEs that the adoption of circular economy practices hinges on the simultaneous presence of economic feasibility, regulatory support, and cultural acceptance, while institutional quality influences the relationship between sustainability values and circular actions.

Moreover, studies on sustainable business model innovation indicate conflicts between profitability and sustainability. Provasnek et al. (2017) created structured frameworks that incorporate Triple Bottom Line metrics into corporate entrepreneurship, while Urbaniec et al. (2022) showed that bioeconomy strategies can promote sustainable entrepreneurship within resource-oriented sectors. Rok and Kulik (2021) further found that circular startups in developing economies grapple with the “sustainable startup paradox,” in which they are expected to meet ambitious environmental targets despite the resource constraints common to early-stage businesses. However, alternative funding approaches, particularly equity crowdfunding, offer opportunities to broaden access to sustainability-focused entrepreneurship (Troise et al., 2021). Nevertheless, according to Testa et al. (2020), the success of these ventures relies heavily on clear communication with stakeholders and the framing of sustainability attributes. Key research gaps still exist, including the need

for long-term evaluations of sustainability performance post-implementation, comparative studies across different institutional arrangements, and investigations into the power dynamics within circular supply chain governance that may affect the terms of SME participation.

### Organic Food Entrepreneurship: An Underexplored Nexus

The organic food sector is an important yet often overlooked area for research in green entrepreneurship. Despite significant market growth in Western Europe and North America (Borsellino et al., 2020). Entrepreneurial dynamics in this field receive relatively little academic attention compared with those of other green industries. This research gap is particularly striking, considering that organic food small and medium-sized enterprises (SMEs) embody hybrid organizational models that strive for environmental sustainability, economic profitability, and the maintenance of a social mission, the core challenge of green entrepreneurship.

Research to date highlights specific sector characteristics that distinguish organic food entrepreneurship from broader green initiatives. Jolink and Niesten (2015) provided groundbreaking empirical insights into how organic food ecopreneurs convert environmental externalities into customer value propositions, while also managing tensions between their sustainability commitments and market competitiveness. Furthermore, Reynolds and Holt (2021) used life-story methodologies, revealing that founders’ sensemaking and personal identity development processes significantly affect strategic choices in hybrid organic enterprises, indicating that adaptive self-awareness is a crucial entrepreneurial skill that goes beyond merely aligning organizational structures.

Nevertheless, significant obstacles persist. Dahiya et al. (2020) identified insufficient government support and limited stakeholder awareness as primary strategic challenges for female entrepreneurs in the organic food sector, particularly in emerging economies, alongside funding access and market development barriers. However, gender-related aspects remain unexamined, with research focusing on identifying barriers rather than on actionable pathways for inclusive entrepreneurship.

The intersection of green entrepreneurship, sustainability practices, and organic food SMEs remains unevenly integrated in the existing literature. First, thematic fragmentation hinders the understanding of sustainable business models, circular economic principles, and implementation challenges. Second, geographic concentration in Western Europe limits cross-regional applicability. Third, research predominantly examines successful cases, overlooking failure dynamics. Fourth, empirical validation linking alternative financing and sustainability performance is lacking. Finally, systematic bibliometric analyses remain limited.

### Materials and Methods

This study uses bibliometrics to identify and describe how research on green entrepreneurship, sustainability,

and organic food SMEs has developed over time, as well as the main conceptual or theoretical themes in these areas. The use of bibliometrics enables the objective and consistent evaluation of large numbers of scholarly documents to identify the most significant studies, emerging lines of inquiry, and major paradigm shifts (Donthu et al., 2021; Zupic & Čater, 2015). Recent applications in related domains provide methodological precedents: Petrolo et al. (2022) using bibliometric analysis along with thematic synthesis, identified 6 clusters in Agri-Food Entrepreneurship research. In addition, Alvarez-Ochoa et al. (2024) conducted a bibliometric analysis using two databases (Scopus and Web of Science) to investigate the use of sustainability strategies in agribusiness. Moreover, Bhardwaj et al. (2023) used VOSviewer to map trends in Green Marketing. The preceding studies show that bibliometric approaches are effective for synthesizing complex, interdisciplinary research areas such as those described here.

Although the current study is based on a method of bibliometrics (citation analysis) rather than a method of systematic literature review (a method that uses inclusion/exclusion criteria), the methodology of collecting the data was based upon the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol to make the data collection as transparent, reproducible, and systematic as possible (Page et al., 2021). By combining citation network analysis, keyword co-occurrence mapping, and thematic evolution tracking, this study follows established bibliometric protocols (Donthu et al., 2021; Zupic & Čater, 2015). Using these three methods of analysis enables the identification of structural relationships between papers through citation analysis and thematic patterns through keyword analysis. These findings align with previous comprehensive reviews conducted by (Takalo et al., 2021) in the field of green innovation.

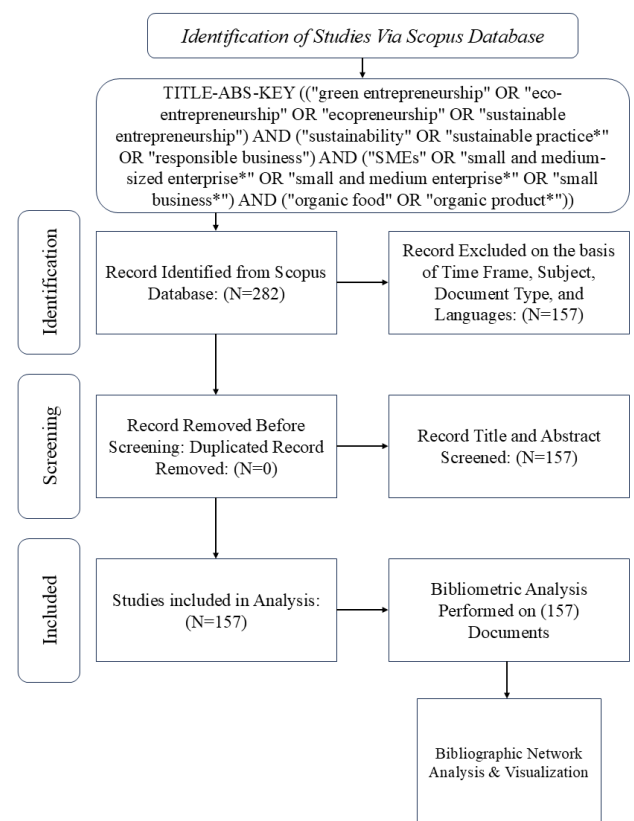
### Data Collection and Selection

The search strategy employed a three-stage keyword identification procedure based on bibliometric methods in entrepreneurship and sustainability research (Alvarez-Ochoa et al., 2024; Petrolo et al., 2022). First, an exploratory review of seminal works on green entrepreneurship (Schaltegger et al., 2016), sustainable business models (Evans et al., 2017), and green innovation (Takalo et al., 2021) identified central conceptual terminology. Second, preliminary scoping searches tested the retrieval sensitivity and specificity of different keyword combinations. Third, the final Boolean search string combined validated terms with logical operators (AND/OR) to identify conceptual overlap among green entrepreneurship, sustainability practices, SME contexts, and organic food systems.

The Boolean query retrieved documents containing: (“green entrepreneurship” OR “eco-entrepreneurship” OR “ecopreneurship” OR “sustainable entrepreneurship”) AND (“sustainability” OR “sustainable practice\*” OR “responsible business”) AND (“SMEs” OR “small and medium-sized enterprise\*” OR “small and medium enterprise\*” OR “small business\*”) AND (“organic food” OR “organic product\*”). Furthermore, query construction

followed iterative bibliometric protocols (Alvarez-Ochoa et al., 2024), combining core concepts with terminological variants to maximize recall while maintaining precision, reflecting variability typical of entrepreneurship and sustainability literatures (Bhardwaj et al., 2023; Petrolo et al., 2022). Additionally, Takalo et al. (2021) stated that wild-card operators (i.e., “practice\*”, “enterprise\*”, “product\*”) capture morphological variations while maintaining conceptual coherence. The temporal scope (2015–March 2025) captures contemporary research and development on green entrepreneurship following the adoption of the UN SDGs and the Paris Agreement (Schaltegger et al., 2018). This timeframe: (1) captures policy-driven acceleration in sustainability-oriented business research post-2015, (2) provides sufficient breadth (10 years) for thematic evolution analysis while excluding pre-paradigm literature, and (3) ensures contemporary relevance for practitioners and policymakers operating within current regulatory frameworks (Alvarez-Ochoa et al., 2024; Petrolo et al., 2022).

Figure 1  
Paper Selection Procedure and Results



Source: adapted from Kumari and Jaiswal (2023)

From the initial search, 282 documents were retrieved. Following Kumari and Jaiswal (2023) selection framework and PRISMA guidelines (Page et al., 2021) (Figure 1), the use of systematic inclusion and exclusion criteria enhanced the dataset’s relevance and methodological robustness. First, subject-area filters (‘Business, Management and Accounting’ and ‘Social Sciences’) limited the scope to managerial and organizational perspectives, excluding

technical or engineering approaches, which are standard in entrepreneurship bibliometrics (Petrolo et al., 2022). Second, document type restrictions ('Article' and 'Review' only) excluded conference papers, book chapters, and editorials, prioritizing peer-reviewed scholarly contributions (Bhardwaj et al., 2023; Takalo et al., 2021). Finally, English-language restriction, while it may introduce geographic and linguistic bias, is a common practice in international bibliometric analyses (Bhardwaj et al., 2023; Petrolo et al., 2022) and facilitates consistent meta-data extraction and keyword analysis. Following these criteria, no duplicates were identified among the 282 documents; 157 were selected for bibliometric analysis.

### Analytical Techniques and Tools

To assess the research field's performance and conceptual framework, a comprehensive bibliometric approach was adopted, following the analytical framework proposed by (Máté et al., 2024) outlined in Figure 2. This approach utilized two primary analytical tools: VOSviewer version 1.6.20 (van Eck & Waltman, 2010) for citation network analysis and clustering, and the bibliometrix R package version 4.4.2 via the Biblioshiny interface (Aria & Cuccurullo, 2017) for thematic and performance analytics. Specifically, VOSviewer mapped intellectual relationships and cluster formation. At the same time, bibliometrix/Biblioshiny conducted keyword co-occurrence network analysis, keyword tree-map visualizations, thematic evolution tracking (time-sliced), trend topics analysis, and three-field plots (AU-DE-SO). Additionally, Scopus-derived performance metrics were used to calculate citation impact indicators (Global Citation Score – GCS) and for descriptive statistics.

Following the framework outlined in Figure 2, bibliometric analysis employed three complementary software platforms. First, Scopus provided citation impact indicators, including Global Citation Scores (GCS) normalized by publication year (Table 2), along with descriptive statistics of the dataset (Table 1). Second, VOSviewer generated citation network visualization, clustering 54 cited documents into six thematic areas based on conceptual similarities (Figure 4a). Third, bibliometrix/Biblioshiny user friendly interface conducted five thematic and performance analyses: keyword co-occurrence networks (Figure 7), keyword tree maps (Figure 6), thematic evolution tracking (Figure 8), trend topics analysis (Figure 9), and three-field plots linking authors, themes, and journals (Figure 11).

### Results

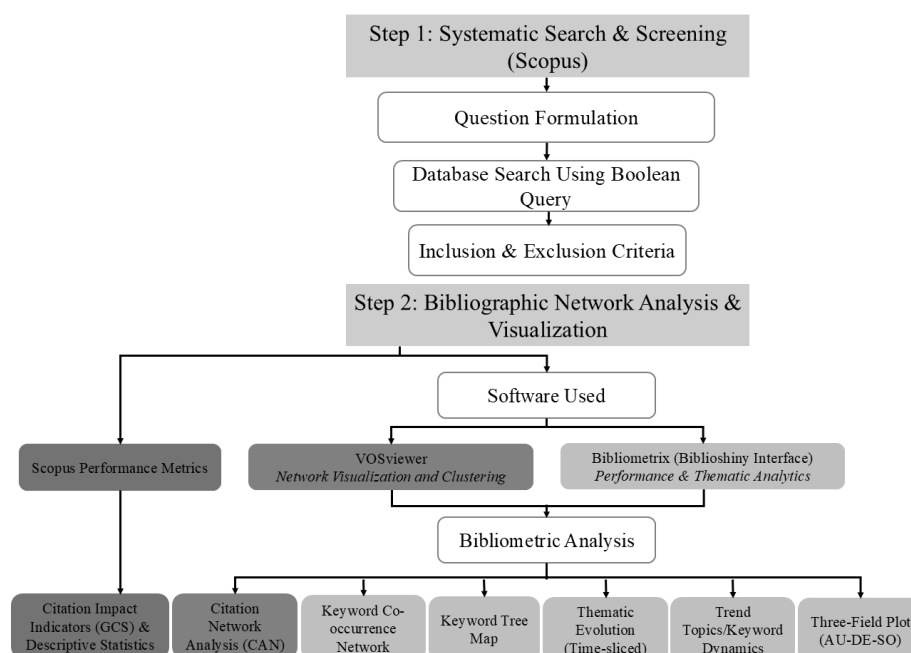
The bibliometric analysis reveals a rapidly evolving research domain characterized by theoretical consolidation, methodological diversification, and geographic concentration. Six thematic clusters emerge from citation network analysis, reflecting distinct but interconnected research streams. The following subsections present descriptive statistics, citation impact metrics, intellectual and conceptual structures, and temporal thematic evolution.

#### Descriptive Overview of the Dataset

The final dataset comprises 157 documents published between 2015 and March 2025, drawn from 86 scholarly sources (see Table 1). There are 523 authors represented in the corpus, and there is considerable evidence of co-authorship among them, with an average of 3.47 co-authors

Figure 2

### Research Methodology of the Study



Source: adapted from Máté et al. (2024)

per document. In addition, there is substantial evidence of international collaboration (i.e., 36.31% international co-authorship), as indicated in Table 1.

