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Factors influencing the development of entrepreneurs' businesses after the age of 50: The case of Poland

Daria Ilczuk, Łukasz Dopierała, Joanna Bednarz

A B S T R A C T
Objective: The article aims to identify and assess factors influencing the development of entrepreneurs' businesses after the age of 50, with particular emphasis on firm age, entrepreneurial motivations, and support from the environment.
Research Design & Methods: We gathered data through a survey of over 1 000 Polish micro and small enterprise founders over 50, including those who started their businesses early and have managed them long-term, as well as those who launched their ventures after turning 50 and have operated them for a shorter period. We used logistic regression to analyse the data.
Findings: The results revealed that firm age serves as a moderator in the influence of entrepreneurial motivation factors on further business development, particularly in relation to family support and the desire to remain active. Internal entrepreneurial factors, such as seeking new challenges and remaining active, positively impacted growth intentions. However, dissatisfaction with previous jobs and job loss reduced growth prospects. External factors, such as family and state support, significantly influenced growth tendencies.
Implications & Recommendations: Entrepreneurs over 50 should not face discrimination, and policymakers should ensure their inclusion in grants, mentorship, and training programs available to all entrepreneurs. Moreover, entrepreneurship support organisations should develop programs that involve family members in the business planning process to enhance emotional support and foster shared understanding.
Contribution & Value Added: This study fills a research gap by explicitly linking entrepreneurial motivations with further business development. Moreover, it expands the existing knowledge on mature entrepreneurs in Central and Eastern Europe. The study's originality lies in its integration of multiple dimensions – internal motivations, firm age, and external support – into a comprehensive model that explains business development among entrepreneurs over 50. It contributes to the broader discourse on prolonging entrepreneurial activity in ageing societies.

Article type:	research article
Keywords:	mature entrepreneurs; ageing population; job creation; firm growth; micro and small enterprises
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INTRODUCTION

The ageing of populations in highly developed countries has been a sustained trend that brings with it a range of negative social and economic consequences, such as the potential failure of social protection systems. Consequently, active ageing and initiatives to mitigate societal ageing's effects have become one of the most significant challenges of the twenty-first century. One aspect of active ageing is maintaining economic activity as long as possible, including individuals' business activities during their mature years. Therefore, the issues surrounding mature individuals who start, manage, and develop business activities represent a critical research area for economic sciences.

People over 50 who run a business represent a substantial and growing demographic group, while their business development plans remain relatively underexplored (Dębkowska *et al.*, 2023; Velilla & Sánchez, 2018). Within this group of mature entrepreneurs, there is considerable diversity in terms of how long they have been running their businesses. Some individuals launched their ventures at a younger age and possess extensive entrepreneurial experience. In contrast, others have begun their entrepreneurial endeavours only after reaching the age of 50. This heterogeneity highlights the need for a deeper understanding of mature entrepreneurs' motivations for starting a business, with the duration of their entrepreneurial activity and the broader impact of these factors on the growth of their ventures (Liu, 2024; Stephan *et al.*, 2015).

Societies with ageing populations increasingly have been observing a phenomenon in which individuals initiate new enterprises during their professional careers' later stages (Bojanić *et al.*, 2024; Kurek & Rachwał, 2011). The literature refers to these individuals as *silver entrepreneurs,* signifying those who start their business ventures at age 50 or older (Kautonen, 2013; Soto-Simeone & Kautonen, 2021). Recent literature highlights the need to consider mature individuals' ability to establish successful enterprises to better understand the silver entrepreneurship phenomenon (del Olmo García *et al.*, 2023; Stephens & Hegarty, 2022). Consequently, the lack of research examining this group's propensity to develop their businesses further and investigating differences in this process compared with other entrepreneurs represents a significant literature gap.

Research conducted on the development of enterprises usually concerns the issue of barriers that entrepreneurs encounter during the process of running a business and ways of preventing them, as well as the needs of entrepreneurs in various areas (Kibler *et al.*, 2012; Maâlaoui *et al.*, 2014; Wach, 2014). However, extant research is limited on whether micro and small entrepreneurs generally tend to expand their activities and what drives their desire for further business development (Caliendo *et al.*, 2023; van Gelderen & Jansen, 2006). In turn, studies conducted in the context of silver entrepreneurs have focused mainly on motivational factors for entering entrepreneurship at a later stage in life, with little extant research examining such conduct and the development of business activity among this group (Backman *et al.*, 2019; Matos *et al.*, 2018). However, some of these studies indicate that an essential determinant that influences subsequent business growth pertains to varying characteristics in the founder, including the founder's age when the company was established and the motivations driving the entrepreneur to initiate business activities (Backman *et al.*, 2019).

The objective of the article is to identify and assess factors influencing the development of entrepreneurs' businesses after the age of 50, with particular emphasis on firm age, entrepreneurial motivations, and support from the environment. Our research concerns broadly defined entrepreneurial motivations and their relationship with the tendency towards further business development, in which we seek to address the following research questions (RQ):

RQ1: Does the firm age influence mature people's tendency to develop business activity further?

RQ2: Which internal entrepreneurial factors arising from emerging opportunities influence mature people's tendency to develop business activity further?

RQ3: Which internal entrepreneurial factors resulting from emerging necessities influence mature people's tendency to develop business activity further?

RQ4: Which external entrepreneurial factors associated with the founder's environment influence mature people's tendency to develop business activity further?

For this purpose, we analysed a sample comprising entrepreneurs over age 50 who launched businesses at different stages of their lives and have been running them for varying lengths of time – specifically, those who started their ventures at a younger age and have operated them for a long time, as well as those who established their businesses only after turning 50, whose firms are relatively young. Our sample comprised over 1 000 founders of micro and small enterprises from Poland. We used logistic regression to ascertain the impact of firm age and entrepreneurial factors on the future development of the company, understood as the planned increase in employment declared by entrepreneurs.

The establishment and growth of micro and small enterprises are indispensable in fostering economic development. Small and micro-enterprises comprise approximately 99% of all businesses in the European Union market, with the corresponding figure in Poland exceeding 99%, as reported by the Polish Agency for Enterprise Development (Skowrońska *et al.*, 2023). These entities are categorised primarily based on staff headcounts (micro-enterprises have fewer than 10 employees, and small enterprises have fewer than 50), as well as their turnover or balance sheets (European Union Commission, 2003). Founders' decisions on the development of their enterprises are pivotal not only for the entities themselves but also for the entire economy, particularly the generation of new job opportunities (Adelino *et al.*, 2017). Therefore, this is a significant research topic, particularly considering post-50 entrepreneurs who initiated their ventures at different stages in life.

This study contributes to the field of entrepreneurship by examining the factors influencing the development of businesses run by entrepreneurs over the age of 50. While prior research has explored mature entrepreneurship, it has often overlooked the direct connection between motivational factors and the growth of businesses led by individuals in this age group. This study fills this gap by explicitly linking entrepreneurial motivations with further business development. Moreover, the research extends the existing knowledge on mature entrepreneurs in Central and Eastern Europe, a region that has been underrepresented in the literature. The study's originality lies in its integration of multiple dimensions, *i.e.*, internal motivations, firm age, and external support into a comprehensive model that explains business development among entrepreneurs over 50. Thus, this research does not merely compile previous findings but offers a fresh perspective on the factors shaping the growth of mature entrepreneurs. It contributes to the broader discourse on prolonging entrepreneurial activity in ageing societies.

The structure of this article is as follows. The second part examines the theoretical background regarding founders and their role in developing their businesses, the dimensions of success for micro and small enterprises, and the three classified groups of entrepreneurial motivations. The third part presents the procedures used for data gathering and analysis, along with the research methodology utilised. Subsequently, the fourth section examines the findings derived from the analyses. The final section summarises the research and discusses conclusions that we can draw from the findings, as well as theoretical and practical implications.

LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

Mature Entrepreneurs in Focus

As population ageing continues to accelerate, researchers have increasingly turned their attention to the phenomenon of mature entrepreneurship, highlighting that we should not regard it as a marginal activity (Coduras *et al.*, 2018). Existing studies primarily compare younger age groups of entrepreneurs to older age groups, seeking to identify differences in business practices, such as tendencies towards innovation (Murmann *et al.*, 2023). However, a significant degree of heterogeneity exists within the group of mature entrepreneurs, especially in terms of the duration of their entrepreneurial activity. While some individuals established their businesses decades ago and have accumulated substantial managerial experience, others embarked on their entrepreneurial journey only after the age of 50 and remain in the early stages of running their ventures.

Few researchers have addressed the issue of individuals starting their own entrepreneurial ventures at a later age (del Olmo García *et al.*, 2023; Kautonen *et al.*, 2008; Stephens & Hegarty, 2022). In previous studies, scholars often referred to this group of entrepreneurs as silver entrepreneurs (Ahmad *et al.*, 2014; Cannon & Kurowska, 2013), though we may also find alternative terms, such as senior entrepreneurs (del Olmo García *et al.*, 2023; Matos *et al.*, 2018) and older entrepreneurs (Conway Lenihan & McGuirk, 2022; Wainwright & Kibler, 2013). Moreover, the literature presents a variety of definitions to describe entrepreneurship among mature individuals, including those who become self-employed or start a new business late in their working careers (Kautonen, 2008), individuals nearing retirement who have launched new businesses after careers as salaried workers (Bornard & Fonrouge, 2012), and entrepreneurs, particularly those who have retired, including those who opted for early retirement to launch entrepreneurship careers (Blackburn *et al.*, 2000). However, researchers similarly

have comprehended the concept of a mature individual entering entrepreneurship in the literature, and differences in definitions arise primarily from specifying the age at which an individual starts their business activity, whether age 45 and up (Ainsworth & Hardy, 2008; Singh & Verma, 2003), above 50 (Isele & Rogoff, 2014; Kautonen, 2013; Soto-Simeone & Kautonen, 2021), or even above 55 (Hantman & Gimmon, 2014; Small, 2012). Based on the literature review, we considered entrepreneurs over the age of 50, including those who start a business at this age (Dębkowska *et al.*, 2023; Ilczuk *et al.*, 2023; Isele & Rogoff, 2014; Kautonen, 2013; Soto-Simeone & Kautonen, 2021).

Numerous studies examined the relationship between the duration of business activity and its subsequent impact on enterprise development (Adelino *et al.*, 2017; Coad *et al.*, 2016; Liu, 2024). Research findings predominantly indicate that as a company remains in the market for a longer period, its founders tend to exhibit a declining willingness to further expand their business (Pervan *et al.*, 2017). However, when comparing mature entrepreneurs based on the length of time they have been running their ventures, particularly in the case of entrepreneurs who establish their businesses later in life and operate for a shorter duration, a significant research gap remains.

Accordingly, we formulated the following hypothesis (concerning RQ1):

H1: Mature individuals who have been in business for longer are less likely to continue to develop their businesses.

The Founder's Influence on Micro and Small Business Growth

Business ownership is crucial, particularly for micro and small enterprises, within which elaborate management structures are lacking, and the owner typically oversees every aspect of the operation directly (Schutjens & Wever, 2000). Prior research focusing on business development primarily has addressed the challenges that micro and small business owners have encountered, listing issues such as competition with larger rivals for market position, maintaining financial stability, human resource management, and effective adaptation to general market changes (Dvorský *et al.*, 2023; Kibler *et al.*, 2012; Wach, 2014). To a very limited extent, these studies have examined individuals' willingness and their tendencies to develop their businesses further, mainly focusing on aspects strictly related to business operations and economic outcomes (de Kok *et al.*, 2010; de Vries *et al.*, 2020). The success of a business is defined primarily through an analysis of the entity's financial performance, including percentage changes in sales, profit, transaction volume, and income from the current period compared with the previous period (Gielnik *et al.*, 2012). However, some scientists notably have emphasized that in the case of micro and small enterprises, and their founders, the entity's success should be assessed through the owner's subjective evaluation of the company and its reference not only to pecuniary dimensions but also to other benefits derived from conducting business that directly impacts their lives (Kautonen *et al.*, 2017; Matos *et al.*, 2018; Soto-Simeone & Kautonen, 2021).

The literature emphasises the entrepreneur's role as the most significant entity within the enterprise itself – the direct decision-maker for the entity's future, the manager overseeing its operations, and the primary individual responsible for implemented ideas' success or failure (Schumpeter, 1934). Previous entrepreneurship studies concerning companies' development typically have considered the founder's fundamental characteristics, particularly demographic factors such as age, gender, education, and marital status (Bosma *et al.*, 2004; Caliendo *et al.*, 2023; de Vries *et al.*, 2020; Kautonen *et al.*, 2013; Lévesque & Minniti, 2011; Wainwright & Kibler, 2013). Researchers also focus on founders' individual characteristics, including overall health status, start-up motivations, and goals for the established venture as success factors in enhancing the company's growth chances further (de Kok *et al.*, 2010; Gielnik *et al.*, 2012; Schutjens & Wever, 2000). Notably, other studies have examined a combination of individual founder characteristics with environmental factors related to the business cycle, choice of industry sector, or region (Amofah *et al.*, 2024; Caliendo *et al.*, 2023; de Vries *et al.*, 2020; Wach, 2014). However, a significant research gap exists concerning founder characteristics' specific impact on the inclination towards developing the company further (Zhou & de Wit, 2009). Therefore,

based on our literature review, we assert that entrepreneurial motivations as individual founder characteristics may exert a significant influence on willingness to develop the business further (Caliendo *et al.*, 2023; de Vries *et al.*, 2020; Kautonen *et al.*, 2013).

Most often, the literature has distinguished between two dimensions of internal motivations driving the entrepreneur to initiate business activities (Harms *et al.*, 2014; van der Zwan *et al.*, 2016). The first group includes positive ('pull') factors related to potential opportunities, such as aspirations for a work-life balance through a reduction in working hours or adoption of a more flexible schedule (Ahmad *et al.*, 2014; Stephens & Hegarty, 2022), pursuit of new challenges in life (Ahmad *et al.*, 2014; Matos *et al.*, 2018), the desire to fulfil dreams (Gimmon *et al.*, 2018; Stephens & Hegarty, 2022), and a intention to maintain vitality, remain active, and interact with the environment (Backman *et al.*, 2019; Bojanić *et al.*, 2024; Soto-Simeone & Kautonen, 2021).

Drawing on the literature review, we put forward the following hypotheses (all in relation to RQ2):

H2: The opportunity for more flexible working hours compared with full-time employment (as a motivating factor for starting a business) positively influences mature people's propensity for further business development.

H3: The desire to seek new life challenges (as a motivating factor for starting a business) positively influences mature people's propensity for further business development.

H4: Dream fulfilment (as a motivating factor for starting a business) positively influences mature people's propensity for further business development.

H5: Willingness to be active and interact with other people (as a motivating factor for starting a business) positively influences mature people's propensity for further business development.

The second group comprises negative ('push') factors associated with encountered necessities, including dissatisfaction with a previous full-time job (Backman *et al.*, 2019; Harms *et al.*, 2014), the issue of age discrimination in the workplace (Harms *et al.*, 2014; Hennekam, 2015; Kautonen, 2013), and the loss of employment and lack of alternative opportunities in the labour market (del Olmo García *et al.*, 2023; Small, 2012).

Based on this framework, we advance the literature by presenting the following hypotheses (in relation to RQ3):

H6: Dissatisfaction with a previous full-time job (as a motivating factor for starting a business) negatively influences mature people's propensity for further business development.

H7: The occurrence of ageism in the workplace (as a motivating factor for starting a business) negatively influences mature people's propensity for further business development.

H8: Loss of employment and lack of alternative opportunities in the labour market (as a motivating factor for starting a business) negatively influences mature people's propensity for further business development.

In addition to internal factors, several external ones originating from an individual's environment also influence the decision to embark on business ventures. Extant research has highlighted the importance of receiving encouragement from family and friends in deciding to establish a business (Gimmon *et al.*, 2018; Kibler *et al.*, 2012), as well as assistance provided by governmental institutions and various stakeholder groups engaged in the enhancement of entrepreneurial activities (Hantman & Gimmon, 2014; Isele & Rogoff, 2014).

Consequently, we hypothesised (in relation to RQ4):

H9: Family support in starting a business positively influences mature people's propensity for further business development.

H10: Friend support in starting a business positively influences mature people's propensity for further business development.

H11: State support in starting a business positively influences mature people's propensity for further business development.

RESEARCH METHODOLOGY

Sample and Data Collection

In this study, data were sourced from a survey conducted by MRC Consulting, which ran from January 5 to February 25, 2022. Before the study, the questionnaire was tested in a pilot study on 20 individuals, and their feedback was incorporated. The methodology for selecting entrepreneurs for the sample was as follows: Businesses were chosen randomly from the REGON registry, a database of economic entities in Poland maintained by the Central Statistical Office. Only active REGON numbers assigned to individuals engaged in business activities were included. The research team initiated contact with each business owner via phone. If the connection was established, a survey was conducted if the owner consented. In cases in which contact could not be made, another entrepreneur was selected randomly. The computer-assisted telephone interviewing method was used to collect data. The initial question was a filter, focusing on the respondents' age, including only those above 50. Through this method, a sample of 1 003 respondents was compiled.

Thus, all of our respondents were entrepreneurs over 50 years of age. Most of them started their business activity at a younger age (that is, before the age of 50), whereas some started their entrepreneurial venture when they were already over 50 years old. Among the entrepreneurs surveyed, 95% were male, ages 51 to 69, with an average age of 56. Most of the research sample comprised married individuals (86%). In terms of education, those with higher education levels comprised the largest segment (48%). Regarding industry, entrepreneurs in wholesale and retail trades were predominant (31%), while representation from other industry sectors varied between 2% and 10%. The average age at which respondents started their business ventures was 42. Approximately 10% of the respondents embarked on their business pursuits after age 50. The average duration of business activity in the sample was approximately 14 years, while for those who started their business after the age of 50, it was around 7 years. Among all surveyed entrepreneurs, the shortest duration of business activity was 1 year, and the longest was 40 years.