Table 1

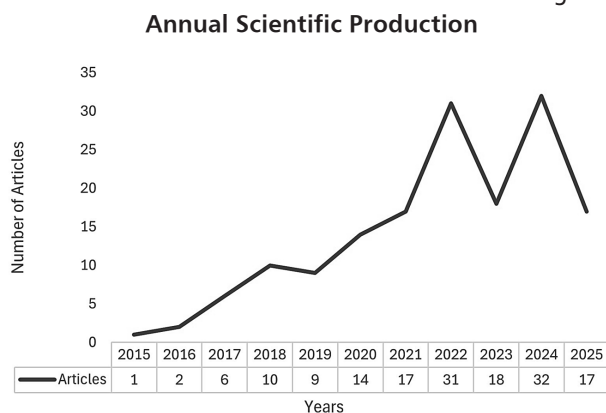
Main Bibliometric Information

Indicator	Value
Timespan (data coverage)	2015–2025 (through March 2025)
Sources	86
Documents (final dataset)	157
Annual growth rate (%)	32.75
Authors	523
Single-authored documents (authors)	15
Co-authors per document	3.47
International co-authorship (%)	36.31
Author keywords (DE)	637
Keywords Plus (ID)	320
Average document age (years)	4.18
Average citations per document	34.75

Source: generated using Bibliometrix/Biblioshiny

Furthermore, annual scientific output shows a significant upward trend over the study period (2015-March 2025), increasing from minimal production in the early years (1-2 papers in 2015-2016) to consistent growth starting in 2017. The pace of publication picked up after 2020 (14 papers in 2020; 17 in 2021), reached a significant peak in 2022 (31), declined in 2023 (18), and surged again in 2024 (32) (see Figure 3). The 2025 (17) prediction should be viewed with caution due to the dataset’s truncation (indexed up to March 2025). Annual scientific production data were exported from the bibliometrix/Biblioshiny user-friendly interface (Aria & Cuccurullo, 2017).

Figure 3



Source: data compiled by the authors

**Performance Analysis (Global Citation Score – GCS)**  
Global Citation Score (GCS) analysis utilizing normalized Scopus citation counts evaluated publication impact. Table 2 presents the ten highest-cited

documents as of March 2025. Takalo et al. (2021) systematic review achieved the highest GCS (8.8), synthesizing knowledge on green innovation and identifying future research directions. Rodríguez-Espíndola et al. (2022) attained a GCS of 8.25 through empirical examination of circular economy strategies in developing-region SMEs. In alternative financing, Troise et al. (2021) analyzed equity crowdfunding and open innovation in agri-food sustainability transitions, obtaining a GCS of 4.75, while Zameer and Yasmeen (2022) investigated consumer-driven sustainability, gaining a GCS of 3.75. Theoretically, Evans et al. (2017) established the foundations of sustainable business model innovation, receiving a GCS of 3.6, and Yi (2021) assessed entrepreneurial and institutional factors in the implementation of sustainability goals, acquiring a GCS of 3.0. Additional contributions came from Majeed et al. (2022), Borsellino et al. (2020), Schaltegger et al. (2016), and Testa et al. (2020), addressing marketing strategies, consumer behavior, and alternative finance mechanisms.

Top-cited publications predominantly employ systematic reviews (Evans et al., 2017; Takalo et al., 2021) and conceptual frameworks (Schaltegger et al., 2016), reflecting theoretical consolidation, while quantitative empirical studies (Rodríguez-Espíndola et al., 2022; Yi, 2021; Zameer & Yasmeen, 2022) constitute the secondary category. Notably, qualitative case studies remain underrepresented. Geographically, research focuses on Western Europe (Schaltegger et al., 2016; Testa et al., 2020) and Asia (Yi, 2021; Zameer & Yasmeen, 2022), with limited representation from Latin America, Africa, and Southeast Asia, which limits cross-contextual generalizability. Moreover, sample characteristics reveal a predominant focus on SMEs (Rodríguez-Espíndola et al., 2022; Troise et al., 2021), with insufficient attention to micro-enterprises and startups in the organic food sector.

**Intellectual Structure:**

**Citation Network Analysis**

A Citation Network Analysis (CNA) was performed with VOSviewer to map the field’s intellectual framework. Applying a minimal citation threshold of one per document, 54 documents were identified, connected by 90 citations. Initially categorized into 20 clusters, these were subsequently refined into six primary thematic areas based on citation relationships and conceptual similarities (see Table 3). Figure 4a (Overlay Visualization) illustrates the network, where node sizes represent citation impact and color shading indicates the year of publication. Notable contributions include those by Schaltegger et al. (2016), Evans et al. (2017), and (Jolink & Niesten, 2015). Figure 4b Citation Network Analysis (Density Visualization) highlights areas of intensive academic activity, with a particular focus on sustainable business models, green innovation, and transformative entrepreneurship. The following section delves deeper into the specifics of each cluster.

Table2

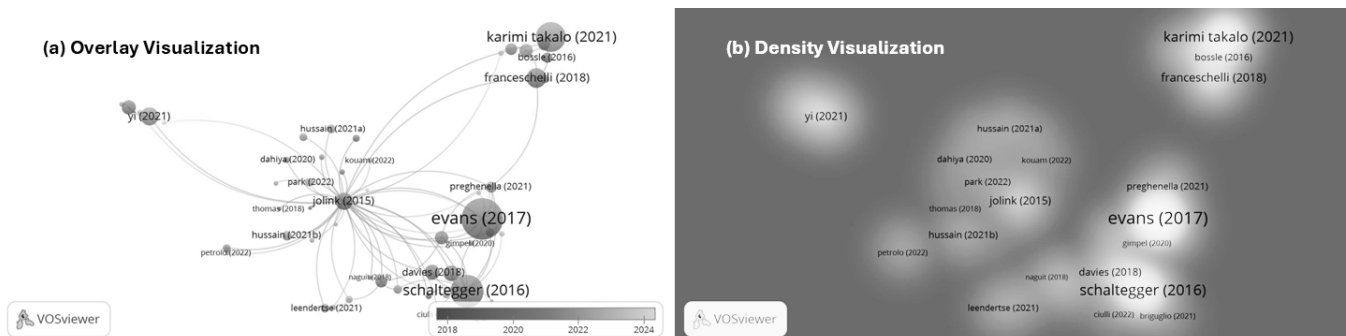
Top 10 Most Cited Articles Ranked by Normalized GCS

Rank	Title	Authors and Year of Publication	Journal	GSC	Normalized GSC	Research Approach	Country Context	Author Affiliation
1	Green innovation: A systematic literature review	Takalo & Tooranloo (2021)	Journal of Cleaner Production	44	8.8	SLR	International	Iran
2	The role of circular economy principles and sustainable-oriented innovation to enhance social, economic, and environmental performance: Evidence from Mexican SMEs	Rodríguez-Espíndola et al. (2022)	International Journal of Production Economics	33	8.25	Quantitative (SEM)	Mexico	UK, Mexico, France, Greece
3	Understanding the implications of equity crowdfunding on sustainability-oriented innovation and changes in agri-food systems: Insights into an open innovation approach	Troise et al. (2021)	Technological Forecasting and Social Change	19	4.75	Quantitative (SEM)	Italy	Italy, USA
4	Green innovation and environmental awareness drive green purchase intentions	Zameer & Yasmeen (2022)	Marketing Intelligence and Planning	15	3.75	Quantitative (SEM)	China	China
5	Business Model Innovation for Sustainability: Towards a Unified Perspective for Creation of Sustainable Business Models	Evans et al. (2017)	Business Strategy and the Environment	32	3.6	Conceptual	International	UK
6	From green entrepreneurial intentions to green entrepreneurial behaviors: the role of university entrepreneurial support and external institutional support	Yi (2021)	International Entrepreneurship and Management Journal	15	3	Quantitative (SEM)	China	China
7	Green Marketing Approaches and Their Impact on Green Purchase Intentions: Mediating Role of Green Brand Image and Consumer Beliefs towards the Environment	Majeed et al. (2022)	Sustainability (Switzerland)	14	2.8	Quantitative (SEM)	Pakistan	Pakistan, Hungary
8	Agri-food markets towards sustainable patterns.	Borsellino et al. (2020)	Sustainability (Switzerland)	12	2	Literature Review	International	Italy
9	Business Models for Sustainability: A Co-Evolutionary Analysis of Sustainable Entrepreneurship, Innovation, and Transformation	Schaltegger et al. (2016)	Organization and Environment	16	1.6	Conceptual	International	Germany, Austria
10	Crowdfunding as a tool to support sustainability-oriented initiatives: Preliminary insights into the role of product/service attributes	Testa et al. (2020)	Business Strategy and the Environment	11	1.6	Qualitative (Content Analysis)	Europe	Italy

Source: data compiled by the authors

Figure 4

Citation Network Analysis: (a) Overlay Visualization and (b) Density Visualization



Source: authors' compilation generated by VOSviewer.

The Citation Network Analysis (CNA) results reveal that scholarly work in this field primarily focuses on a few critical themes: sustainable business model innovation, green innovation in agri-food systems, circular entrepreneurship, and green entrepreneurial intentions. Table 3 outlines these significant thematic groups and their most impactful documents, serving as the basis for the thematic synthesis discussed in the next section.

The six clusters identified through citation network analysis (see Figure 5) represent distinct, yet interconnected research streams within green entrepreneurship, sustainability, and organic food SMEs. The following analysis examines each cluster’s theoretical foundations, key empirical contributions, methodological approaches, and critical research gaps.

Table 3

Summary of Main Research Clusters Identified Through Citation Network Analysis

Cluster	Nodes	Links	Topics	Top 3 cited papers	Period	Size %
1	8	39	Innovating Sustainable Business Models: Strategic Approaches and Future Directions	Evans et al. (2017); Stubbs (2019); Preghenella & Battistella (2021)	2017-2024	20.5%
2	8	20	Green Innovation in Agri-Food Startups and the Role of Open and Crowdfunded Models	Takalo et al. (2021); Franceschelli et al. (2018); Troise et al. (2021)	2016-2023	40%
3	7	24	Transformative Entrepreneurship for Sustainability: Co-evolution and Taxonomies	Schaltegger et al. (2016); Schaltegger et al. (2018); Olteanu & Fichter (2022)	2016-2022	29%
4	6	18	Corporate Entrepreneurship and Circular Start-up Strategies for Sustainable Impact	Provasnek et al. (2017); Rok & Kulik (2021); Leendertse et al. (2021)	2017-2022	33%
5	5	13	Green Entrepreneurial Intentions and Institutional Support Systems	Yi (2021); O’Neill & Gibbs (2016); Alshebami (2023)	2016-2025	38%
6	5	47	Organic Food Entrepreneurship and the Dynamics of Hybrid Business Models	Jolink & Niesten (2015); Reynolds & Holt (2021); Dahiya et al. (2020)	2015-2022	10%

Source: data compiled by the authors

Figure 5

Intellectual Structure of Green Entrepreneurship in Organic Food SMEs



Source: developed by the authors

**Cluster 1: Innovating Sustainable Business Models: Strategic Approaches and Future Directions** (Network: 8 nodes, 39 links, 20.5% representation, Period: 2017-2024)

Cluster 1 places sustainable business model (SBM) innovation at the forefront of theoretical discussions in the field (see Figure 5). Evans et al. (2017) introduced a foundational conceptual framework linking SBM to systematic innovation, while Preghenella and Battistella (2021) conducted a bibliographic meta-analysis that identified six distinct research streams and highlighted disciplinary fragmentation. Stubbs (2019) provided the sole empirical validation through case studies of Australian B-Corps, although this was confined to organizations structured as hybrids by law. However, three major limitations hinder practical relevance for organic food SMEs: (1) survivorship bias due to the focus on only successful cases, (2) temporal limitations stemming from cross-sectional approaches that fail to capture the evolution of SBM over time, and (3) scale ambiguity concerning the applicability to SMEs compared to large corporations. The cluster's mainly normative focus risks producing idealized models that are disconnected from the realities of resource-constrained hybrid value creation.

**Cluster 2: Green Innovation in Agri-Food Startups and the Role of Open and Crowdfunded Models** (Network: 8 nodes, 20 links, 40% representation, Period: 2016-2023)

Cluster 2 investigates the integration of sustainable development into agri-food innovation processes, highlighting a divergence between technology and finance streams. Takalo et al. (2021) identified three key factors of green innovation: regulation, economics, and institutions, though they did not provide an agriculture-specific context. Moreover, Franceschelli et al. (2018) illustrated the integration of sustainability into value propositions through a case study of an Italian pizzeria, while Troise et al. (2021) positioned equity crowdfunding as a method for open innovation aimed at stakeholder engagement, yet they overlooked the campaign failure rates exceeding 60% and the associated regulatory complexities. A temporal analysis shows a shift in focus, earlier studies (Bossle et al., 2016; Franceschelli et al., 2018) emphasized operational efficiency, while more recent research (Testa et al., 2020; Troise et al., 2021) stresses transparency and communication with stakeholders. Dangelico et al. (2019) introduced variations among organizations by comparing family-owned and non-family-owned firms. The remaining gap is the longitudinal assessment of sustainability and financial viability after the launch of crowdfunded projects.

**Cluster 3: Transformative Entrepreneurship for Sustainability: Co-evolution and Taxonomies** (Network: 7 nodes, 24 links, 29% representation, Period: 2016-2022)

Cluster 3 views transformative entrepreneurship as a change at the systems level through the lens of evolutionary economics. Schaltegger et al. (2016 & 2018)

developed co-evolutionary frameworks that highlight the importance of adaptive collaboration among multiple stakeholders in line with the UN Sustainable Development Goals. Olteanu and Fichter (2022) further put this into practice by developing an empirical taxonomy of transformation orientations among German startups. Additional contextual studies include Viciunaitė (2022), which focuses on consumer engagement; Stöhr and Herzig (2022), which examine pioneers in Germany's organic sector; and Briguglio et al. (2021), which study enablers of circular business, although there is limited integration across levels. Additionally, Frederick (2018) concept of "Biosphere Entrepreneurship" broadens the transformative scope beyond social and commercial entrepreneurship but remains largely theoretical. However, a contradiction arises: while the rhetoric promotes substantial systemic change, empirical findings indicate a tendency toward gradual niche development. Notable deficiencies include the absence of longitudinal studies tracking the progression from niche innovation to regime-level change, and a theoretical framework that addresses the resource limitations faced by SMEs that hinder their transformative potential.