Variable Measurement

Table 1 presents a detailed overview of the variables utilised in this study. We adopted the respondents' declarations regarding the increase in employment as a measure of the enterprise's future development. Plans for employment growth are not sensitive questions, so they are suitable for use in survey research, as respondents are more likely to provide honest answers. Many authors have utilised job creation as a metric for measuring enterprise development (Bosma *et al.*, 2004; Caliendo *et al.*, 2023; Gielnik *et al.*, 2012). In a further analysis, we utilised the binary variable *Expansion*, which takes the value of 1 if the respondent planned to hire additional employees in the next 5 years and 0 otherwise.

To assess our research hypotheses' validity, we employed a set of independent variables, each corresponding to a specific hypothesis and inquiry. To examine whether mature individuals who have been in business longer are less likely to continue developing their businesses, we included the independent variable *Firm age* in the study, which represents the duration of business activity in years (Adelino *et al.*, 2017; Murmann *et al.*, 2023). Pervan *et al.* (2017) also considered firm age as an independent variable, highlighting its dual impact on business development. A longer market presence provides accumulated knowledge in key areas – advanced technology, supply chains, customer relationships, and resource access – which supports expansion. However, older firms often show organisational inertia, avoiding risk and resisting structural change, which ultimately hinders development.

The next set of independent variables revolved around the support received from various sources, *i.e.*, family, friends, and governmental assistance, in initiating entrepreneurial ventures, as the participants reported. Gimmon *et al.* (2018) mentioned the importance of the entrepreneurial individual's environment in terms of the support provided by family members, surroundings, and friends in fostering the initiation of entrepreneurial endeavours. Isele and Rogoff (2014) indicated that the United States offers government programs that encourage and support entrepreneurship among groups, such as women, minorities, and immigrants, but that few programs specifically target mature entrepreneurs. However, Hantman

Table 1. Research variables' characteristics

Variable	Definition/survey question	Response categories	Source
Dependent variables			
Expansion	Planning to increase employment in the next 5 years.	1 (if yes); 0 (if no)	Bosma *et al.*, 2004; Caliendo *et al.*, 2023; Gielnik *et al.*, 2012
Independent variables			
Firm age	Duration of company operations	An integer greater than or equal to 0	Adelino *et al.*, 2017; Murmann *et al.*, 2023; Pervan *et al.*, 2017
Family support	I felt encouraged by my family to start my own company.	Five-point Likert scale ranging from 'strongly disagree (1)' to 'strongly agree (5)'	Gimmon *et al.*, 2018; Kautonen, 2013; Kibler *et al.*, 2012
Friend support	I felt encouraged by my friends to start my own company.		Ahmad *et al.*, 2014; Gimmon *et al.*, 2018; Kibler *et al.*, 2012
State support	I got enough support from government institutions to run my own company.		Hantman & Gimmon, 2014; Isele & Rogoff, 2014
Flexibility	I started my own business to have a more flexible work schedule compared to regular employment.		Ahmad *et al.*, 2014; Stephens & Hegarty, 2022
Challenge	I am always seeking new challenges, which is why I chose to start my own business.		Ahmad *et al.*, 2014; Matos *et al.*, 2018
Dream	Launching my own company made my dream a reality.		Gimmon *et al.*, 2018; Stephens & Hegarty, 2022
Staying active	I enjoy being active and social, and having my own business makes that possible.		Backman *et al.*, 2019; Bojanić *et al.*, 2024; Soto-Simeone & Kautonen, 2021
Job dissatisfaction	I was not satisfied with my previous job, so I chose to start my own company.		Backman *et al.*, 2019; Harms *et al.*, 2014
Ageism	I experienced or observed unequal treatment of older workers at my previous job.		Harms *et al.*, 2014; Hennekam, 2015; Kautonen, 2013
Job loss	After being unemployed with no other income sources, I decided to		del Olmo García *et al.*, 2023; Small, 2012

Variable	Definition/survey question	Response categories	Source
	launch my own company.		
Control variables			
Former manager	Have you ever held a full-time managerial position?	1 (if yes); 0 (if no)	Bosma *et al.*, 2004; Cannon & Kurowska, 2013; Schutjens & Wever, 2000
Respondent's age	Age of the respondent	An integer greater than or equal to 0	Ilczuk *et al.*, 2023; Isele & Rogoff, 2014; Kautonen, 2013; Lévesque & Minniti, 2011; Soto-Simeone & Kautonen, 2021
Employment	Current number of employees at the company	An integer greater than or equal to 0	de Kok *et al.*, 2010; Schutjens & Wever, 2000
Gender	Gender of the respondent	1 (if male); 0 (otherwise)	Caliendo *et al.*, 2023; de Vries *et al.*, 2020; Gielnik *et al.*, 2012; Wainwright & Kibler, 2013
Marital status	Marital status of the respondent	*Single* *Married* *Informal relationship* *Divorced* *Widow/widower*	Bosma *et al.*, 2004
Education	Education of the respondent	*Primary* *Vocational* *Secondary* *Higher*	Caliendo *et al.*, 2023; de Vries *et al.*, 2020; Wainwright & Kibler, 2013
Residence	Residential location of the respondent	*Rural area* *Town (fewer than 50 000 inhabitants)* *City (from 50 000 up to 100 000 inhabitants)* *City (over 100 000 up to 250 000 inhabitants)* *City (over 250 000 inhabitants)*	Cannon & Kurowska, 2013; Schutjens & Wever, 2000
Industry	Business industry of the respondent	*Manufacturing activities* *Construction and renovation services* *Wholesale and retail trade* *Transportation services* *Medical services* *Beauty and fitness services* *Hotel, restaurant, and catering services* *Automotive services* *Financial and insurance services, real estate trade* *Professional, scientific, and educational services* *Other services* *Other industry*	Caliendo *et al.*, 2023; de Vries *et al.*, 2020; Stephens & Hegarty, 2022

Source: own study.

and Gimmon (2014) described the results from an experimental project created in cooperation with social workers and college staff, aimed at supporting active ageing through entrepreneurial activities

among adults from one of the senior centres in Israel. We hypothesised that such support from the environment would have a positive correlation with the inclination towards business growth.

The last set of independent variables concerned the positive (pull) and negative (push) factors that impact the decision to engage in business activities. Based on the literature review, we considered the following factors (as opportunities): the aspiration for more flexible working hours compared with full-time employment (Ahmad *et al.*, 2014; Stephens & Hegarty, 2022); the desire to seek new life challenges (Ahmad *et al.*, 2014; Matos *et al.*, 2018); dream fulfilment (Gimmon *et al.*, 2018; Stephens & Hegarty, 2022); and willingness to be active and interact with other people (Backman *et al.*, 2019; Bojanić *et al.*, 2024; Soto-Simeone & Kautonen, 2021). We also considered the second group of factors (as a necessity): dissatisfaction with prior full-time employment (Backman *et al.*, 2019; Harms *et al.*, 2014); experiencing age discrimination in the workplace (Harms *et al.*, 2014; Hennekam, 2015; Kautonen, 2013); and facing job loss, along with limited opportunities in the labour market (del Olmo García *et al.*, 2023; Small, 2012). According to Stephens and Hegarty (2022), Irish public service retirees' decision to start a small enterprise generally is framed by opportunity recognition, encompassing the pursuit of a dream or passion. Simultaneously, del Olmo García *et al.* (2023) assumed in their research that the Spanish entrepreneur is a necessity-based entrepreneur due to long-term unemployment that prompts mature professionals to become entrepreneurs. We anticipated a positive association between pull factors and the tendency to develop a business, and a negative correlation for push factors. We quantified these variables, representing both negative and positive influences, using a five-point Likert scale in the survey questions.

Drawing from the existing literature, we incorporated a range of control variables into our research. Current studies suggest that skills and experience acquired from previous full-time employment can influence business management later in life (Schutjens & Wever, 2000). For instance, Cannon and Kurowska (2013) indicated a strong association between holding managerial positions and participation in the industrial sector, as well as self-employment among women. Furthermore, Bosma *et al.* (2004) state that prior experience in a leadership role increases the company's survival time. In this context, we factored in whether the participants previously had held a managerial role in their full-time careers, as this experience could affect their propensity to employ staff and their capacity for employee management significantly.

Empirical data also indicated that the size and scope of a company's operations can impact its ongoing development (de Kok *et al.*, 2010). Schutjens and Wever (2000) included a number of employees as one of the firm-associated factors in their research on determinants of success among Dutch start-ups, linking it to the company's future achievements. Consequently, we accounted for the current number of employees in the company as a control variable.

Furthermore, our study considered respondents' sociodemographic attributes, including age, gender, marital status, educational background, and place of residence (Caliendo *et al.*, 2023; Cannon & Kurowska, 2013; de Vries *et al.*, 2020; Lévesque & Minniti, 2011; Wainwright & Kibler, 2013). Following Bosma *et al.* (2004), we included respondents' marital status because the emotional support of the business founder's spouse could be important for entrepreneurial performance. We also considered the specific industry sector in which the respondents were operating their businesses (Caliendo *et al.*, 2023; de Vries *et al.*, 2020; Stephens & Hegarty, 2022). For further analysis and modelling, we transformed these categorical variables into quantitative data by assigning a corresponding dummy binary variable to each category. Table 2 provides descriptive statistics for the variables utilised in this study.

The average value of the dependent variable *Expansion* stood at 0.34, signifying that in the analysed sample, around 34% of the respondents indicated plans to expand the team size in their companies within the next 5 years. Notably, the research sample comprised business owners who employed a maximum of 14 employees at the time of the survey, with the average number of staff being close to 4. Furthermore, in Table A1 of Appendix, we present the results from the multicollinearity analysis and pairwise correlation between the dependent variable *Expansion* and the independent variables. Notably, the variance inflation factor (VIF) values for the independent variables indicated that collinearity was not present in this set of variables.

Table 2. Descriptive statistics

Variable	Responses categories	Mean	Std. Dev.	Min	Max
Expansion		0.342	0.474	0	1
Firm age		14.062	7.282	1	40
Family support		3.147	1.009	1	5
Friends support		3.828	1.057	1	5
State support		2.565	0.881	1	5
Flexibility		3.470	0.901	1	5
Challenge		3.501	1.193	1	5
Dream		3.543	1.164	1	5
Staying active		3.254	1.018	1	5
Job dissatisfaction		3.216	0.995	1	5
Ageism		2.592	0.873	1	5
Job loss		2.119	1.114	1	5
Former manager		0.155	0.362	0	1
Respondent's age		56.37	3.901	51	69
Employment		3.724	2.438	0	14
Gender		0.948	0.221	0	1
Marital status	Single	0.004	0.070	0	1
	Married	0.856	0.350	0	1
	Informal relationship	0.046	0.211	0	1
	Divorced	0.078	0.269	0	1
	Widow/widower	0.012	0.113	0	1
Education	Primary	0.000	0.031	0	1
	Vocational	0.152	0.359	0	1
	Secondary	0.369	0.483	0	1
	Higher	0.476	0.499	0	1
Residence	Rural area	0.013	0.117	0	1
	Town (fewer than 50 000 inhabitants)	0.163	0.370	0	1
	City (from 50 000 up to 100 000 inhabitants)	0.285	0.451	0	1
	City (over 100 000 up to 250 000 inhabitants)	0.341	0.474	0	1
	City (over 250 000 inhabitants)	0.195	0.396	0	1
Industry	Manufacturing activities	0.082	0.275	0	1
	Construction and renovation services	0.061	0.240	0	1
	Wholesale and retail trade	0.313	0.463	0	1
	Transportation services	0.097	0.297	0	1
	Medical services	0.099	0.299	0	1
	Beauty and fitness services	0.059	0.237	0	1
	Hotel, restaurant and catering services	0.087	0.283	0	1
	Automotive services	0.081	0.274	0	1
	Financial and insurance services, real estate trade	0.021	0.146	0	1
	Professional, scientific and educational services	0.048	0.215	0	1
	Other services	0.015	0.125	0	1
	Other industry	0.028	0.167	0	1

Source: own study.

Modelling Strategy

We applied logistic regression to identify the determinants associated with the binary variable *Expansion*. Scholars frequently employ this technique in contemporary entrepreneurship studies and in investigations that have examined ageing's impact on entrepreneurial tendencies (Le Loarne-Lemaire & Nguyen, 2019; Rodríguez-López & Souto, 2019; von Bonsdorff *et al.*, 2019). Logistic regression is effec-

tive at examining the connection between various independent variables and the likelihood of a particular outcome occurring. In this research, we analysed the probability of mature entrepreneurs declaring an increase in employment over the next 5 years.

The baseline logistic regression model applied in our study took the following form:

$$\ln\frac{P(Y=1)}{1-P(Y=1)} = \beta_0 + \sum_{k=1}^{n}\beta_k X_k + \sum_{l=1}^{m}\gamma_l C_l \tag{1}$$

in which:

$P(Y=1)$ - denotes the conditional probability that the dependent variable (*Expansion*) takes the value 1;

$\quad\beta_0$ - indicates the model's intercept;

$\quad X_k$ - refers to the *k*-th independent variable;

$\quad\beta_k$ - captures the effect of the *k*-th independent variable on $P(Y=1)$;

$\quad C_l$ - indicates the *l*-th control variable;

$\quad\gamma_l$ - measures the impact of the *l*-th control variable on $P(Y=1)$.

In our research, we computed the model's parameters using the maximum likelihood estimation method through Stata 13 software. Initially, we calculated the model by incorporating all the variables at our disposal. The likelihood ratio chi-square test demonstrated that a subset of the explanatory variables markedly influenced the likelihood of a reported increase in employment within the company over the next five years.

The analysis of sensitivity and specificity revealed that the model is relatively effective at classifying cases despite the pseudo R^2 not being notably high. Nevertheless, a thorough examination of the parameter values and their standard errors led us to consider removing certain variables that were not statistically significant. We experimented with various model iterations, eliminating variables that exhibited a p-value greater than 0.1 in each step. We detail the outcomes of the preliminary and refined final models in the subsequent section of the article (Table 3).

However, the baseline model indicated that some variables, including the *Firm age*, were statistically insignificant. Since the literature (Anderson & Eshima, 2013; Coad *et al.*, 2016; Naldi & Davidsson, 2014) suggests that this factor may exert either a direct or moderating influence, we decided to extend the model by incorporating the moderating effects of the *Firm age* variable.

The extended logistic regression model applied in our study took the following form:

$$\ln\frac{P(Y=1)}{1-P(Y=1)} = \beta_0 + \sum_{k=1}^{n}\beta_k X_k + \sum_{k=1}^{n}\delta_k(X_k \times X_M) + \sum_{l=1}^{m}\gamma_l C_l \tag{2}$$

in which:

$P(Y=1)$ - denotes the conditional probability that the dependent variable (*Expansion*) takes the value 1;

$\quad\beta_0$ - indicates the model's intercept;

$\quad X_k$ - refers to the *k*-th independent variable;

$\quad\beta_k$ - captures the effect of the *k*-th independent variable on $P(Y=1)$;

$\quad X_M$ - is the moderating variable (*Firm age*);

$\quad\delta_k$ - captures the moderation effect between X_k and X_M;

$\quad C_l$ - indicates the *l*-th control variable;

$\quad\gamma_l$ - measures the impact of the *l*-th control variable on $P(Y=1)$.

Consistent with our previous analysis, we initially estimated comprehensive models using all independent variables, moderating effects, and control variables. Subsequently, we examined the parameter values and standard errors, and in successive iterations, we discarded variables for which the p-value exceeded 0.1. However, we retained the moderator and the factors for which the moderation effects were significant. In the following section, we present both the initially estimated broad model and the final refined model (Table 4).

RESULTS AND DISCUSSION

In this section, we present the results from both the main effects (Table 3) and the extended (Table 4) model estimations. Noteworthy, in the final extended model, the pseudo R^2 was 0.196, compared to 0.188 in the final basic model. This suggests that the extended model has slightly better predictive properties.

The baseline logistic regression analysis of the *Expansion* variable suggests that both support from their environment at the start of their business operations and their internal entrepreneurial motivations influence the probability of mature entrepreneurs declaring the development of their businesses. Among the environmental factors, family support impacted business development strongly and positively. The parameter for the *Family support* variable was statistically significant at the 5% level. Our findings partially aligned with previous results from Bosma *et al.* (2004), who found that emotional support from a spouse is also crucial for business performance because entrepreneurs who receive such support earn approximately 40% more than their peers who experience no such support.

The findings also indicated that government institution support was marginally significant (the parameter for the *State support* variable was statistically significant at the 10% level), which is consistent with previous results. Wach (2014) indicated that local policy favouring entrepreneurship in southern Poland predominantly focuses on potential entrepreneurs and that financial support aimed mainly at forming or newly formed enterprises, omitting established enterprises and micro firms at all stages of their development. Furthermore, Bojanić *et al.* (2024) stated that for European Union members, small-scale support from governmental organisations is identified primarily with financing of silver entrepreneurship, compared with other target groups for inclusive entrepreneurship, particularly in terms of grants for business creation, loan guarantees, and microfinance loans. Our study confirmed that *State support* was rated at a lower level (mean response: 2.56) than *Family support* (3.15) or *Friend support* (3.83).

Among the internal motivational factors related to starting a business, the inclination to take on challenges (with the parameter for the *Challenge* variable being statistically significant at the 1% level) significantly impacted the propensity for further business development. Similarly, the desire to remain active (with the parameter for the *Staying Active* variable significant at the 1% level) exerted a comparable influence. However, other pull factors did not significantly impact the probability of further business development, as the respondents stated. Our findings on pull factors were partially consistent with Caliendo *et al.* (2023), who demonstrated that individuals driven by the opportunity motive (understood as deriving satisfaction from implementing and executing their own ideas) perform better in terms of innovation and business expansion activities. Furthermore, Stephens and Hegarty (2022) found that social need, as a primary reason for retirees beginning their entrepreneurial journeys, significantly impacted outcomes associated with further development of their enterprises, manifested in the delivery of a new product or service.