**Cluster 4: Corporate Entrepreneurship and Circular Start-up Strategies for Sustainable Impact** (Network: 6 nodes, 18 links, 33% representation, Period: 2017-2022)

Cluster 4 emphasizes the differences in organizational strategies for adopting a circular economy. Provasnek et al. (2017) created frameworks for sustainable corporate entrepreneurship that incorporate Triple Bottom Line metrics, aligning with the work of Urbaniec et al. (2022) and Naguit (2018). On the other hand, Rok and Kulik (2021) observed how startups demonstrate agility by turning environmental challenges into competitive advantages through regenerative models that are not limited by legacy systems. Nonetheless, a key tension emerges: corporations have the resources for implementation but struggle with organizational inertia, while startups provide innovative agility but lack the scale of resources. This is referred to as the "sustainable startup paradox" (Leendertse et al., 2021). Hinderer and Kuckertz (2022) describe transitions to a bio-economy as enablers of the circular economy, although analyses by sector show disparities in access to opportunities and asymmetries in value capture. The geographic focus on European countries (e.g., Germany, Austria, Poland) restricts the generalizability of the regulatory environment. Additionally, notable gaps include analyses of comparative institutional configurations and the dynamics of governance power within circular supply chains.

**Cluster 5: Green Entrepreneurial Intentions and Institutional Support Systems** (Network: 5 nodes, 13 links, 38% representation, Period: 2016-2025)

Cluster 5 shows the highest network density at 38%, indicating a strong conceptual alignment with Theory of Planned Behavior frameworks (see Figure 5). Yi (2021) illustrated how support from universities and external

institutions facilitates the translation of intention into action, although the focus on the university context restricts the generalizability across broader ecosystems. O'Neill and Gibbs (2016) promote a dynamic, process-oriented approach in which entrepreneurial identities evolve alongside environmental conditions, necessitating empirical evidence. Moreover, Alshebami et al. (2023) explored the mechanisms of knowledge sharing that expedite transitions, while Lopez et al. (2021) presented ecocentric management, highlighting practices centered on the environment. Meanwhile, Iqbal et al. (2025) signify new frontiers that merge with digital transformation. Theoretical closure centered on TPB might overlook other explanatory perspectives, such as effectuation logic, identity-based entrepreneurship, and institutional entrepreneurship

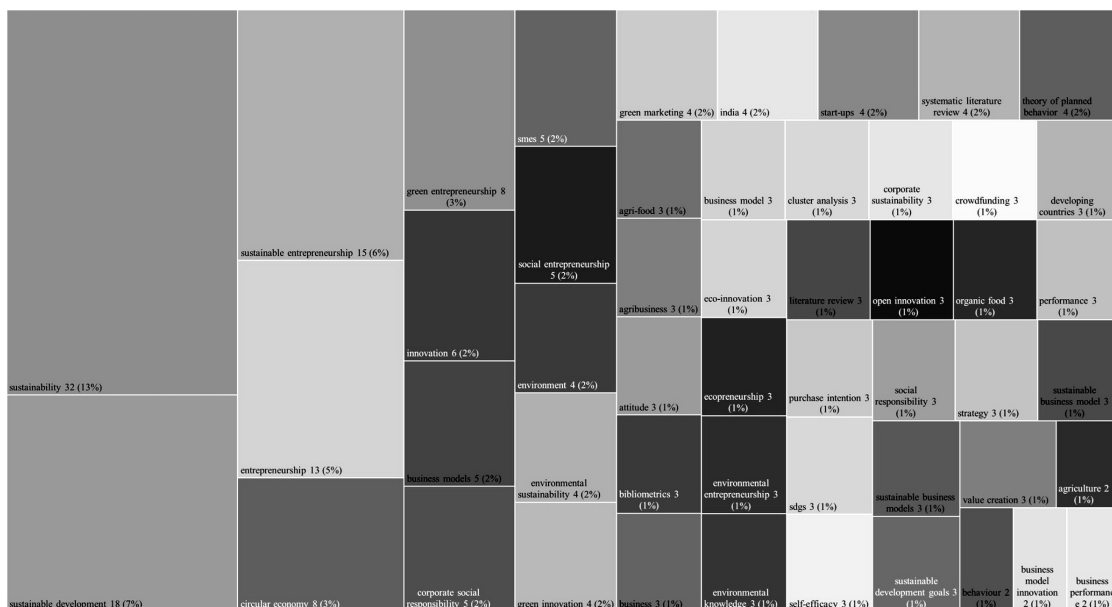
theories, that could better characterize the creation of organic food ventures. Notable gaps in cluster 5 include research into longitudinal intention trajectories and the development of a comprehensive theory on institutional support adaptation specifically for hybrid organic food business models.

**Cluster 6: Organic Food Entrepreneurship and the Dynamics of Hybrid Business Models** (Network: 5 nodes, 47 links, 10% representation, Period: 2015-2022)

Cluster 6 specifically examines organic food entrepreneurship, yet despite its importance in the sector, it remains relatively small, highlighting considerable research gaps. Jolink and Niesten (2015) delivered groundbreaking empirical insights into ecopreneurs who convert

Figure 6

**Keywords Tree Map**



Source: generated using Bibliometrix/Biblioshiny

**Keyword Co-occurrence Network**

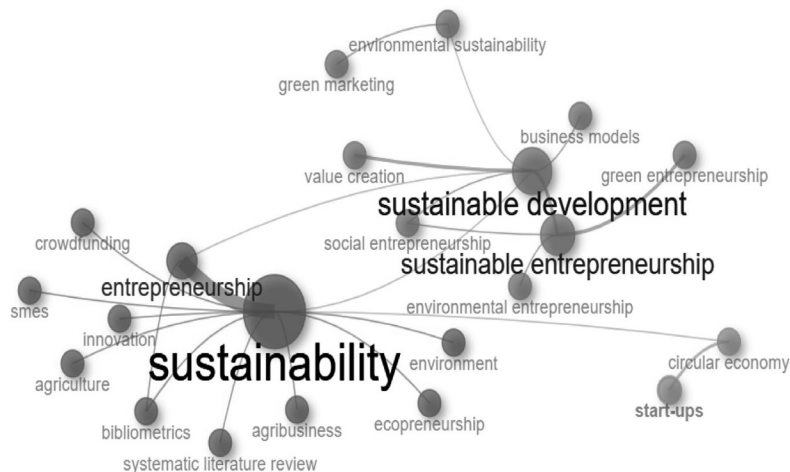


Figure 7

Source: generated using Bibliometrix/Biblioshiny

environmental externalities into customer value propositions while addressing tensions between sustainability and competitiveness. In addition, Reynolds and Holt (2021) used life-story narratives to examine how founders in hybrid ventures make sense of their experiences, indicating that personal identity development and reflexive processes shape strategic choices, although they did not identify cross-case patterns. Dahiya et al. (2020) further analyzed gender obstacles in Indian organic food entrepreneurship using total interpretive structural modeling, revealing socio-cultural limitations and suggesting inclusive frameworks. Whereas Kumar and Pathak (2022) linked sustainable corporate entrepreneurship to the UN SDGs and Kouam and Asongu (2022) examined the effects of tax policy on social innovation, neither study thoroughly addressed the specific characteristics of the organic food sector. Nevertheless, notable critical deficiencies include the need for integrative frameworks that link environmental, economic, and social imperatives and address resource orchestration challenges unique to organic food SMEs.

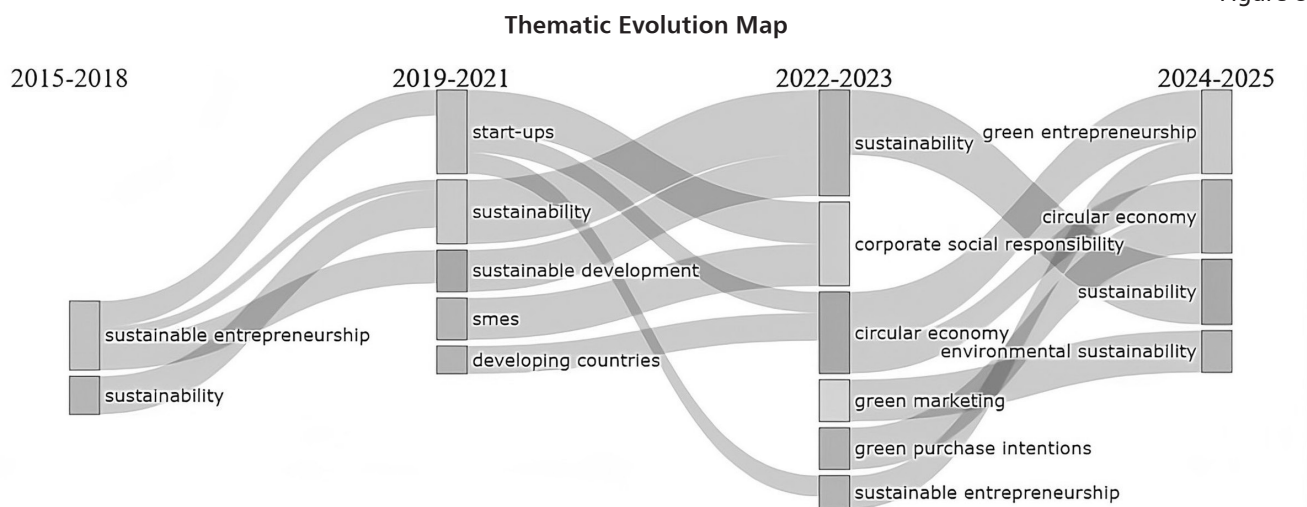
**Keyword Analysis**

Keyword tree map analysis (Figure 6) indicates that the most prominent keywords are sustainability (13%), sustainable development (7%), and sustainable entrepreneurship (6%). However, the keyword co-occurrence network (Figure 7) shows four thematic clusters. The red cluster comprises core sustainability and entrepreneurship concepts, combined with sectoral frameworks (agriculture, SMEs, agribusiness) and methodological terms, for example, systematic literature reviews. The blue cluster contains sustainable development, sustainable entrepreneurship, and business model concepts. Moreover, the green cluster links circular-economy concepts to startup ventures, and the purple cluster links environmental sustainability concepts to green marketing.

**Thematic Evolution**

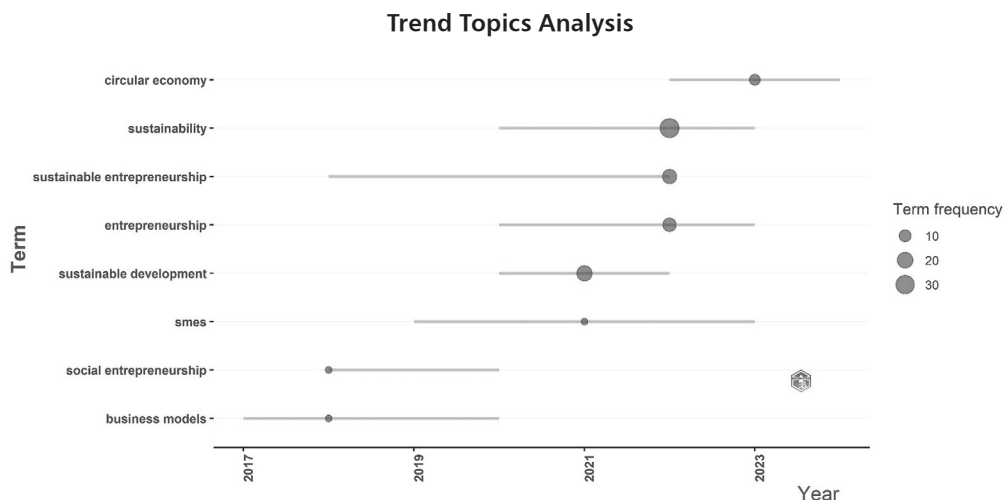
Thematic Evolution (Figure 8) indicates a progression in the maturity of thought on intellectual development, from a general discussion of sustainability to a greater focus on specific innovation strategies by 2024-2025.

Figure 8



Source: generated using Bibliometrix/Biblioshiny

Figure 9



Source: generated using Bibliometrix/Biblioshiny

Expansion into socio-economic levels (SMEs, developing countries) occurred in 2019-2021; 2022-2023 was the year of tactical diversification (Circular Economy, CSR, Green Marketing); and the present day focuses on Green Entrepreneurship and Circular Economy Integration, indicating a policy-driven, accelerated process.

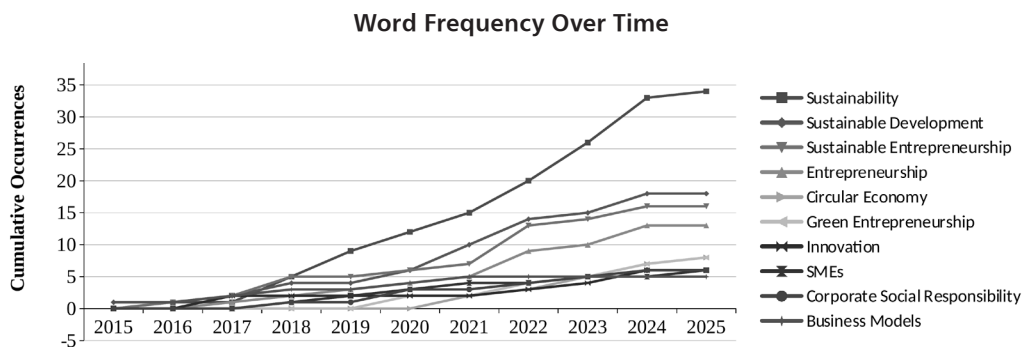
**Temporal Trend Analysis**

Temporal visualizations show how thematic priorities evolve over time. Trends Topics Analysis (Figure 9) shows that “sustainability,” “sustainable entrepreneurship,” “entrepreneurship,” “sustainable development” and “circular economy” have consistently been discussed since 2021. Similarly, the data from Word Frequency Over Time (Figure 10) supports this conclusion by showing a continuous increase in frequency of words such as “sustainability,” “sustainable entrepreneurship,” “circular economy,” “green entrepreneurship,” “corporate social responsibility,” and “business model innovation” for all years from 2015-2025. Therefore, there is clear evidence of an increasing focus on sustainable business practices.