We found that starting a business due to dissatisfaction with a previous job decreased the likelihood of further development of the enterprise (with the parameter for the *Job dissatisfaction* variable being negative and statistically significant at the 1% level). Likewise, starting a business due to job loss also reduced the probability of ongoing business development (with the parameter for the *Job loss* variable being negative and statistically significant at the 1% level). Our results regarding push factors do not align with those of Caliendo *et al.* (2023), in which the necessity motives (including the unavailability of a regular job) did not exert a significantly negative impact on entrepreneurial performance when the control variables associated with founder characteristics were included in the study. However, de Vries *et al.* (2020) found that the necessity-driven solo self-employed (mainly due to unemployment, entrepreneurship being the only option for suitable paid work, or voluntarily leaving a previous paid job) perform worse than the opportunity-driven solo self-employed.

Notably, the final model also incorporated a selection of control variables, one of which was the *Former manager* variable, indicating that individuals who previously held managerial positions were more likely to express an intention to increase employment at their firms. This aligns with Cannon and Kurowska (2013), in which entrepreneurs from managerial and senior officer backgrounds were the only group not exhibiting fear of failure or hesitation to take risks when considering investments and

growth in a small business. Schutjens and Wever (2000) added that specific entrepreneurship or management experience is a clear precondition for new firm success.

Table 3. The results for the main effects models

Independent/control variable	Dependent variable *Expansion*			
	Initial model		Final model	
	Coefficient	Standard Error	Coefficient	Standard Error
Independent variables				
Firm age	0.001	0.012	-	-
Family support	0.190**	0.082	0.172**	0.079
Friends support	0.079	0.079	-	-
State support	0.177*	0.095	0.189**	0.092
Flexibility	-0.151	0.099	-	-
Challenge	0.367***	0.074	0.348***	0.071
Dream	0.016	0.072	-	-
Staying active	0.237***	0.082	0.221***	0.080
Job dissatisfaction	-0.191**	0.081	-0.189***	0.079
Ageism	0.024	0.098	-	-
Job loss	-0.317***	0.084	-0.330***	0.076
Constant	-0.697	1.499	-2.376***	0.627
Control variables				
Former manager	incorporated		incorporated	
Respondent's age	incorporated		omitted	
Employment	incorporated		incorporated	
Gender	incorporated		omitted	
Marital status	incorporated		omitted	
Education	incorporated		omitted	
Residence	incorporated		incorporated	
Industry	incorporated		incorporated	
Model fit				
Number of observations	964		965	
LR chi2 p-value	246.52		231	
Log likelihood	-504.86		-510.42	
Pseudo R^2	0.196		0.188	
Sensitivity	52.62%		50.58%	
Specificity	83.87%		83.90%	
Correctly classified	72.72%		72.02%	

Note: Table 3 displays the baseline logistic regression outcomes for the dependent variable *Expansion*.
The symbols ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively.
Source: own study.

The current employment level within the enterprise also influenced the propensity to expand employment, possibly because some of the businesses surveyed were sole proprietorships, which inherently did not intend to increase employment scale. Conversely, entrepreneurs who already employed workers possess greater experience in this area, so for them, increasing employment tends to be less problematic. This is similar to Schutjens and Wever (2000), who found that among individuals attempting to establish some form of self-employment and working independently, only 6% had hired new personnel within three years. However, the number of employees at the beginning and the presence of a business partner within the firm also increase the probability of employee growth.

Additional control variables influencing the inclination towards further development of the enterprise by hiring new staff were the place of residence and industry sector. Conversely, respondent's age, gender, marital status, and education level did not exhibit statistical significance at any of the standard significance levels and, therefore, were omitted from the final model. Regarding industry sectors,

Caliendo *et al.* (2023) noted that the tendency to employ workers is greater among businesses originating from the manufacturing sector. When it comes to gender, de Vries *et al.* (2020) noticed a strong negative relation for women solo self-employed, with their business development measured by annual turnover. Similar to our results, Bosma *et al.* (2004) also considered the parameter of marital status, which was found to be insignificant, while emotional support from family proved to be statistically significant.

Table 4. The results for the extended models

Independent/control variable	Dependent variable *Expansion*			
	Initial model		Final model	
	Coefficient	Standard error	Coefficient	Standard error
Independent variables				
Firm age	0.048	0.072	0.053	0.045
Family support	-0.100	0.193	-0.069	0.174
Friends support	-0.063	0.184	-	-
State support	0.072	0.220	-	-
Flexibility	-0.232	0.227	-	-
Challenge	0.705***	0.177	0.415***	0.071
Dream	0.338**	0.166	-	-
Staying active	0.738***	0.196	0.730***	0.179
Job dissatisfaction	-0.089	0.189	-	-
Ageism	-0.198	0.219	-	-
Job loss	-0.534***	0.202	-0.384***	0.078
Constant	-1.780	2.003	-1.533	1.547
Moderation effects of firm age				
Family support x Firm age	0.020*	0.011	0.019*	0.011
Friends support x Firm age	0.011	0.011	-	-
State support x Firm age	0.009	0.014	-	-
Flexibility x Firm age	0.006	0.014	-	-
Challenge x Firm age	-0.022**	0.011	-	-
Dream x Firm age	-0.020**	0.010	-	-
Staying active x Firm age	-0.034***	0.012	-0.035***	0.010
Job dissatisfaction x Firm age	-0.004	0.012	-	-
Ageism x Firm age	0.017	0.013	-	-
Job loss x Firm age	0.014	0.012	-	-
Control variables				
Former manager	incorporated		incorporated	
Respondent's age	incorporated		incorporated	
Employment	incorporated		incorporated	
Gender	incorporated		omitted	
Marital status	incorporated		incorporated	
Education	incorporated		incorporated	
Residence	incorporated		incorporated	
Industry	incorporated		incorporated	
Model fit				
Number of observations	964		964	
LR chi2 p-value	269.06		246.17	
Log likelihood	-493.59		-505.04	
Pseudo R^2	0.214		0.196	
Sensitivity	56.40%		55.23%	
Specificity	84.84%		85.16%	
Correctly classified	74.69%		74.48%	

Note: Table 4 displays logistic regression outcomes for the dependent variable *Expansion*, incorporating moderation effects of the *Firm age* variable. The symbols ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively. Source: own study.

The extended logistic regression model yielded results similar to those of the baseline model for the *Challenge*, *Staying active*, and *Job* loss variables. However, in the final model, the *Family support* variable's parameter was not statistically significant unless considered in interaction with the company age. Among the introduced moderation effects between the *Firm age* variable and specific entrepreneurial motivations, two merit special attention.

First, the interaction between the *Family support* and *Firm age* variables was positive and statistically significant at the 10% level. This finding implies that the longer a company operates in the market, the stronger the positive impact of initial family support at the business's inception on subsequent expansion decisions. In other words, more established firms appear to leverage family support more effectively when considering further development. This finding is comparable to previous research. For instance, Gielnik *et al.* (2012) suggested that, in addition to mental health, family support may serve as a personal resource that moderates the relationship between business owners' age, opportunity focus, and enterprise growth.

Secondly, the interaction between the *Staying active* and *Firm age* variables is negative and statistically significant at the 1% level. This suggests that although the *Staying active* variable exerts a strong positive main effect on expansion, its influence gradually diminishes as the company's age increases. We may interpret this as indicating that in firms with a short business lifespan, the desire to remain active serves as a stronger motivator for development, whereas in enterprises with a longer duration of business activity, it plays a relatively smaller role in expansion decisions. This partially aligns with previous literature, which suggest that as firms remain in the market longer, their founders exhibit a reduced tendency to seek additional growth opportunities (Pervan *et al.*, 2017).

Furthermore, the extended model incorporates a broader set of control variables compared to the model with only main effects. Notably, it includes the respondent's age, suggesting that the propensity for enterprise development declines as the entrepreneur ages. Our findings align with several prior studies. For example, de Kok *et al.* (2010) found that entrepreneurs who establish ventures later in life (at an older age) are less likely to engage in full-time work within these businesses, exhibit lower risk tolerance, and tend to underestimate their entrepreneurial abilities. However, Brieger *et al.* (2021) highlighted that the connection between an entrepreneur's age and their propensity to generate social value through their ventures depends on the formal institutional framework, particularly the level of economic, social, and political freedoms within a given country. Moreover, Stephens and Hegarty (2022) observed that mature entrepreneurs, like many entrepreneurs, encounter challenges in expanding their customer base and generating revenue as their businesses grow. On the other hand, Cannon and Kurowska (2013) challenged the negative stereotypes about post-50 entrepreneurs, demonstrating that many possess the necessary assets and attributes for business success.