**Three-Field Plot**

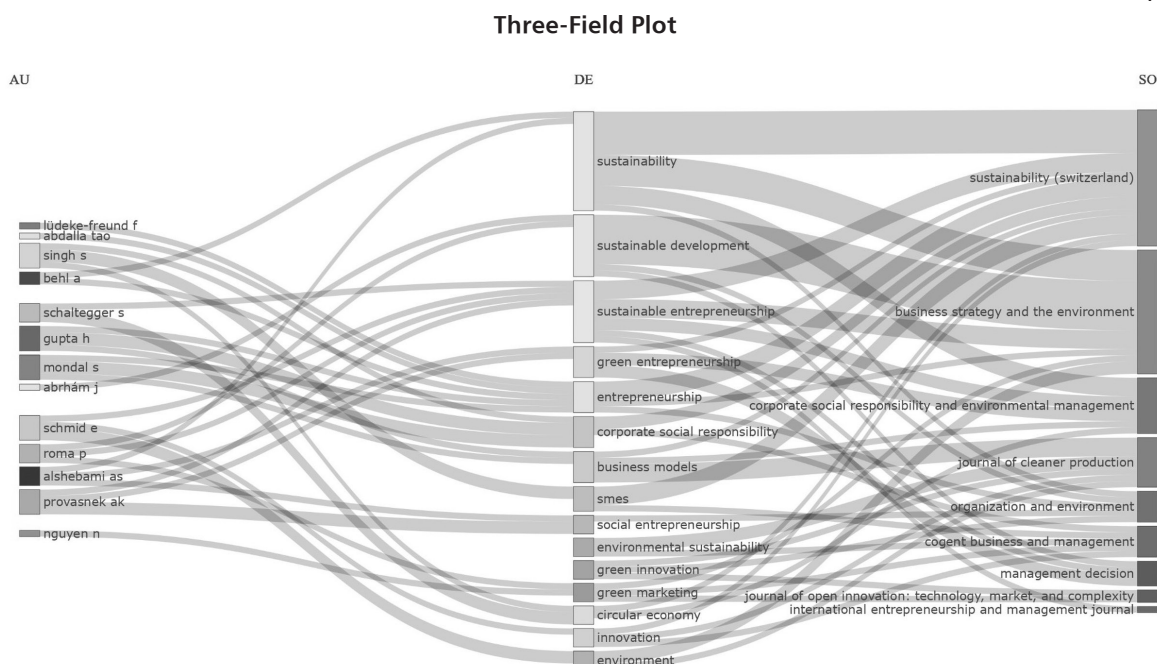
The Three-Field Plot (Figure 11) shows how researchers use their relationships with each other, research topics, and research venues to identify relationships among prolific authors, research themes, and publication venues. The key contributors to the field (Alshehami et al., 2023; Lüdeke-Freund et al., 2024; Schaltegger et al., 2016, 2018) have concentrated upon sustainability-related entrepreneurship research. The thematic landscape is organized hierarchically, with major themes (sustainability, sustainable entrepreneurship, sustainable development) connected to sub-themes (green entrepreneurship, corporate social responsibility, business model innovation, social entrepreneurship). Research output is concentrated in three journals (Sustainability, Business Strategy and the Environment, and Journal of Cleaner Production), but also appears in a large number of additional journals (Corporate Social Responsibility and Environmental Management; Journal of Open Innovation; International Entrepreneurship and Management Journal).

Figure 10



Source: generated using Bibliometrix/Biblioshiny

Figure 11



Source: generated using Bibliometrix/Biblioshiny

## Discussion and implications

This study addressed the four stated research objectives through bibliometric analysis of 157 publications. First, the performance analysis (*RO1*) identified leading publications, including Takalo et al. (2021) and Evans et al. (2017), as well as key journals such as *Sustainability* and *Business Strategy & Environment*. Second, the citation network analysis (*RO2*) identified six thematic clusters representing the field's intellectual structure. Third, tracking the temporal evolution (*RO3*) showed a shift from broad sustainability frameworks before 2020 to more focused innovation strategies by 2024-2025. Building on these empirical findings, the fourth objective (*RO4*) addresses critical research gaps related to longitudinal validation, geographic representation, and gender-inclusive research. This section provides theoretical, practical, and policy recommendations while also acknowledging the limitations of the methodologies used.

### *Thematic Synthesis and Cross-Cluster Insights*

The results underscore a diverse yet disjointed research arena (see Figures 7, 8, and 11). Business model innovation aimed at sustainability has emerged as a key focus, with studies such as Evans et al. (2017) and Stubbs (2019) highlighting the strategic reshaping of value-creation, delivery, and capture mechanisms. Recent meta-analytical evidence confirms the positive link between green and sustainable business models and sustainability outcomes across economic, social, strategic, and environmental dimensions (Mondal et al., 2022). Furthermore, the fusion of open innovation with alternative financing options, such as equity crowdfunding, offers a hopeful but less explored path. Additionally, Troise et al. (2021) and Franceschelli et al. (2018) demonstrate how novel funding frameworks can democratize access to sustainable entrepreneurship, with empirical evidence indicating that sustainability-oriented attributes in crowdfunding campaigns significantly impact funding success (Testa et al., 2020). However, empirical assessment across various contexts remains limited. This highlights a larger issue: although theoretical advancements outpace practical applications, challenges such as regulatory hurdles and consumer doubt hinder real-world implementation.

In addition, an interesting realization is the emergence of hybrid and transformative entrepreneurship models that aim to balance profitability, social impact, and environmental responsibility (Olteanu & Fichter, 2022; Schaltegger et al., 2016). Similarly, Reynolds and Holt (2021) provide evidence on how founders of hybrid organizations manage tensions between competing institutional logics, illustrating that sensemaking processes are essential for sustaining dual value propositions. However, the journey to achieving this equilibrium relies heavily on context and is often riddled with trade-offs, especially for SMEs with limited resources. These tensions highlight the importance of moving beyond idealized narratives toward sophisticated, multi-level evaluations that consider institutional, cultural, and market dynamics. Moreover, examining organic food SMEs has highlighted the key role of

niche markets in promoting sustainability shifts. These organic food businesses exhibit mixed objectives but face obstacles such as gender barriers (Dahiya et al., 2020) and the challenge of cultivating consumer trust (Reynolds & Holt, 2021). Furthermore, effectively communicating sustainable business models to consumers remains a significant challenge, with translation theory indicating that companies should present sustainability initiatives as relevant product features and impacts rather than using vague business model language (Viciunaite, 2022). This implies that entrepreneurship focused on sustainability needs to be considered within broader socio-cultural frameworks and linked to evolving consumer expectations identified in the temporal trend analysis.

### *Theoretical Implications*

This science mapping enhances the theoretical domain in multiple respects. Firstly, it advocates transitioning from static to dynamic, co-evolutionary models of green entrepreneurship (Schaltegger et al., 2016). Besides, recent advances in the theoretical understanding of sustainable business models underscore the importance of incorporating the principles of doughnut economics, which harmonize environmental limits with social essentials (Lüdeke-Freund et al., 2024; Preghenella & Battistella, 2021). Secondly, it highlights the crucial role of incorporating finance, governance, and entrepreneurial identity into models of sustainable business change. The notion of “biosphere entrepreneurship” (Frederick, 2018) further expands the horizon by making environmental responsibility a core entrepreneurial objective rather than a side concern. Additionally, existing literature still shows a divide between studies focused on micro-level entrepreneurship and analyses centered on macro-level policies or institutions. To address this gap, it is essential to integrate insights from circular economy research, which highlights how SMEs can implement sustainability principles through closed-loop systems and enhanced resource efficiency (Briguglio et al., 2021; Rodríguez-Espíndola et al., 2022).

### *Practical and Policy Implications*

The study highlights the need to empower entrepreneurs, especially in organic food SMEs, to embrace hybrid business models that combine environmental sustainability with profitability. Key strategies include using crowdfunding platforms, clearly articulating sustainability principles, and boosting stakeholder interaction to enhance market presence and organizational strength. Furthermore, empirical data from agricultural and food systems show that combining equity crowdfunding with open innovation methods can accelerate sustainability-focused innovation. However, the success of this approach relies on clear communication and active involvement of stakeholders (Troise et al., 2021). At the policy level, there is a significant necessity for comprehensive support systems that facilitate access to alternative funding sources, promote regulatory adaptability, and encourage cross-sector collaboration. Studies on institutional support frameworks indicate that both university-based entrepreneurial assistance and external institutional

backing are vital to translating green entrepreneurial intentions into action (Yi, 2021). However, the effectiveness of policies can vary significantly across geographical and institutional contexts, with facilitators and obstacles differing between startups that are inherently circular and established companies moving towards circularity (Briguglio et al., 2021; Rok & Kulik, 2021). Additionally, policies must also acknowledge the organic food industry's distinct social and cultural factors and address specific obstacles faced by underrepresented groups, such as female entrepreneurs. For example, Dahiya et al. (2020) highlight inadequate government support and limited awareness among stakeholders as the primary strategic obstacles facing women entrepreneurs in the organic food sector. They propose that targeted policy measures addressing these foundational issues could have beneficial ripple effects on related challenges, such as access to funding and market growth. Moreover, educational institutions and business incubators are crucial in equipping future green entrepreneurs. Cultivating skills in systems thinking, financial creativity, and strategic sustainability communication will be essential for providing entrepreneurs with the necessary tools to drive effective, sustainable transitions. Recent findings indicate that entrepreneurial education should focus not only on technical skills but also on aligning values and developing sensemaking abilities essential for navigating hybrid organizational logics (Reynolds & Holt, 2021). These actionable and policy insights highlight the importance of a unified ecosystem approach, where entrepreneurial innovation, supportive policy measures, and specialized education converge to promote sustainability in the organic food domain, in alignment with the emergent thematic clusters identified in the co-occurrence analysis.

### Future Research Directions

Three priority research areas arise from this study's findings. First, there needs to be long-term (longitudinal) studies on sustainable business models for organic food Small and Medium Enterprises (SMEs). These studies will need to examine the development of the business model during a period when an SME is transitioning from hybrid intent to institutional embeddedness, and also the role that digital financing platforms play in supporting or hindering the SME's sustainability outcomes. Furthermore, recent advances in digital transformation and sustainable entrepreneurship suggest that digital platforms can improve eco-efficiency in e-commerce (Iqbal et al., 2025), but there remains a lack of empirical evidence on eco-efficiency among organic food small and medium-sized enterprises (SMEs). Second, multi-regional comparative studies need to occur to determine how different institutional arrangements, gender dynamics, and consumer trust mechanisms influence green entrepreneurial emergence and persistence in under-represented contexts (i.e., Africa, Latin America, and Southeast Asia); as well as how organic certification infrastructures continue to evolve in these regions. Research conducted across different countries on the adoption of a circular economy indicates that the quality of institutions, levels of economic development, and cultural

influences notably affect how sustainability values relate to circular practices (Rodríguez-Espíndola et al., 2022; Urbaniec et al., 2022). This suggests that research designs tailored to specific contexts are crucial for making valid generalizations. Finally, it is important to empirically validate the integration of the circular economy within resource-constrained SME settings, using mixed-methods designs to both identify implementation barriers and document the micro-processes by which environmental commitments become operational practices. Recent studies by Briguglio et al. (2021) and Leendertse et al. (2021) on circular entrepreneurship indicate that startups integrating circular principles face unique challenges compared with established companies moving towards circularity, which affects both theoretical frameworks and practical applications. In addition to the previously mentioned areas, the field could benefit from critical examination of the "Sustainable Startup Paradox" through failure case analyses, in order to address the current survivorship bias in the literature; as well as, from gender-inclusive research designs that progress past barrier identification to include interventionist studies that document pathways to women's entrepreneurial success in the organic food sectors.

### Methodological Reflections and Limitations

The study used a multi-method bibliometric approach that included Citation Network Analysis, Global Citation Score Analysis, Keyword Co-occurrence Mapping, Thematic Evolution tracking, and Three-field Plot mapping to assess the overall intellectual structure of the literature. The extended time frame (2015-2025) enabled the identification of temporal trends, while following PRISMA-guided documentation standards ensured the clarity and reproducibility of the methodology.

However, several limitations warrant acknowledgment. The first limitation is that the study was limited to English language publications indexed in Scopus, which could introduce bias related to language and database coverage. As a result, academic works from non-Anglophone regions or indexed in other databases may be underrepresented. A second limitation is that citation metrics can indicate an article's scholarly influence, but do not necessarily reflect the actual application of that knowledge in practice or its potential policy impact. Accordingly, the study cannot directly assess the real-world applicability or policy influence of the analyzed articles. A third limitation is that minimum citation thresholds were required to visualize the citation networks. These thresholds may exclude recent articles that have not yet accumulated sufficient citations, particularly those published close to the data collection date (March 2025), and therefore may not appear in the citation network visualizations.

A fourth limitation concerns the interpretive aspect inherent in bibliometric analysis. While VOSviewer, used for citation network clustering, and Biblioshiny, used for keyword co-occurrence analysis, thematic evolution, and three-field plots, rely on systematic algorithms to uncover structural patterns, interpreting these results requires analytical judgment. Specifically, researcher involvement

was essential to (1) confirm the initial algorithmic cluster allocations; (2) merge the 20 initial clusters produced by VOSviewer into six theoretically coherent thematic groups; (3) provide conceptually meaningful labels for the cluster boundaries; and (4) clarify the conceptual links among the final thematic categories. Thus, alternative yet equally valid interpretations of the same algorithmic outputs may exist.

A final limitation is that bibliometric methods tend to identify measurable structural patterns rather than provide in-depth contextual interpretation. While they effectively reveal intellectual architectures and thematic trajectories, they do not capture the substantive contextual complexity embedded within individual studies. Future research might therefore benefit from integrating qualitative or mixed-methods approaches to triangulate and theoretically refine the patterns identified in citation and keyword networks.

## Conclusion

This bibliometric analysis of 157 publications (2015–March 2025) systematically mapped the intellectual structure of green entrepreneurship research within organic food SMEs, uncovering six interrelated thematic areas: sustainable business model innovation, financing green innovations, transformative entrepreneurship, circular economy strategies, institutional support systems, and hybrid business models for organic food. Citation network analysis reveals that the field has evolved from foundational theoretical concepts to empirical verification and context-specific applications, influenced by major sustainability policy frameworks such as the European Green Deal (2019) and the UN Sustainable Development Goals (SDGs).

Despite these advances, critical empirical gaps persist. Research predominantly concentrates in Western Europe and selects Asian contexts, limiting cross-contextual generalizability to Africa, Latin America, and Southeast Asia, where institutional frameworks differ significantly. Methodologically, the field relies heavily on cross-sectional studies and exhibits survivorship bias by focusing exclusively on successful cases, limiting understanding of mechanisms of sustainable business model failure and temporal development. Issues related to gender dynamics, digital transformation pathways, and the interplay between policy-entrepreneurship in emerging economies remain largely underexplored.

For researchers, this synthesis provides a structured framework for longitudinal, comparative, and context-sensitive methodologies addressing identified gaps. For policymakers, the findings underscore the need for tailored institutional support systems accounting for regional entrepreneurial ecosystem configurations, particularly in underrepresented areas. For practitioners, the analysis shows that hybrid business models and alternative financing mechanisms offer viable pathways to align sustainability goals with profitability in organic food enterprises. Advancing this research domain requires shifting from normative frameworks toward empirical validation, adopting diverse methodologies, and fostering

cross-regional collaborative networks reflecting the global diversity of green entrepreneurial ecosystems.