CONCLUSIONS

We aimed to identify and assess factors influencing the development of entrepreneurs' businesses after the age of 50, with particular emphasis on firm age, entrepreneurial motivations, and support from the environment. Our research concerned broadly defined entrepreneurial motivations and their relationship with the tendency towards further business development, in which we sought to address 4 research questions (Table 5).

As for RQ1, we determined that the duration of a company's activity does not always have a direct effect on further business development, as its main effect is statistically insignificant (H1 was not supported). However, it serves as a moderator, strengthening or weakening the influence of other entrepreneurial motivation factors among mature individuals. Family support gains significance as companies operate in the market longer, suggesting that long-term business management may facilitate more effective utilisation of resources and support from the family environment. The desire to remain active is generally an important motivator of business expansion, but the role of this factor decreases with the time

of operation. It is likely that in enterprises with a longer operational history, other, more critical factors emerge as primary drivers of development, while the motivation to remain active loses its significance. This configuration of results indicates that in the analysis of expansion decisions, it is important not only what motivations accompanied the mature founders at the start, but also how long the firm has been operating, because the age of the firm may change the importance of individual motivations.

Table 5. Verification of hypotheses regarding post-50 entrepreneurs

Hypotheses		Supported/Unsupported
The influence of firm age on the tendency to develop business activity further (RQ1)		
H1:	Mature individuals who have been in business for longer are less likely to continue to develop their businesses.	Unsupported
The influence of internal ('pull') entrepreneurial factors on the tendency to develop business activity further (RQ2)		
H2:	The opportunity for more flexible working hours compared with full-time employment (as a motivating factor for starting a business) positively influences mature people's propensity for further business development.	Unsupported
H3:	The desire to seek new life challenges (as a motivating factor for starting a business) positively influences mature people's propensity for further business development.	Supported
H4:	Dream fulfilment (as a motivating factor for starting a business) positively influences mature people's propensity for further business development.	Unsupported
H5:	Willingness to be active and interact with other people (as a motivating factor for starting a business) positively influences mature people's propensity for further business development.	Supported
The influence of internal ('push') entrepreneurial factors on the tendency to develop business activity further (RQ3)		
H6:	Dissatisfaction with a previous full-time job (as a motivating factor for starting a business) negatively influences mature people's propensity for further business development.	Supported
H7:	The occurrence of ageism in the workplace (as a motivating factor for starting a business) negatively influences mature people's propensity for further business development.	Unsupported
H8:	Loss of employment and lack of alternative opportunities in the labour market (as motivating factors for starting a business) negatively influence mature people's propensity for further business development.	Supported
The influence of external entrepreneurial factors on the tendency to develop business activity further (RQ4)		
H9:	Family support in starting a business positively influences mature people's propensity for further business development.	Supported
H10:	Friend support in starting a business positively influences mature people's propensity for further business development.	Unsupported
H11:	State support in starting a business positively influences mature people's propensity for further business development.	Supported

Source: own study.

In relation to RQ2, two internal entrepreneurial factors arose from emerging opportunities that statistically significantly and positively impacted mature individuals' tendency to develop their business activity further: the desire to seek new life challenges and willingness to be active and interact with other people (H3 and H5 were supported). However, the opportunity for more flexible working hours, compared with full-time employment, negatively impacted the declared employment growth rate (H2 was not supported). Moreover, the other pull factor, dream fulfilment, did not statistically significantly impact the probability of further business development, as indicated by respondents' statements (H4 was not supported).

Concerning RQ3, two internal entrepreneurial factors resulting from emerging necessities decreased the likelihood of further development of enterprises by individuals post-50: dissatisfaction with previous full-time jobs and the loss of employment, combined with a lack of alternative opportunities in the labour market (H6 and H8 were supported). The occurrence of ageism in the

workplace did not have a statistically significant impact on the probability of further business development, as declared by the respondents (H7 was not supported).

As for RQ4, two external entrepreneurial factors associated with the founder's environment statistically significantly and positively impact mature individuals' propensity for further business development: family support and state support (H9 and H11 were supported). However, the friend support factor did not statistically significantly impact the probability of further business development, as the respondents indicated (H10 was not supported).

A practical implication of our study is that individuals conducting businesses after age 50 should not face discrimination from stakeholders, particularly government agencies. Our research indicates that government support can enhance the propensity for business development within this group. Policymakers should include mature entrepreneurs in grants, mentorship, and training programs targeted at all entrepreneurs. Moreover, entrepreneurship support organisations should develop programs that involve family members in the business planning process to enhance emotional support and foster shared understanding.

A potential area for future research is to challenge stereotypes about mature entrepreneurs' business operations in the context of their propensity for business growth, such as through the introduction of innovations or market survival in highly competitive conditions. Another potential research area could focus on a specific group of mature entrepreneurs motivated by positive internal factors to start a business but lack the desire to expand it in the future, particularly in the context of moderating effects related to firm age. The application of qualitative methods, such as in-depth interviews, could provide valuable insights into these founders' attitudes towards defining business success and the benefits derived from conducting business that directly impacts their lives.

Another topic worth exploring is the role of family in starting, running, and developing businesses by mature individuals in a broader context. This includes drawing inspiration from observing other family members who are also entrepreneurs, hiring family members in their own businesses, shaping the ownership structures of family firms, and succession issues in companies led by both mature individuals who have been running their businesses for some time and silver entrepreneurs who started their businesses for the first time later in life.

However, this study has certain limitations, one of which entails gender distribution among participants. As highlighted in the report of the Polish Economic Institute (Dębkowska *et al.*, 2023), the majority of post-50 entrepreneurs in Poland are male. In our study, this gender imbalance is evident in the sample's notable overrepresentation of men. Furthermore, the nature of entrepreneurs as respondents poses another limitation. Entrepreneurs often have tight daily schedules, which correlate with their reluctance to participate in lengthy surveys. Consequently, the questionnaire had to be concise, limiting the number of questions per topic and influencing the choice of research methods applied in this study. Noteworthy, the study sample might have comprised individuals who identify as entrepreneurs, but are actually full-time employees using self-employment merely for tax purposes with their employers. Employment growth is an imperfect measure of enterprise development, as its correlation with sales growth has weakened due to digitalisation, which enables scale-independent resources and diminishes the traditional link between employment and revenue. Alternative indicators, such as revenue growth, could be considered; however, for Polish entrepreneurs, financial data is often a sensitive subject, leading to reluctance in disclosure. For this reason, we used projected employment growth as a measure of the expected development of the company. Future studies should note these limitations.

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Appendix:

Table A1. Multicollinearity diagnostics and pairwise correlation between dependent and independent variables

Variable	1	2	3	4	5	6	7	8	9	10	11	12
Expansion (1)	1.000											
Firm age (2)	-0.001	1.000										
Family support (3)	0.019	-0.060	1.000									
Friends support (4)	0.045	0.005	-0.213*	1.000								
State support (5)	0.096*	-0.008	0.034	0.216*	1.000							
Flexibility (6)	-0.058	-0.131*	0.061	0.128*	0.094*	1.000						
Challenge (7)	0.140*	-0.052	-0.036	0.086*	0.118*	0.065*	1.000					
Dream (8)	0.009	-0.035	0.104*	-0.019	0.056	0.113*	-0.051	1.000				
Staying active (9)	0.122*	-0.120*	0.023	0.058	0.040	0.135*	0.059	0.100*	1.000			
Job dissatisfaction (10)	-0.085*	-0.036	-0.001	0.039	0.031	0.074*	0.038	-0.053	0.032	1.000		
Ageism (11)	0.058	0.045	-0.005	-0.023	0.150*	-0.052	0.163*	0.185*	0.033	-0.004	1.000	
Job loss (12)	-0.121*	-0.082*	0.076*	0.012	-0.049	0.260*	0.136*	-0.102*	-0.084*	0.159*	-0.217*	1.000
VIF		1.04	1.08	1.13	1.10	1.16	1.09	1.09	1.06	1.03	1.15	1.22

Note: * indicates statistical significance at the 5% level.
Source: own study.