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# REVIEW OF PREPARATIONS FOR CSRD – AN EXAMINATION OF THE HIDDEN COMPLEXITY OF SUSTAINABILITY REPORTS AT HUNGARIAN PUBLIC INTEREST ENTITIES BASED ON INTERVIEWS

## A CSRD-RE VALÓ FELKÉSZÜLÉS ÁTTEKINTÉSE – A FENNTARTHATÓSÁGI JELENTÉSEK REJTETT ÖSSZETETTSÉGÉNEK VIZSGÁLATA A MAGYAR KÖZÉRDEKLŐDÉSRE SZÁMOT TARTÓ SZERVEZETEKNEÉL INTERJÚK ALAPJÁN

This study investigates the organisational preparedness and challenges Hungarian public interest entities (PIEs) face when implementing the Corporate Sustainability Reporting Directive (CSRD). This paper addresses a novel and relevant aspect of corporate sustainability, providing one of the first systematic, interview-based insights into an area of growing regulatory concern with limited empirical knowledge in the European Union's evolving sustainability landscape. Through semi-structured interviews conducted with sustainability leaders from eleven companies, this study reveals that regulatory alignment is enhancing reporting transparency, yet transitioning to externally assured non-financial data poses a substantial challenge. Interviewees repeatedly pointed to the assurance process as the forthcoming milestone and one of the most intricate aspects of sustainability reporting. This research suggests that fragmented data systems and rapidly changing reporting standards further impose difficulties for compliance with reporting, which demands greater accuracy, transparency, and methodological rigour. The empirical results offer valuable insights for both practitioners and policymakers.

**Keywords:** qualitative interview, sustainability reporting, Public Interest Entities, Hungary, CSRD

E tanulmány a magyar közérdeklődésre számot tartó gazdálkodók felkészültségét és a Vállalati Fenntarthatósági Jelentéstételi Irányelvhez (CSRD) való alkalmazkodás során felmerülő kihívásokat vizsgálja. A kutatás a vállalati fenntarthatóság egy újszerű és releváns aspektusával foglalkozik, és az egyik első mélyreható, interjúkon alapuló tanulmányt nyújtja egy olyan területről, amely egyre növekvő szabályozási aggodalomra ad okot, és amelyről korlátozott empirikus ismeretek állnak rendelkezésre az Európai Unió fejlődő fenntarthatósági környezetében. Tizenegy fenntarthatósági vezetővel folytatott félig strukturált interjú alapján feltártuk, hogy bár a szabályozói megfelelés növeli a fenntarthatósági jelentések átláthatóságát, a külső bizonyossággal alátámasztott fenntarthatósági adatokra történő áttérés jelentős új kihívást a vállalatok számára. A tanúsítási folyamatot egy következő mérföldkőként azonosították a vállalatok, mint a fenntarthatósági jelentéskészítés egyik legösszetettebb eleme. Eredményeink alapján a széttagolt adatrendszerek és a folyamatosan változó beszámolási követelmények tovább nehezítik a megfelelést, amely a pontosság, az átláthatóság és a módszertani szigor fokozott követelményeket támaszt.

**Kulcsszavak:** kvalitatív interjú, fenntarthatósági jelentéstétel, közérdeklődésre számot tartó szervezetek, Magyarország, CSRD

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### Authors/Szerzők:

Dr. Attila Jámbor<sup>a</sup> (attila.jambor@uni-corvinus.hu) professor (<https://orcid.org/0000-0001-8089-7222>); Anett Zanócz<sup>a</sup> (anett.zanocz@stud.uni-corvinus.hu) PhD student (<https://orcid.org/0009-0003-8849-0138>)

<sup>a</sup>Corvinus University of Budapest (Budapesti Corvinus Egyetem) Hungary (Magyarország)

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Over the past two decades, sustainability reports have become one of the most important measures for linking corporate performance to broader social and environmental performance. Global challenges such as climate change, biodiversity loss, and social inequality have heightened expectations that companies should be accountable not only to their shareholders but also to a broader range of stakeholders (Jain & Tripathi, 2023). Against this background, the Corporate Sustainability Reporting Directive (CSRD) represents a paradigm shift in corporate reporting and accountability, mandating standardized, externally assured, and sustainability-related disclosures useful for economic decision-making across the European Union (EU). The shift toward comprehensive, standardized, and assured sustainability reporting is pivotal to the European Union's sustainability agenda. CSRD expands the scope and rigor of required disclosures, placing significant new demands on companies (European Commission, 2022). Understanding how organisations prepare and navigate these changes is essential for policymakers and practitioners aiming to promote sustainability and transparency in corporate practices.

Although the EU's objectives are ambitious in improving transparency, comparability, and reliability, there is still growing concern that the transposition and implementation of the CSRD is underestimated. Hungarian Public Interest Entities<sup>1</sup> (PIEs), due to their scale, regulatory exposure, and public visibility, offer a critical lens for identifying these implementation barriers.

Despite apparent regulatory urgency, little is known about the organisational preparedness and practical obstacles these entities face during CSRD alignment.

This research addresses this gap by leveraging semi-structured interviews with ESG and sustainability leaders across eleven Hungarian Public Interest Entities. It sheds light on organisational and operational challenges that remain invisible in formal disclosures, such as problems with data transfer between departments, human resource constraints, and strategic uncertainty. This study is timely to inform policymakers, companies, and other decision-makers about the on-the-ground realities of sustainability reporting. The primary goal of this research is to critically examine the perception and reality of the challenges Hungarian companies face in preparing for compliance with the Corporate Sustainability Reporting Directive (IAASA, n.d.).

In short, this study aims to go beyond surface-level assessments of technical readiness and uncover deeper, often less visible barriers to effective implementation of CSRD. The research question is therefore:

*What are the key organisational, strategic, and operational challenges Hungarian Public Interest Entities face in preparing for CSRD-compliant sustainability reporting?*

To answer this question, the article is structured as follows. Section 2 reviews the evolving literature on sustainability reporting and regulatory developments. Section 3 outlines the qualitative, interview-based research methodology and sampling procedures. Section 4 presents the empirical findings, structured thematically to examine the current state of sustainability reporting, key organisational and strategic challenges, the integration of ESG considerations into governance, and comparative insights between local and multinational entities. This project contributes empirical, qualitative insights to the broader academic and policy discourse on sustainability regulation, particularly in CSRD post-transition economies. Section 5 discusses the implications of these findings for policy and practice, while Section 6 concludes with recommendations and future research directions. This study seeks to inform both scholarly understanding and regulatory development by capturing grounded, practitioner-level perspectives.

## Literature review

The growing emphasis on corporate accountability, along with rising stakeholder expectations and a changing regulatory environment, has significantly increased the importance of sustainability reporting. As a consequence, organisations are under greater pressure than ever to transparently communicate their environmental, social, and governance impacts (Papafioratos & Fragidis, 2025). This paradigm shift shows that people are beginning to recognize that business and social well-being are connected, and it challenges the standard idea that companies should only focus on creating value by making money for their shareholders (Yu et al., 2020). The increase in the number of sustainability reports can be explained by several factors, including growing pressure from stakeholders, regulatory requirements, and growing awareness of business risks and opportunities related to environmental, social, and governance issues (Bednárová et al., 2019). Stakeholders are demanding greater transparency and accountability from companies regarding their environmental, social, and governance, non-financial as well as financial performance (Amran & Ooi, 2014). Inadequate management of environmental, social, and governance risks can damage a company's credibility and reputation. Transparency and public disclosure can also help companies build trust with stakeholders,

attract and retain employees, and improve their access to external capital (Oprean-Stan et al., 2020).

In response to the growing demand for greater transparency and accountability, the European Union has taken a leading role in advancing sustainability reporting practices. The CSRD introduced by the European Union marks a turning point in the development of sustainability reporting standards, as it gradually requires a wider range of companies to disclose detailed information on their sustainability impact, performance, risks, and opportunities (Taliento & Netti, 2020). This directive aims to enhance the comparability and reliability of sustainability information, enabling investors and other stakeholders to make more informed decisions (Katterbauer et al., 2022).

This new directive is expected to promote transparency and accountability among companies, encouraging them to integrate sustainability factors into their core business strategies (Masud et al., 2018). The shift to comprehensive sustainability reporting, though, is a big deal for a lot of companies, especially small and medium-sized entities, which need to comply with the complexity of new reporting standards and develop the skills needed to collect, analyse, and report sustainability data (Permatasari & Gunawan, 2023). Sustainability reporting provides stakeholders with helpful financial and non-financial information in a more open and reliable manner (Benameur et al., 2023).

Despite the increasing global momentum towards sustainability reporting, substantial research gaps remain in understanding the specific challenges and opportunities faced by companies in different national contexts, particularly in emerging economies such as Hungary. Hegedűs et al. (2023) concluded that Hungarian listed companies show inconsistent and often limited compliance with EU non-financial reporting requirements, which reveals major shortcomings in their preparedness for upcoming stricter sustainability regulations, like the CSRD. Surman and Böcskei (2025) identified divergences in the way Hungarian SMEs interpret sustainability, underlining the differences in strategic and policymakers' orientations. While the EU promotes sustainable investments and non-financial disclosures in terms of sustainability and climate change (Bruno & Lagasio, 2021), the practical implications of these policy measures at the national level need further investigation. Although EU directives set out a common framework for sustainability reporting, their implementation and impact can vary significantly across EU Member States, depending on legal and institutional structures, business culture, and levels of economic development (Torre et al., 2018). This is also supported by the fact that some EU countries have still not fully transposed the CSRD (Accountancy Europe, n.d.). Understanding the localized impacts of ESG mapping could allow cross-country research comparisons (Papafloratos & Fragidis, 2025). Not to mention the firm size in terms of sustainability reporting, as Surman and Böcskei (2023) pointed out that SMEs are under increasing pressure, putting them in a more difficult position, not only in terms of reporting but also in terms of market competition.

There is a temporary suspension of certain CSRD reporting requirements, called the 'Stop the clock' initiative, which presents a complex challenge to the European Union's comprehensive ambitions for sustainability and corporate transparency. While this postponement reduces the immediate pressure on companies struggling with enhanced sustainability reporting, it also calls for a critical examination of the implications for the long-term direction of EU environmental and social governance (Nagy et al., 2025). It could also, unintentionally, slow down the integration of sustainability considerations into core business and investment decisions, undermining the EU's commitment to shift financial resources towards environmentally and socially responsible businesses (Pouille et al., 2024). Delaying action may allow companies to downplay sustainability initiatives, especially if they appear costly or complex, potentially slowing society's transition to a more sustainable economic model (Hamann et al., 2022).

In the meantime, many companies examine sustainability management and publish sustainability reports; however, the primary goal of these efforts remains unclear, indicating a need for the development of a clear strategy (Baumgartner & Ebner-Karestinos, 2010). Leadership commitment is key to successful quality changes, including the introduction of ESG practices, which is a significant step forward for any business. (Kim & Li, 2021). Managers have many roles to play, including articulating a clear vision for the future, continuously improving systems, aligning the organisation, delegating authority, providing adequate training, caring for employees, and ensuring appropriate style and role modelling (Niu et al., 2022).

Companies are increasingly realizing that ESG is not just a fashionable term, but a fundamentally important business requirement that contributes to long-term shareholder value and competitive performance (Lee et al., 2022). Corporate social responsibility and ESG are closely linked, and both reflect responsible business practices by companies (Mariappanadar, 2025). Integrating ESG into corporate operations has numerous benefits, including better risk management, more efficient use of resources, increased employee engagement, and improved corporate reputation (Kim & Li, 2021). The evaluation of ESG indicators is key for investors to make informed investment decisions, especially when looking at non-financial performance factors like corporate governance structures (Ahmad et al., 2023). The integration of ESG criteria is not only a costing exercise but can also represent a competitive advantage for companies (Barbosa et al., 2023).

Current ESG ratings, scores, and reporting mechanisms are inconsistent, non-standardized, and lack transparency and assurance, leading to greenwashing risks, flawed decision-making, and an urgent need for harmonization and regulation (Jámbor & Zánócz, 2023). Mayer and Ducsay (2023) investigated the differences in the methodologies used by the most reputable ESG rating agencies and highlighted the issues associated with historical ESG data from many companies. There is an observable difference in environmental and ESG disclosures between

European and Asian corporations. Therefore, regulatory authorities and policymakers can benefit from the results of studies to formulate comprehensive guidelines and practices for environmental disclosure and sustainability reporting to attain sustainability objectives (Almaqari et al., 2023).

Furthermore, there is a gap in the literature concerning the role of financial information in influencing the quality of non-financial reporting based on sustainable development goals (Nechita et al., 2020). While some studies have explored the relationship between financial performance and sustainability disclosure, more research is needed to examine how economic factors influence the scope, accuracy, and credibility of sustainability information reported by companies. The effect of financial statements on sustainability has to be investigated to determine if the annual financial data and disclosures influence sustainability disclosures.

The lack of research on sustainability reporting practices and CSRD readiness in Hungary represents a significant gap in the literature. It is particularly important given the growing importance of sustainability reporting in attracting investment from abroad and enhancing corporate reputation (Cicchiello et al., 2021). Prior research concentrated on organisational impediments to environmental actions at Hungarian firms (Zilahy, 2003), but more research is needed to examine the scope to which these barriers impact CSRD readiness. This study aims to contribute to filling this gap by providing insights into the current state of sustainability reporting practices in Hungary and the challenges and opportunities faced by companies in preparing for the CSRD.

## Research Design and Methodology

In this article, we show the behind-the-scenes aspects of sustainability reporting to provide a comprehensive view of stakeholders' current experiences, challenges, and perspectives. Between July and September 2024<sup>2</sup>, eleven interviews were conducted to gather insights on non-financial reporting from recent years, focusing on companies previously covered by the Non-Financial Reporting Directive (NFRD). This includes large domestic companies of public interest that are now subject to sustainability reporting requirements under the CSRD starting in 2024. Each interview typically lasted one hour and included 2-3 experts from the respective companies. With the exception of the insurance sector, we successfully included banks and manufacturing/service companies in the review.

The research was conducted in two phases: first, companies were identified, and the sustainability reporting background was examined. This allowed us to understand how companies have addressed sustainability reporting in recent years. We used this background knowledge to prepare for interviews, having already gained an understanding of the strategic integration of sustainability within the company, the level of reporting, and the involvement of independent external auditors. This study aims to uncover background knowledge that would suggest sustainability

is already integrated to some extent into the strategic processes of companies. We also examined the external assurance dimensions used in companies' most recent ESG/sustainability reports or integrated reports. Due to the novelty of the topic and the recent introduction and continuous changes in legal requirements, our aim was to identify past experiences, present challenges, and future goals that are not yet captured in formal published documents of companies but are only present in the minds of those responsible for ESG (Bowen, 2009). Overall, the study aimed to collect context-specific, detailed, and sufficiently comprehensive data that may not necessarily be revealed in sustainability reports, to frame better current corporate strategies for sustainability transition and legislative preparation.

The methodological approach for this research centres on conducting semi-structured interviews with key individuals within Public Interest Entities. We chose semi-structured interviews to balance between exploring predefined topics and allowing for flexibility in exploring emerging topics, thereby ensuring a comprehensive understanding of the research topic (Sharma & Choubey, 2021). The companies interviewed are those pre-identified by Opten Ltd. to be under the scope of CSRD (and were those required to prepare non-financial reports by NFRD) and verified by us as falling within the statutory term of large Public Interest Entities in Hungary under the first phase of CSRD regulation. The focus on PIEs is based on the fact that they play a crucial role in the economy, and their awareness of regulatory monitoring and public accountability makes their operational and strategic decisions particularly relevant for academic research (Birt et al., 2017).

This qualitative research design is specifically tailored to gather in-depth insights into the perceptions, experiences, and strategies these entities employ in navigating the dynamic landscape of the Hungarian PIEs (Nawangარი & Sutawijaya, 2019). Triangulation is essential in qualitative research, particularly in interviews, as it enhances the validity and depth of research findings. While respondents often provide valuable insights into their experiences, their stories may be biased, incomplete, or influenced by memory or self-interest. Triangulation mitigates these limitations by supplementing data from semi-structured interviews with data from multiple methodological sources, such as document analysis, observations, and cross-checking by multiple researchers. Document analysis is particularly common, as it enables researchers to acquire extensive contextual knowledge about respondents and their circumstances, thereby improving the accuracy and reliability of data interpretations (Natow R. S., 2020).

These techniques were used throughout the analysis, starting with the formulation of the interview questions: in all cases, we conducted interviews after a preliminary document analysis, which explored the companies' experiences in sustainability reporting based on publicly available information. This allowed us to focus more specifically on the answers to the interview questions when

asking further interpretative questions. We cross-checked the interview transcripts to ensure that both of us had arrived at similar conclusions, and we had each transcript validated by the companies themselves to confirm that what we had understood during the transcription process was indeed what the companies intended. Afterwards, the interviews were analysed and classified, thereby confirming the objectivity of the research findings.

The interview questions were explicitly tailored to the unique situation of each organisation, ensuring that responses were relevant and detailed, and truly reflected the organisations' current role in sustainability reporting (Adeoye-Olatunde & Olenik, 2021). The interviews followed a clear chronological order, beginning with past experiences and historical background, proceeding to the present, and concluding with hopes, opportunities, and plans for future growth. This timeline was intentionally created to illustrate how the organisation's sustainability efforts have evolved and changed over time, and to provide an idea of how these initiatives have developed and are expected to grow in the future (Longhurst, 2009).

Table 1

## Structure of the interview questions

Group of questions	Purpose of questions
<i>General characteristics of the company (2 questions)</i>	Getting to know the companies, exploring their activities, identifying industry specifics
<i>Reporting practices in previous years (4 questions)</i>	Exploring the extent to which reports comply with domestic non-financial reporting practices, and whether there are any related risks or challenges.
<i>The current relevance of sustainability reporting in the company's operations (4 questions)</i>	Exploring the role sustainability has been given in corporate life and how it is reflected in corporate operations and strategy
<i>Complying with the requirements of the Corporate Sustainability Reporting Directive (4 questions)</i>	The challenges and opportunities companies have found in CSRD and assurance processes.
<i>Future perspectives and improvements (2 questions)</i>	Further plans to integrate sustainability into business activities and advice for companies that are just starting or have not yet prepared their own sustainability reports

Source: authors, based on interview data

In addition to the chronological dimension, we also grouped the interview questions thematically, moving from general, broad questions to more specific, company-focused topics (Table 1). The open-ended questions created a comfortable and open atmosphere for respondents, encouraging them to share their opinions honestly and experiences freely, while the semi-structured questions ensured that key areas of concern were thoroughly addressed (McIntosh & Morse, 2015). It also provided rich

and detailed insights into the specific sustainability challenges and opportunities faced by companies (Lozano et al., 2018). The use of this type of interview allowed us to systematically explore sustainability practices while providing flexibility to explore new topics and individual experiences in greater depth (Adeoye-Olatunde & Olenik, 2021).

The clear, time-based structure of finalized interview scripts was particularly useful when examining organisational functioning, institutional changes, and adaptation to rules, as it allowed respondents to share their experiences based on their insights (Tureta et al., 2021). This approach enabled a consistent understanding of the evolution over time of organisations' responses to sustainability challenges and opportunities (Adeoye-Olatunde & Olenik, 2021). The iterative nature of qualitative research allowed for the modification of interview questions as preliminary data analysis provided further insight, making it more efficient to elicit the necessary information (DiCicco-Bloom & Crabtree, 2006). Following these principles, this study has gathered comprehensive and rich data that provide a solid basis for understanding the challenges associated with corporate sustainability efforts.

The interview participants (*online Appendix 1*) were selected based on a targeted sampling strategy, aiming at individuals in leadership positions or those directly involved in sustainability decision-making processes at the selected public interest banks and corporations. This approach made sure that the people in the sample had the knowledge and experience to give valuable insights into the research and interview questions. It should also be noted that the planned interviews began with the involvement of all relevant Hungarian Public Interest Entities in the scope of CSRD, and the sample was then formed based on their feedback, depending on whether we received positive feedback for conducting the interviews. The interviews were conducted in the participants' native language, Hungarian, to ensure clear and sophisticated communication (Pratihari & Uzma, 2019).

After data collection, we aimed to transcribe the interviews as completely as possible. The transcripts were reviewed by both authors, and the combined versions were subjected to rigorous qualitative data analysis using NVivo, a software programme specializing in qualitative data management and analysis. Table 5 in online Appendix 1 shows the steps involved in data collection, processing, and analysis. This study employs a thematic coding method, in which the interview transcripts were systematically analysed to find patterns, topics, and concepts that kept coming up in relation to the research questions. The coding process was iterative, allowing for refining and expanding the coding system as new topics were identified in the data. The actual codes were generated from the existing literature and the research question (Loganathan et al., 2022). In addition, reflexivity throughout the research process was applied, critically examining assumptions, biases, and perspectives to minimize the impact on data analysis and interpretation.

## Results

In the next section, the analysis of results structured into three thematic areas is presented, which in many cases correspond to and supplement the literature review.

### Experiences from prior years

A set of frequently recurring challenges and lessons is presented in Table 2 as the ‘greatest common denominators’. The purpose of the non-financial reports is to present the company’s sustainability achievements, challenges, and changes and to meet the information needs of capital market participants, shareholders, investors, and analysts. Banking and industry interviews have consistently highlighted that aggregating sustainability data has become a complex, multi-level challenge. Entities need to gather data from countries with diverse regulatory environments, while covering an increasingly broad range of topics, including customer ESG profiles and Scope 3 emissions. Group-level compliance requires further coordination with foreign-owned companies, while the scope of supervisory reporting, particularly to the MNB and the EBA, has been constantly expanding. Collecting sustainability data is a significant challenge, particularly when information must be gathered from various parts of the company and external partners, which necessitates substantial coordination and effective internal communication across different countries. Interviewees emphasized that reliable and consistent data require long-term, coordinated work across multiple departments, with several data collection cycles per year.

In several interviews, company executives emphasized that the strategic importance of sustainability reports should not be underestimated; they have become key documents for credibility, capital market confidence, and regulatory compliance. Large companies publish reports with increasing amounts of data every year and are also investing more energy in internal communication so that employees understand both the workload involved in preparing the reports and their value in terms of reputation. All of this resonated with the idea that, according to company executives, a culture of sustainability can only be built through gradual, consistent mindset changes. Several respondents literally stated that *‘the mindset must be shaped continuously, step by step and consistently’* – internal training, thematic campaigns, and external partnerships can therefore become the drivers of change. CIB Bank Nyrt. said that *‘Integrating data collection and analysis into the corporate management system is a huge challenge, and this goes hand in hand with continuously developing our employees’ knowledge so that they can deal with sustainability issues in a professional way’*. This learning curve is not just about knowledge transfer, but also about transforming the logic of decision-making and risk management. According to the research subjects, the most critical limiting factor for sustainability transformation is human and financial capacity. Many companies indicated that a lack of expertise and dedicated working hours hinders the development of ESG data collection, especially

among smaller actors. Even large Public Interest Entities require several years of resource allocation to build control systems and auditable databases. The time-consuming nature of organisational preparation means that it is advisable to secure extra capacity during the planning phase. Continuous compliance with regulatory requirements is therefore not a one-off exercise, but a long-term, resource-intensive corporate programme. Richter Gedeon Nyrt. concluded that *‘Sustainability information is generally collected from a variety of sources, which can make it difficult to harmonize and synthesize the data. Therefore, it is advisable to allocate adequate human resources and systems from the outset’*. Entities without an international parent company have to build everything from the ground up, while working under constant time pressure alongside their core activities.

Some of the interviews highlighted the rapidly changing EU-level rules (CSRD, ESRS, EU Taxonomy, SFDR, CSDDD) and Hungarian ESG laws as a concern. Companies were not only tasked with ‘translating’ and interpreting legal texts, but also with incorporating more than 1,100 new data reporting indicators under the CSRD and developing a double materiality assessment methodology. As a result, sustainability reporting has become a separate, cross-functional project at many companies.

Table 2

#### Summary of prior years’ experiences of companies preparing non-financial reports

<b>Developing data collection and integration process</b>	Collecting sustainability data is a significant challenge, especially when information needs to be gathered from different parts of the company and external partners, which requires significant coordination and effective internal communication.
<b>Understanding the importance of reporting</b>	Don’t underestimate the value of sustainability reports. They present a significant and often overlooked challenge that is worth bringing to the attention of your colleagues.
<b>Resources and time allocation</b>	Reporting is ‘extra work’ that needs to be treated as a separate project. It can take up to 1.5-2 years of preparation and can be done more efficiently with serious IT support.
<b>Interpretation of regulations and other requirements</b>	Interpreting and adapting to new regulatory requirements is a time-consuming task for almost all companies during the first reporting period and changing data collection practices requires continuous updating.
<b>Quality over quantity</b>	Rather than focusing on the quantity of sustainability measures, prioritizing quality can yield better results.

Source: authors, based on interview data

Experienced preparers also pointed out that excessive data volumes can reduce the comprehensibility of reports. The market and investors prefer well-structured, visually supported content rather than an accumulation of indicators;

therefore, companies are increasingly highlighting relevant indicators and presenting them in an easy-to-understand way using infographics. Also, the polarization of commitment level has an impact on data availability and quality, which means companies have experienced varying degrees of engagement to sustainability among corporate leaders and experts, particularly within the supply chain.

**Impact on corporate decision-making**

Integrating sustainability data into corporate governance goes hand in hand with continuous training for employees, so it is essential for companies to put emphasis on both internal and external training. In addition, most interviewees are aware that, as the first to be involved, they play an exemplary role in sustainability reporting. They mentioned that they do workshops and other educational content to help their internal and external stakeholders understand ESG. OTP Bank Nyrt. is one of the pioneers in this area, as they mentioned, *‘In addition to complying with legal requirements, OTP Bank produces sustainability materials that are easier to understand and more accessible to stakeholders’*.

Due to the approximately 1,100 indicators in the CSRD, the double materiality analysis, and the rapidly changing set of expectations, dedicated, cross-functional teams are needed instead of a single *‘all-purpose’* ESG expert. There is often a lack of knowledge on the advisory side, while companies have to deal with complex financial and operational details. Several respondents also emphasized the role of IT and resource development in supporting sustainability goals *‘at all levels’*. Due to the labour-intensive nature of manual data collection, several companies are already working on developing automated platforms for digital data automation. Magyar Telekom stated that most ESG data comes from outside the ESG team, and coordination success depends on aligning numerous data owners and audit-ready processes within the group, emphasizing the importance of expert roles in data management and reporting governance. MOL Nyrt. also formalise these tasks into a dedicated ESG coordination team that manages the entire reporting process: *‘We have a separate ESG coordination team that manages the entire reporting process and is able to think strategically in collaboration with individual managers’*. Raiffeisen Bank, meanwhile, treats preparation for CSRD as a separate project, carrying it out through cross-functional teams and, where necessary, forwarding it to ESG experts for in-depth review. This points to specialization of roles rather than expecting a single professional to know everything. In addition, several market participants aim for the EU Taxonomy to serve as a common language, K&H Bank Zrt. referred to as a *‘golden standard’* for investors and other stakeholders, reducing the risk of greenwashing through clear definitions. This includes standardizing ESG metrics and ensuring they are closely aligned with financial performance so that reports provide truly comparable, decision-supporting information.

Sustainability reporting extends beyond simple data collection, and it integrates sustainability metrics into

strategic planning, risk management, pricing, and overall corporate governance. Companies are increasingly recognizing that the expectations of customers, investors, and financiers often go beyond legal requirements. In banking, ESG scores are integrated into credit assessments, and low scores can *‘induce reputational or credit risk’*. In production companies, customer demands in the supply chain often require higher sustainability standards than mandated by law. With CSRD requirements, companies can expect external pressure to intensify, so transparency in sustainability reporting will not only be a compliance requirement but will also become critical to reputation and competitiveness. Several banks confirmed that open data reporting improves reputation and market position. Because these are profit-driven companies and major contributors to the economy, it is essential to contribute to increasing competitiveness or staying competitive. A recurring issue in interviews was that these growing external pressures are driving cultural change within organisations, from a traditional, *‘stability first’* top-down compliance approach focused on risk avoidance to a more participatory, bottom-up culture.