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Use of Artificial Intelligence

The manuscript is free of AI/GAI usage.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Development and validation of the Customer Engagement Orientation scale: Assessing firms' customer engagement orientation and its impact on performance

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A B S T R A C T
Objective: The article aims to develop and validate a new scale – Customer Engagement Orientation (CENOR) – to measure a firm's customer engagement orientation and to provide evidence of its impact on firm performance. Although customer engagement marketing has received growing scholarly attention, the concept of a firm's customer engagement orientation – particularly in capturing value from non-transactional customer behaviour – remains underexplored. Its precise definition, measurement, and firm-level effects are still unclear.
Research Design & Methods: We followed Churchill's procedure (1979) to create and validate the CENOR scale and analyse its impact on firm performance. Firstly, we proposed the scale items based on insights gathered from the literature review and qualitative research of six company managers. Subsequently, the scale underwent assessment and validation through a quantitative study of 100 firms in the household appliances industry and 101 firms in the financial services industry. Finally, we tested nomological validity through a separate quantitative study of 201 firms in the food, beverage, and fashion industries, using structural equation modelling to examine the relationships between the firm's CENOR and overall performance.
Findings: We developed and validated a comprehensive measurement tool for assessing the customer engagement orientation of marketing managers. Our findings demonstrate that the CENOR scale is reliable and valid across three distinct samples of companies operating in a developed economy of Poland. It remains invariant across consumer goods and services industries. Our findings support the external validity of the CENOR as a predictor of initiatives aimed at developing customer engagement behaviour. Furthermore, we confirmed a firm's customer engagement orientation as a critical factor in driving business performance.
Implications & Recommendations: The prepared measurement tool provides a robust basis for future investigations into the implementation of customer engagement orientation within firms stemming from different industries operating in developed markets. It offers practical guidance for implementing a customer engagement-oriented approach within an organisation and equips practitioners with tools to systematically assess and improve their customer engagement orientation, ultimately driving improved performance.
Contribution & Value Added: The unique contribution of this study to the theory of customer engagement marketing lies in combining the development of a new scale for measuring a firm's customer engagement orientation with an analysis of its impact on performance. It contributes to the knowledge of strategic marketing by identifying a firm's engagement orientation as an organisational culture focused on encouraging customers to interact and build relationships beyond transactions. It provides evidence of the positive impact of this orientation on firm performance enhancing our understanding of how a company's management system can successfully capture value from customer resources involved in their non-transactional activities.

INTRODUCTION

Recently, marketing has shifted away from a purely transactional approach towards identifying alternative ways customers can contribute to a firm (Pansari & Kumar, 2017). This shift has led to the emergence of the concept of customer engagement in marketing (Pansari & Kumar, 2018). Customer engagement behaviour encompasses a customer's actions and interactions with a brand or firm that extend beyond mere purchases (van Doorn *et al.,* 2010). Such a behaviour includes various non-transactional customer activities, such as word-of-mouth recommendations, assisting fellow customers, writing reviews, pursuing legal actions, offering feedback and complaints, and suggesting new product ideas (Bijmolt *et al.,* 2010; Braun *et al.,* 2016).

For marketers, prioritising engagement behaviour can create value and impact firms' competitive advantage (Kumar *et al.,* 2010; Verhoef *et al.,* 2010). This underscores the need for management strategies that benefit both the company and its customers (van Doorn *et al.,* 2010; Verhoef & Lemon, 2013). Consequently, developing a framework enabling managers to cultivate customer engagement-oriented firms and foster customer relationships has emerged as an important theme in marketing (Alvarez-Milán *et al.,* 2018; Venkatesan, 2017).

However, academic research on this subject remains limited, leading to two critical research gaps. First, there is a lack of clarity on what constitutes a firm's customer engagement orientation and how to measure it. While previous consumer studies have introduced various scales to gauge customer engagement (Hollebeek *et al.,* 2023), managerial approaches have primarily focused on broader measurement frameworks, such as market or relationship orientation, without adequately addressing strategies for effectively engaging customers. A seminal study by Kumar and Pansari (2016) introduced the concept of a firm's engagement orientation, assessing it through a measurement of both customer and employee engagement. However, the literature does not adequatly explore the issue of a firm's specific customer engagement orientation and a comprehensive and validated measure for assessing the extent of such an orientation is lacking. Secondly, there is ambiguity regarding whether a firm's customer engagement orientation positively affects performance. While customer engagement can drive increased sales (Wirtz *et al.,* 2013) or enhance customer equity (So *et al.,* 2016), suggesting that fostering a firm's customer engagement orientation may improve performance, potential downsides also exist. Negatively valenced customer engagement, such as negative reviews, and challenges in integrating non-transactional customer activities into the firm's value formation process – such as information overload or diminished control (Naumann *et al.,* 2020; Echeverri & Skålén, 2021) – may have adverse effects on performance.

The present research aims to bridge these gaps by proposing a new comprehensive measure of a firm's customer engagement orientation and assessing its impact on performance, thereby advancing the existing literature. It contributes to the non-transactional research stream on customer engagement in marketing by identifying a firm's engagement orientation as an organisational culture focused on encouraging customers to interact and build relationships beyond transactions. Moreover, it provides a practical tool – the CENOR scale – to measure this orientation. CENOR, a cross-industry validated measure, provides a foundation for future investigations into the implementation of customer engagement orientation by firms. It is applicable to various industries operating in developed economies, including those beyond Poland. It also offers practical guidance for a customer engagement-oriented approach within an organisation and equips practitioners with tools systematically assessing and improving their customer engagement orientation, leading to improved performance.

The article is structured as follows. Firstly, we present how we developed and validated a concise scale for measuring a customer engagement orientation among firms' executives, utilising established procedures from the literature. We begin by providing a brief conceptual foundation for constructing the framework of a firm's customer engagement orientation. Subsequently, we detail the process used to create its measurement scale, and we go on with the scale's validation. Finally, we evidence how the CENOR influences the studied companies' performance. We conclude by discussing the research findings, implications for theory and practice, and directions for future research.

LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

Customer Engagement Behaviour

We may define customer engagement behaviour (CEB) as the interactions and connections that customers (or potential customers) have with a brand or a firm's offerings and activities (Chen *et al.*, 2020; Vivek *et al.*, 2014). We may find various typologies of CEB in the current academic literature, including, *e.g.*, consumer liking, commenting, and resending marketing messages (Bijmolt *et al.,* 2010; Verleye *et al.,* 2014; Roy *et al.,* 2018; Żyminkowska *et al.,* 2023; Febrian, 2023). The literature considers customer actions, which extend beyond purchases, as voluntary contributions of resources that centre on a brand or firm but surpass what is strictly required for the transaction (Jaakkola & Alexander, 2014). According to Hollebeek *et al.* (2016), customer engagement involves a customer's motivated and voluntary investment of their resources into brand interactions, including both operant resources (knowledge and skills) and operand resources (equipment). Harmeling *et al.* (2017) identify four types of customer-owned resources that are contributed through their engagement with a firm's marketing function: network assets, persuasion capital, knowledge stores, and creativity.

The resources that customers contribute through their non-transactional behaviour (*i.e.*, CEB) can be valuable to a firm in many ways beyond mere transactions. Firms have come to recognise the value of CEB (Lemon & Verhoef, 2016; Verhoef *et al.,* 2010) and consider it essential to their business success. Consequently, in the development of marketing strategies, the non-transactional sources related to CEB are critical as they contribute to firm performance and form an integral part of customer engagement value for firms (Kumar *et al.,* 2010; Kumar & Pansari, 2016; Pansari & Kumar, 2017).

Conceptual Framework of a Firm's Customer Engagement Orientation

The conceptualisation and measurement of firm's customer engagement orientation within a firm represents a significant research gap. Previous measurement frameworks for strategic orientations in marketing, such as market or relationship orientation, have not tackled strategies for effectively engaging customers (Table 1). Although customer engagement marketing is gaining traction – incorporating artificial intelligence (Gupta & Khan, 2024) or corporate social responsibility (Kumar *et al.*, 2025) – the comprehensive framework for a firm's customer engagement orientation remains largely overlooked. A notable exception is the initial study by Kumar and Pansari (2016), which conceptualised a firm's engagement orientation and proposed assessing it based on the level of engagement among both its customers and employees. Their measurement approach requires conducting two separate studies with distinct groups of informants and utilising two different scales: one to assess customer engagement with the firm and another to assess employee engagement. However, measuring firms' orientations is often part of larger studies aimed at exploring relationships between constructs, where keeping measurements concise is crucial for practical and economic reasons (Deshpandé & Farley, 1998; Hakala, 2011). Thus, a dual perspective on engagement orientation – encompassing both customer and employee engagement – fails to adequately address this need. Moreover, when conceptualising and measuring customer engagement, Kumar and Pansari (2016) include not only non-transactional customer behaviour (CEB) but also customer purchasing behaviour. Thus, their measurement approach is not well-suited to demonstrate how a firm's customer engagement orientation – focused solely on encouraging non-transactional CEB (van Doorn *et al.*, 2010) – affects performance.

Therefore, there is a need to develop a new, concise scale for measuring a firm's customer engagement orientation, aligning with the non-transactional perspective on CEB. Addressing this need, this study aims to introduce a comprehensive measure of customer engagement orientation to enhance our understanding of how a company's management system can successfully capture value from customer resources involved in their non-transactional activities. Such a concise measurement scale, referred to as CENOR, will help identify how firm's customer engagement orientation influences overall performance. In developing the conceptualisation and measurement of customer engagement orientation, we drew upon previous definitions, and we reviewed the measurement approaches in prior studies assessing strategic orientations to compare them to this article.