Based on the interviews, sustainability considerations have to be deeply embedded in strategic business decision-making, as these reports are not merely communication products but essential tools for risk management, product development, and governance systems. CIB Bank, for example, reported that following the NFRD and later the CSRD, the *‘sustainability report has become a real strategic tool that is integrated into all areas of the bank’s operations’*. Similarly, their publication’s analysis highlights that the synergistic exploitation of sustainability and social responsibility dimensions will be a prerequisite for competitiveness in the future (CIB Bank Zrt., n.d.). The summarised results can be found in *Table 3*.

Table 3

**Summary of impact on corporate decision-making**

<b>Employee education</b>	Developing employee expertise is a key element in improving corporate sustainability performance. This affects and requires almost all areas of a company.
<b>Developing specific roles</b>	There is no such thing as a <i>‘one-size-fits-all’</i> expert. It is unrealistic to expect someone to handle operational details while also having a wide range of knowledge: still, the sustainability experts must have a broad range of skills.
<b>Golden standards for transparent communication</b>	The aim is for the EU taxonomy to become a generally understandable and clear gold standard for all stakeholders.
<b>Thinking beyond regulatory compliance</b>	It is not enough for companies to comply with regulatory requirements; they must also consider the growing sustainability demands of their customer base.
<b>Enhanced strategic integration</b>	Corporate sustainability practices should not only be an integral part of strategy but also strengthen market competitiveness.

Source: authors, based on interview data

### Tips, best practices, and business opportunities

Five areas were identified for future development, as well as best practices for companies that are not yet preparing sustainability reports, and the summarised results can be found in *Table 4*. The logic is as follows: ‘leadership – communication – culture – process – technology’. Based on the interviews, sustainability reports can turn into a real competitive advantage if they are backed by years of persistent commitment from management. Waberer’s, for example, highlights nearly a decade of gradual development, in which reporting has become ‘*an integral part of everyday operations*’ and the auditor is involved from the very beginning of the process. Some banks similarly emphasize that management is creating a culture ‘*step by step and consistently*’, because without a long-term vision, regulatory compliance alone does not create reputation or market advantages.

A common goal for the future is that sustainability reports should honestly present the results achieved and areas for improvement. Waberer’s specifically mentions the confidence-building effect of ‘transparent communication’, while Richter considers it a strategic priority that all employees understand and spread the company’s ESG messages. According to the banks, credible, well-structured external communication also improves access to funding and investor acceptance.

Several interviews revealed that a breakthrough in sustainability can be achieved not only through top-down management, but also by involving committed employees. Some companies’ long-term plans include ‘empowering enthusiastic colleagues to take the lead’ because this enables rapid adaptation and innovation. Respondents identified internal awareness, achieved through training, company-wide environmental or social campaigns, and podcasts, as a potential competitive advantage. Companies preparing their first CSRD report should involve key areas and external partners as early as possible. Waberer’s and K&H also emphasize early consultation with auditors to develop evidence and documentation systems together. MBH Bank and Magyar Telekom, on the other hand, warn that coordinating diverse internal data sources, standardizing definitions, and timing will be particularly resource-intensive in the first round.

Interviewees also suggest that companies start sustainability reporting gradually, developing their approach step by step while keeping their practices and sustainability goals aligned. This allows for continuous improvement without overburdening resources at the start. It is essential to balance sustainability initiatives with core business activities, as overly ambitious goals can give the impression that core business activities are secondary. Raiffeisen Bank Zrt. thinks that ‘*The key to success lies in adaptation and commitment to meeting CSRD guidelines and sustainability goals*’.

The key to the future is an automated, auditable data platform: K&H is already working on digitizing data to reduce the number of manual errors. CIB Bank has long-term plans to integrate the IT support needed for ESEF tagging and double materiality reporting, while OTP’s

in-house platform simplifies group-level data collection. As we can see, the interviews highlight that IT developments are essential for future quality and business expansion. They summarised their progress in sustainability reporting with ‘*However, this process is only the tip of the iceberg, as the real challenge lies in how to benchmark the data and integrate it into business operations to create real value for the bank*’. – K&H Bank Zrt.

Table 4

#### Summary of future targets and best practices for other companies

<b>Step-by-step long-term management commitment</b>	The benefit of the sustainability report lies not in the report itself, but in the years of dedicated work that have gone into it, which translates into market strength.
<b>Clear corporate communication</b>	Sustainability performance must be presented and areas for improvement acknowledged through honest and transparent communication.
<b>Bottom-up initiatives for a sustainable corporate culture</b>	Success can also come through bottom-up initiatives and motivation, enabling quick adaptation to economic changes and creating a real competitive advantage from sustainability reporting.
<b>Internal coordination processes</b>	Starting the reporting process early and coordinating work with other departments leads to better results.
<b>Technology – IT support establishment</b>	Integrating long-term IT support to improve the quality and scope of sustainability reports, in line with processes and regulatory requirements.

Source: authors, based on interview data

### Discussion

Based on interviews with eleven large Hungarian Public Interest Entities participating in the research, the most important experiences and challenges related to the introduction of CSRD can be clearly outlined. Focusing on PIEs is necessary because, compared to other companies, PIEs are subject to higher expectations and more rigorous legal obligations in terms of corporate transparency. In addition, these companies are the first to be involved in sustainability reporting and will remain so in the coming period. Examining PIEs’ responses to CSRD provides early indicators of systemic challenges and practical solutions that may be relevant for other types of organisations as reporting obligations expand. Furthermore, the complexity and diversity of the challenges faced by PIEs makes the models developed for PIEs highly informative for both regulators and other firms seeking to navigate an evolving sustainability landscape.

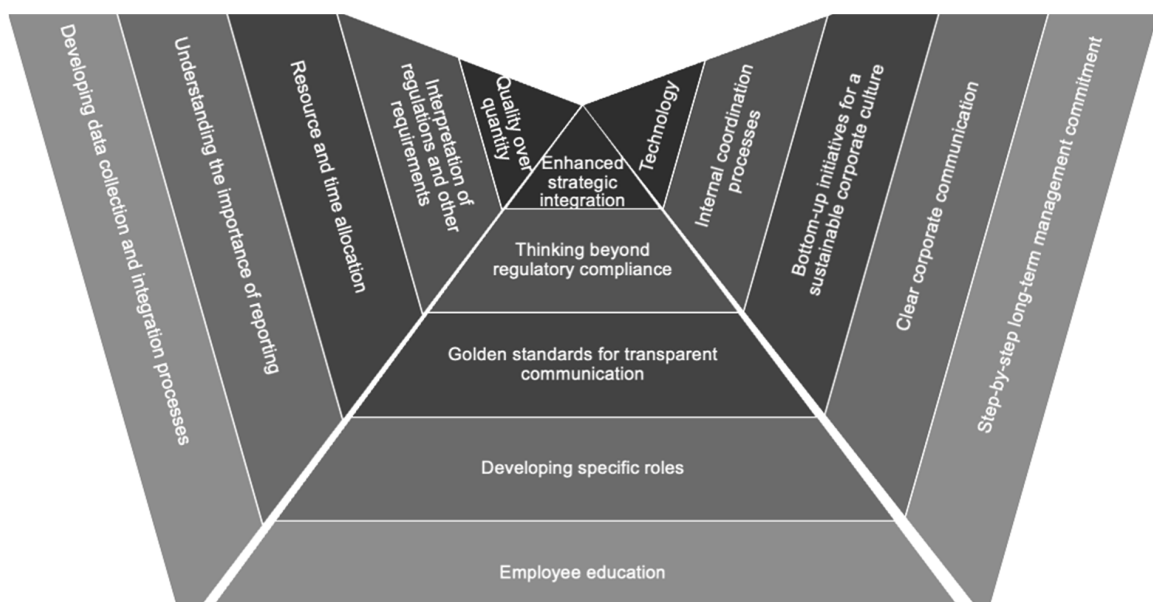
*Figure 1* presents the hierarchical clustering of the main thematic areas identified during the analysis of Hungarian PIEs for CSRD compliance. The left-hand side of the figure illustrates the challenges arising from past reporting practices, the centre of the figure shows

the current challenges and reporting difficulties faced by companies, while on the right-hand side, future-oriented issues are highlighted. This structure visually summarises the CSRD transition, as Hungarian PIEs not only have to overcome long-standing structural barriers but also adapt to the unique new requirements of the directive. This evolution reflects the argument of Katterbauer et al. (2022) that regulatory changes in transition economies bring existing operational constraints to the front. This complements the findings of Hegedűs et al. (2023), who argue that while inconsistent compliance is widespread in Hungary, the CSRD accelerates and enhances both previous and newly emerging challenges. Companies that had already prepared reports, whether with GRI standards or other frameworks, had a significant advantage. This is consistent with the Western European findings of Baumgartner and Ebner-Karestinos (2010). However, it differs from the literature that considers regulation to be a linear driver of change; therefore, a comprehensive and long-term strategic approach is still lacking in many cases.

The CSRD outlines new reporting requirements, accompanied by strict and tight deadlines for disclosure, which will be validated by an independent auditor. Companies recognized that independent assurance of sustainability reports is becoming a mandatory regulatory requirement under the CSRD, rather than an optional practice, which significantly increases the complexity of reporting processes. This aligns with OTP's approach: *'In our reporting processes, we place great emphasis on the role of independent external assurance, which adds further trust and credibility to our published reports'*. The development of transparent and standardized data reporting is also of paramount importance. Data collection, particularly for Scope 3 emissions and supply chain data, presents a significant organisational and technological challenge. According to companies, IT system development and early coordination are needed to address these challenges. Based on the interviews, it also became clear that the success of preparations for CSRD depends largely on honest, quality-focused communication. Instead of dis-

Figure 1

### Thematic clusters of Hungarian PIEs' CSRD compliance challenges in the past, present, and future



Source: authors, based on interview data

In line with our findings, PIEs are moving away from a 'stability first' compliance model towards a stakeholder-driven, bottom-up adaptation model. Compliance with EU and international regulations is a foundational step, but interviewees strongly recommended that companies should not wait until requirements become mandatory for them; if they can, they should start voluntary, proactive compliance processes to better manage the complexity of the transition and strategies. These qualitative data support the idea put forward by Lee et al. (2022) that leadership and culture are key factors in ESG maturity. Amran & Ooi also stated that stakeholder expectations often push companies much further than legal requirements would do, demanding deeper integration and innovative approaches to sustainability.

torting data or greenwashing, transparency and openly presenting areas for improvement can build trust in the long term and provide a competitive advantage.

Figure 2 summarises the most important findings from the interviews for developing corporate sustainability. The increased demand for continuous education of ESG professionals and closer cooperation between universities and companies will be essential to maintaining high professional standards in sustainability. The crucial role of continuous professional training, improving internal knowledge sharing, and transparent communication is closely aligned with the points highlighted by Niu et al. (2022) and Kim & Li (2021), who emphasize capacity building and organisational learning as critical factors for

ESG development. It is worth noting that the figure treats strategic data integration, transparent and reliable data systems, and regulatory compliance as equal to cultural and educational priorities – a subtle point that has rarely been highlighted in previous Western European or global studies, but which the respondents placed great emphasis on due to Hungary’s recent rapid regulatory changes. This visualization, therefore, not only shows the interconnection of human and technical factors but also the explicitly holistic approach that is necessary for the successful implementation of CSRD after the transition period.

Figure 2 Key findings from Hungarian PIEs on corporate sustainability development



Source: authors, based on interview data

The relief of immediate reporting obligations through the ‘Stop the clock’ proposal may inadvertently signal a weaker commitment to corporate sustainability in the EU, which could lead to scepticism among stakeholders about the ambition and credibility of the EU’s sustainability programme (European Council, n.d.). This supposed uncertainty may undermine the effectiveness of sustainability reports as a mechanism for promoting changes in corporate behaviour and strengthening environmental responsibility. The Directive’s impact extends far beyond mere compliance requirements, shaping companies’ overall approach to sustainability (Torre et al., 2018). The question of whether the ‘Stop the clock’ directive weakens previous EU regulatory objectives requires further detailed analysis.

Reporting challenges are not stand-alone findings but are widely confirmed by the research of Bednárová et al. (2019) and Oprean-Stan et al. (2020), who also document the complexity of ESG data integration in Central and Eastern European countries. According to interviewed companies, the real benefit of sustainability reporting lies not in the document itself, but in the years of internal work, structured process organisation, and education that underpin it. This research provides a significant empirical insight by being the first known study to systematically

explore the challenges Hungarian Public Interest Entities face in implementing the CSRD through qualitative interviews. By gathering in-depth, firsthand perspectives from ESG professionals and corporate leaders, the study captures subtle barriers that are often absent from formal documentation or public reporting. The study also holds strong practical relevance by supporting corporate ESG professionals and auditors in identifying internal challenges to high-quality reporting. These results can help companies improve their reporting practices and prepare more effectively for regulatory monitoring, ultimately enhancing transparency and accountability.

The limitations of the research primarily concern the relatively small sample size, although it was carefully selected in terms of depth and quality, as well as the context-dependent nature of the findings. Future research could be extended to comparative studies in other EU Member States or specific industry analyses, longitudinal studies to monitor ongoing adjustments and adaptations, and quantitative analyses to validate the qualitative findings presented. Overall, although regulation suspension temporarily eases the immediate reporting pressure, companies should not let up on their sustainability efforts. As MOL Nyrt. concisely stated: *‘Being sustainable is now a moral responsibility’*. Companies must therefore stay focused on promoting sustainable strategies and transparent reporting, ensuring that short-term regulatory adjustments don’t hinder long-term sustainable development and the integration of environmental and social considerations into their core business.

## Conclusion

This study is one of the first to present a qualitative, interview-based insight into the specific challenges and responses of Hungarian organisations during the initial implementation of the CSRD. This systematic study of Hungarian Public Interest Entities’ CSRD preparation offers insights distinct from SMEs or Western EU cases but contains knowledge that can be applied generally. Drawing from the insights shared by the interviewed companies, it is evident that sustainability reporting has evolved significantly, driven particularly by regulatory pressures. By capturing the experiences of practitioners in a post-transition EU economy, this research fills a critical gap in the European sustainability reporting literature. Even though the companies highlighted that the sustainability report reflects long-term commitment, the value of the sustainability report lies not in the report itself, but in the years of dedicated work that went into it, making it a source of market strength and a model of best practice. One of the main influencing factors is corporate structure, which is given for companies, since a company with a foreign parent company faces different problems than one that wants to build its own sustainability reporting system independently at the domestic level.

In contrast to previous studies focusing on technical compliance, our results reveal the hidden complexity, organisational learning processes, and the importance of

certainty in CSRD compliance. The value of this study lies in the practical guidance it provides, supporting both policymakers and business practitioners with evidence-based recommendations drawn from real-world business experience. The most important point that emerged from the interviews is that, although many organisations have made significant progress in their sustainability strategies and data reporting processes, auditing sustainability data is the next major milestone for them – and perhaps the most challenging element – in terms of compliance. However, the path to reliable assurance presents several challenges. These include ensuring accurate, complete, and consistent data collection, maintaining reliable methodologies, and establishing transparent processes that meet strict auditing standards. The interviewees noted that assured ESG data enables higher accountability and transparency, as it necessitates deeper internal coordination, thorough documentation, and increased cooperation among various parts of the organisation. It can also be argued that integrating sustainability considerations into business and strategic activities has been directly or indirectly influenced by the NFRD and other domestic requirements. With the introduction of the CSRD, this trend is further strengthening among companies.

Consistent handling and interpretation of definitions is a common problem among companies, which is a particularly complex task. In addition, tracking changes in data from year to year and developing a data collection structure can also be challenging, especially for larger companies and corporate groups that often engage in diverse activities. Data collection is further complicated by the dual logic of banks, which means that they not only have to produce their own sustainability data but also consider the sustainability data of their customers in order to optimize their internal operating processes. Therefore, it is vital that companies develop transparent and consistent reporting systems that allow them to operate more effectively and accountably. However, the reliability and usefulness of these reports are currently limited, despite companies' commitment to providing accurate information.

Reporting and assurance require patience, time, and the involvement of experts from various fields, as well as the support of accounting colleagues. Most interviewed banks and companies have placed great emphasis on the timely preparation of the necessary reporting processes and data collection tasks, as well as on the double materiality assessment introduced as part of the new directive, which changes reporting practices. Although it is essential for all companies to strengthen their credibility in the external assurance process, they are aware that this requires a significant investment of resources on their part, as they have to deal with large amounts of new data and assurance under new systems, and even with completely new methods. Companies consider the first few years as a learning process, as the new regulations also pose challenges for auditors and require preparation.

It is good advice for companies to start preparing for CSRD early and educate their employees – even on a

voluntary basis – so that they can set up their data collection systems in a thoughtful manner and have enough time to collect data and select the right people to carry out the relevant tasks. The current regulatory changes also allow time and space for this, with the 'Stop the clock' mechanism. The extensive experience and best practices presented by the featured Hungarian companies can support other domestic organisations as they navigate this transition, fulfilling one of the central aims of this publication.

Beyond these practical implications, this research enhances theoretical understanding of how institutions in emerging EU member states may respond to the complexity of regulatory requirements. By highlighting the importance of organisational culture, institutional maturity, and policy framing, this study also offers valuable insights for policymakers at both the European and national levels. These findings provide constructive feedback to refine sustainability reporting frameworks further, ensuring that future regulations balance ambition with practical feasibility in various economic contexts.

Ongoing regulatory changes – particularly those introduced by the Omnibus proposal – underscore the continued relevance of these empirical results, and their usefulness in helping business leaders and policymakers prepare for a dynamic regulatory environment. Future research can be built upon these findings through longitudinal studies that track the development of compliance and assurance practices over time. Comparative research with other Central and Eastern European countries can deepen the understanding of region-specific challenges. Additionally, investigating the long-term effects of regulatory adjustments, such as the 'Stop the Clock' initiative, on organisational commitment to sustainability will provide further practical and theoretical insights. Finally, broader quantitative studies may also be needed to validate the patterns observed and to assess the effectiveness of emerging best practices within sustainability leadership.

## Notes

1 According to Hungarian Law (Act LXXXV of 2015), Public Interest Entities include: (1) companies issuing securities admitted to trading on a regulated market (i.e. listed companies), (2) credit institutions (with exceptions for the Hungarian National Bank (MNB), Hungarian Development Bank (MFB) and Hungarian Export-Import Bank (Exim Bank), which, while not credit institutions, may have PIE status due to listed bonds), (3) insurance companies (excluding small insurers and mutual insurance associations), and (4) investment firms.

2 The information contained in this study for each company can be found in the ESG Kőrök 2024 report, which was published based on our interviews in 2024 following approval by the companies (Ásványi et al., 2024).

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## Appendix 1

Table 5

## The process of data analysis

Data collection	
Preparation	Understanding the sustainability regulatory environment.
	Identify a research gap on the need for in-depth insights into the development of sustainability reporting systems in companies.
	Definition of the research objective and methodology.
Conducting interviews	Mapping the scope of companies potentially involved in sustainability reporting.
	Contacting companies directly and indirectly to conduct interviews.
	Schedule online/offline appointments, with interview questions sent in advance.
	Conducting semi-structured in-depth interviews in about one hour
	Preparing and summarising transcripts.
	Sending transcripts back to the company for validation, making any necessary additions.
Data processing	
Before interviews	Literature review, preparation of preliminary notes. Explore corporate sustainability reporting practices using corporate websites and publications.
During interviews	Manual note taking (in a Word document) by the two interviewers.
After interviews	Clarification and collation of the manual notes and summary in a single document.
Data analysis	
Exploring results from interview data	Analysis of aggregated interviews based on merged and reviewed Word documents, with content analysis using NVivo software. Finding similarities and differences according to a preliminary structure of past experiences, present challenges, future plans, and good practices. Following the qualitative analysis, the results were corroborated with external sources, and the inconsistencies found in the analysis were identified and evaluated.

Source: authors, based on interview data

Table 6

## Sample characteristics

Eleven large Public Interest Entities in Hungary, of which	
Bank	7
Production/service company	4
Form of operation	
Zrt.	5
Nyrt.	6
Positions of interviewees	
ESG/Sustainability Expert	at 7 companies
ESG/Sustainability Director	at 2 companies
Capital Market Relations HUB Lead	at 1 company
Head of Strategy and Corporate Governance	at 1 company

Source: authors, based on interview data

Table 6 summarises the information related to the interview subjects, which clearly shows that in nine of the eleven companies, separate managers and departments were established to handle sustainability issues for strategic reasons. In two cases, companies have integrated sustainability into their existing corporate structure.

Table 7

## Summary of the experiences of the companies interviewed regarding sustainability reporting

Interview participants	Entities' experience in sustainability reporting
<b>CIB Bank Zrt.</b>	CIB Bank has been regularly preparing sustainability reports based on international standards in Hungary for more than 20 years and was one of the first banks to publish its sustainability information. Initially, they reported on their sustainability activities in the form of CSR reports, then in the NFRD, and from this year onwards, they plan to publish their reports in the framework of the CSRD. The preparation of sustainability reports is closely aligned with the Bank's business strategy, in particular the measurement and monitoring of the achievement of ESG objectives.
<b>ERSTE Bank Hungary Zrt.</b>	ERSTE Bank Hungary, one of the main operators in the Hungarian banking sector, has been preparing sustainability reports at group-level since 2013. As a member of the ERSTE Group, the Austrian-based company is one of the largest banking groups in Central and Eastern Europe to produce its annual non-financial reports. The domestic bank published its sustainability report in 2021, which did not yet mirror the structure of the parent company report but was a good experience for the company. The bank's disclosure and reporting practices not only comply with local laws and regulations but are also closely aligned with Erste Group's international reporting processes.
<b>K&amp;H Bank Zrt.</b>	K&H Bank has been committed to sustainability reporting since 2006 and has continuously expanded its efforts in this regard over the years. As a member of the KBC Group, it is indirectly considered a listed company through the Belgian Universal Bank. This ultimate parent company is included in the Non-Financial Reporting under the NFRD. In addition, K&H Bank prepares a domestic GRI Sustainability Report covering a wide range of topics in an understandable way. Even though there is currently no external assurance of the domestic report, through KBC, they have already encountered the tasks and challenges related to the assurance of sustainability performance.
<b>Magyar Telekom Nyrt.</b>	Magyar Telekom Nyrt., Hungary's leading telecommunications provider, pays special attention to sustainability, regularly reporting on this since 2002 with Group-wide reports. The sustainability performance report is prepared in accordance with strict international standards to ensure comparability and analysability. In order to ensure credibility and transparency, Magyar Telekom has its report assured annually by an independent external auditor, which also contributes to strengthening the transparency of the company.
<b>MBH Bank Nyrt.</b>	Magyar Bankholding Zrt. (MBH) was established in 2020 through the merger of 3 banking groups (MKB Bank, Budapest Bank, Takarékbank). MKB Bank and Budapest Bank prepared their first sustainability report in 2022, and from 2024, they are preparing a single sustainability report based on GRI standards. Being 100% Hungarian-owned banks, they have no foreign parent company, and their sustainability reports have not been externally assured by an independent third party yet.
<b>MOL Nyrt.</b>	Since 2008, the MOL Group has published an annual integrated report that includes both financial and non-financial performance, which since 2016 has been subject to independent third-party assurance to ensure reliability and credibility. The report also covers MOL's domestic and foreign interests and subsidiaries, refining and petrochemical activities, logistics and R&D, as well as retail, consumer services and waste management.
<b>OTP Bank Nyrt.</b>	OTP Bank Nyrt. has been involved in social and corporate responsibility reporting since 2006 and has been at the forefront of sustainability reporting in the financial sector since 2015, with a strong commitment to ESG practices. These annual publications - produced as an integrated report since 2022 - will enable shareholders and other stakeholders to better understand and gain insight into the bank's performance and operational strategy. By continuously improving and integrating all aspects of its sustainability operations, OTP Bank aims to set an example in the industry, providing a sustainable future for stakeholders and the business.
<b>Raiffeisen Bank Zrt.</b>	Raiffeisen Bank has not yet prepared a separate domestic sustainability report in Hungary but has contributed data on its sustainability and ESG activities to the group-wide report of its parent company, Raiffeisen Bank International (RBI), which has been prepared every year since 2010 by RBI. Both RBI and Raiffeisen Bank Zrt. disclose their reports for the first time in the first quarter of 2024, according to the CSRD guidelines, which brings a significant change in the field of sustainability reporting. In Hungary, the sustainability reporting practices in the banking sector are not yet uniform, which will become more transparent and accountable to users, including rating agencies and investors, with the introduction of the CSRD Directive.

Interview participants	Entities' experience in sustainability reporting
<b>Richter Gedeon Nyrt.</b>	Richter Gedeon Plc. is one of Hungary's leading pharmaceutical companies. The company attaches great importance to sustainability and social responsibility, which is also inherent in the company's core business. The company has published sustainability reports since 2008, providing a comprehensive picture of the environmental, social, and corporate governance performance of Richter and its subsidiaries.
<b>UniCredit Bank Zrt.</b>	UniCredit's first sustainability report was published in 2003, and the Group has been producing integrated reports since 2014. It is important to note that the Hungarian subsidiary does not produce its own sustainability report but reports on its sustainability activities as part of the group-wide integrated report. UniCredit Bank Hungary Zrt. has been reporting on its domestic sustainability performance in its own publication since 2021.
<b>WABERER'S INTERNATIONAL Nyrt.</b>	In recent years, Waberer's has made significant progress in sustainability practices and reporting, committing to environmentally responsible operations and continuously expanding its green services to meet customer needs. Initially starting with a Green Division, they have strengthened their commitment to the environment by establishing an ESG Directorate. The company is now pursuing an integrated sustainability strategy and, since 2021, has published its sustainability goals, which include environmental, social, and governance (ESG) aspects, in line with tightening regulatory requirements and market expectations.

Source: authors, based on interview data

# CALL FOR PAPERS – THEMATIC ISSUE

## STARTUP EXCELLENCE – STRATEGY, INNOVATION AND ENTREPRENEURSHIP

Startups have emerged as a unique form of organization operating under extreme uncertainty, rapid experimentation, and limited resources. Instead of viewing startups solely as entrepreneurial ventures, this thematic issue considers them as evolving entities whose structures, processes, capabilities, and performance are continually influenced by strategic decisions, technological developments, and ecosystem dynamics.

Although the study of startups has expanded significantly across entrepreneurship, strategic management, innovation studies, and organizational research, the field remains fragmented. Existing literature often examines entrepreneurial processes, innovation dynamics, or ecosystem structures in isolation, while the interdependencies between strategy formation. In particular, there is still limited integration of work connecting entrepreneurial action with broader questions of organizational design, leadership, capability development, and performance in startup settings. One particularly persistent tension concerns the experimentation–scaling paradox: while startups rely on iterative learning, rapid experimentation, and strategic flexibility in their early stages, long-term growth requires the development of stable organizational capabilities, scalable business models, and coherent strategic positioning. Understanding how startups manage this transition – while navigating technological disruption, institutional complexity, and resource constraints – remains a central challenge for contemporary management and strategy research.

Against this background, this thematic issue aims to enhance theoretical and empirical understanding of startups from a strategic management and organizational perspective. It invites contributions that explain how startups develop and adjust strategies, build capabilities, professionalize organizational processes, leverage digital technologies, and create sustainable value within changing entrepreneurial ecosystems. Contributions examining entrepreneurial ecosystems and startup development in Central and Eastern Europe or other emerging innovation contexts are particularly welcome, given the increasing importance of these regions in the global innovation landscape.

The English language thematic issue focuses on original research papers, conceptual contributions, and interdisciplinary studies that extend existing theoretical frameworks, develop new conceptual perspectives, or provide rigorous empirical evidence on the management of startups. Submissions employing qualitative, quantitative, or mixed-method approaches are encouraged, as are comparative and cross-country studies. All submissions should clearly state their original contribution to the international literature, demonstrate methodological transparency and rigor, and show their relevance for management research and practice.

Possible topics include, but are not limited to, the following areas:

- designing and reconfiguring startup strategies
- digital technologies as enablers of entrepreneurial advantage
- people, leadership, culture, and entrepreneurial capabilities
- sustainable and responsible innovation via entrepreneurship
- entrepreneurial ecosystems and institutional contexts
- resilience, risk, and strategic renewal in startups

This thematic issue is organised in connection with the InnoVaCyBridge, a Horizon Europe EIT Higher Education Institutions (HEI) Project, which focuses on strengthening innovation capacity and entrepreneurial collaboration in emerging innovation ecosystems, whilst inviting submissions openly.

### Guest editors:

- Anitha Chinnaswamy, Aston University, [a.chinnaswamy@aston.ac.uk](mailto:a.chinnaswamy@aston.ac.uk)
- Vivien Surman, Budapest University of Technology and Economics, [surman.vivien@gtk.bme.hu](mailto:surman.vivien@gtk.bme.hu)

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Full paper submission deadline: 31.08.2026

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