Table 1. Measurement scales for strategic orientations in marketing

Construct and scale label	Authors	Focus / Construct conceptualisation	Scale dimensions and items	Informants
Market orientation: MARKOR	Kohli *et al.,* 1993	Activities that need to take place for the firm to be considered market-oriented.	Three-dimensional scale, 20 items in total.	**Marketing** and non-marketing **executives**
Market orientation: MORTN	Deshpandé & Farley, 1998	Cross-functional processes and activities directed at creating and satisfying customers through continuous needs assessment.	One-dimensional scale, 10 items.	**Marketing executives**
Market orientation: MKTOR	Narver & Slater, 1990	A culture that most effectively and efficiently creates the behaviours for creating superior value for buyers. Measured through behaviours that manifest those values.	One-dimensional scale, 15 items.	Top managers
Market orientation	Hooley *et al.,* 1990	Guiding philosophy for the entire organisation.	One-dimensional scale, 5 items.	**Chief marketing executives**
Relationship marketing orientation: RMO	Sin *et al.,* 2005b	Distinct organisational culture/value that places the buyer-seller relationship at the centre of the firm's strategic and operational thinking.	Six-dimensional scale, 19 items in total.	**Marketing directors/managers**
Online relationship quality	Brun *et al.,* 2014	An integrative model of relationship quality in online banking services.	Three-dimensional scale, 21 items in total.	Retail banking customers
Relationship marketing instruments: RMI	Binti Che Wel & Bojei, 2009	A set of relationship marketing instruments/tactics/ strategies that can be practiced to manage and strengthen customer relationships.	Five-dimensional scale, 54 items in total.	Customers of retail stores
B2C relationship quality	Roberts *et al.,* 2003	Measurement of quality of a relationship with the firm, perceived by the consumers; the extent to which consumers want to maintain the relationship with service providers.	One-dimensional scale, 15 items	Service firm consumers
Engagement orientation: EO	Kumar & Pansari, 2016	An organisation's culture and the process of embedding engagement in the organisation as a policy decision and ensuring that all strategies of the organisation focus on engaging the customers and the employees, along with value maximisation for all stakeholders.	Two separate scales to measure: (a) Customer engagement: four-dimensional scale, 16 items (b) Employee engagement: five-dimensional scale, 20 items	Customers and employees
Customer engagement orientation: CENOR	This paper	The customer engagement culture of the organisation reflected in cross-functional processes and activities at various levels in an organisation, incl. the firm's strategy and structure, enabling customers to interact and broaden their relationships beyond the purchase.	One-dimensional scale	Marketing executives

Source: own study.

As Table 1 shows, previous conceptualisations of strategic orientations in marketing, including engagement orientation have frequently linked them to organisational culture (Narver & Slater, 1990; Sin *et al.,* 2005b; Kumar & Pansari, 2016). Such a culture is assessed through behaviours that manifest

organisational values and beliefs (Slater & Narver, 1995; Narver & Slater, 1990; Kohli *et al.,* 1993) and is also conceptualised as the set of cross-functional processes and activities (Deshpandé & Farley, 1998). Notably, it can manifest at various levels within an organisation, including the firm's strategy and structure (Hurley & Hult, 1998). This enables considering customer engagement orientation in this article as the customer engagement culture of the firm, reflected in cross-functional processes and activities at various levels in an organisation, incl. the firm's strategy and structure, enabling customers to interact and broaden their relationships beyond the purchase. We also propose examining the attitudes and opinions of staff involved in shaping organisational culture. This approach aligns with previous literature (the 'Informants' column in Table 1), which provides comprehensive scales for studying firm executives (Sin *et al.,* 2005b; Deshpandé & Farley, 1998; Kohli *et al.,* 1993; Hooley *et al.,* 1990).

Operationalisation of the Firm's Customer Engagement Orientation

To identify the components of customer engagement orientation as previously conceptualised, we scrutinised key cross-functional processes that facilitate customer engagement at various organisational levels. We studied the recent findings on how to develop customer engagement behaviour (CEB) profitably, encompassing the CEB management process (van Doorn *et al.,* 2010; Verhoef & Lemon, 2013), customer engagement marketing (Harmeling *et al.,* 2017; Karam, 2018), strategic customer engagement marketing (Alvarez-Milán *et al.,* 2018), and firm's customer engagement initiatives (Beckers *et al.,* 2018; Karam *et al.,* 2019). Building upon this, we delineated components of the customer engagement orientation construct, which resulted in seven items for the CENOR scale.

Firstly, the integration of the customer engagement strategy with the customer relationship management. Beckers *et al.* (2018) suggest that firm-initiated non-transactional customer engagement, where firms adopt explicit strategies to promote customer engagement, does not solely aim to induce an immediate sale to an individual customer but to forge solid and enduring relationships with them. Consequently, an engagement strategy complements the conventional relationship strategy, which emphasises long-term transactional relations built on trust and commitment. As posited by Venkatesan (2017), executing a customer engagement strategy entails mapping the various stages of customer relationships alongside customer journey stages.

The second component involves the existence of organisational units dedicated to CEB within a firm, responsible for customer engagement assessment, dissemination within the firm, and acting accordingly. The concept of CEB management process (van Doorn *et al.,* 2010), implies the development of analytical capabilities and dedicated human resources within the firm focused on CEB management. Moreover, while acting on CEB, customer contributions, such as product or service suggestions, must be effectively disseminated within the firm and available to the right employees for appropriate utilisation. Addressing negative CEB adequately and converting into positive one also demands skilled personnel to manage negative engagements, offer refunds, or apologies.

The third component of the firm's customer engagement orientation involves the services from external providers to manage CEB, such as consultancy, IT solutions, and software. Thus, aside from internal organisational structures dedicated to customer engagement processes, the external ecosystems of firms and their respective supply chains may prove essential for customer engagement-oriented firms (Venkatesan, 2017).

The next constituents of the firm's CENOR refer to the organisational infrastructure that facilitates customer-to-firm interactions (fourth component) and enables customer-to-customer interactions (fifth component). Both these enable information flow through networked communication between the customer and the firm, as well as among customers (Harmeling *et al.,* 2017). Firms must establish customer engagement routes to facilitate CEB (Alvarez-Milán *et al.,* 2018; Vivek *et al.,* 2019). This includes providing platforms to express customer ideas, as well as establishing customer communities (van Doorn *et al.,* 2010). It may also necessitate the amplification, connective, feedback, and creative tools (Harmeling *et al.,* 2017).

The sixth element of the firm's customer engagement orientation involves a set of incentives offered by a firm to engage customers. Harmeling *et al.* (2017) and Van Doorn *et al.* (2010) emphasise the establishment of incentives for customers, including rewards for recommendations, or granting a status level within the ranking system.

Finally, the seventh component of the firm's CENOR involves assessing the costs and effects of CEB within the firm. According to van Doorn *et al.* (2010), evaluating CEB manifestations constitutes a pivotal stage of the CEB management process. The conceptualisation of customer engagement value has been devised to address this fundamental aspect of profitable customer engagement (Kumar *et al.*, 2010; Kumar, 2013).

Table 2. Proposed items for the customer engagement orientation scale (CENOR)

	Proposed scale item	References
P1	The firm's customer engagement strategy is seamlessly integrated with its customer relationship management.	Kumar *et al.,* 2010 Venkatesan, 2017 Beckers *et al.,* 2018
P2	Within the organisation, there are designated units responsible for overseeing customer engagement.	van Doorn *et al.,* 2010 Kumar & Pansari, 2016
P3	The firm collaborates with external partners to procure certain services aimed at managing customer engagement.	van Doorn *et al.,* 2010 Venkatesan, 2017
P4	Effective information systems and procedures are in place to facilitate direct communication between customers and the firm for sharing concerns, complaints, suggestions, or ideas.	van Doorn *et al.*, 2010 Harmeling *et al.,* 2017 Alvarez-Milán *et al.,* 2018 Vivek *et al.,* 2019
P5	The firm has established processes and platforms that empower customers to interact with one another, facilitating the exchange of opinions, advice, pictures, and more.	van Doorn *et al.,* 2010 Harmeling *et al.,* 2017 Alvarez-Milán *et al.,* 2018 Vivek *et al.,* 2019
P6	The firm offers a range of tangible and intangible incentives to encourage customer engagement, including rewards for recommendations, ideas, and rankings.	van Doorn *et al.,* 2010 Harmeling *et al.,* 2017
P7	The firm actively measures both the costs and the effects of customer engagement initiatives.	van Doorn *et al.,* 2010 Kumar *et al.,* 2010 Verhoef & Lemon, 2013

Source: own study.

In conclusion, the operationalisation of the firm's customer engagement orientation construct, enabled us to formulate the initial items for the CENOR scale (Table 2).

Customer Engagement Orientation-related Constructs and Hypotheses Development

In this section, we present the nomological network and hypotheses concerning the connections between the firm's customer engagement orientation and its outcomes. The network draws from previous research related to customer engagement behaviour (CEB). Specifically, it encompasses the firm's initiatives in developing CEB and firm performance (Figure 1).

We incorporated two general categories of firm initiatives in CEB development (Beckers *et al.,* 2018; Karam *et al.,* 2019). Firstly, these aimed at stimulating customer-to-customer communication behaviour, and promoting CEB in customer-to-customer interactions. Customer communication may encompass customer referrals, customers influencing others through word-of-mouth initiated by customers themselves, and content generation, including blogging, writing reviews, and sharing opinions with other customers (Jaakkola & Alexander, 2014; Romero, 2018). Secondly, there are initiatives designed to stimulate customer collaboration behaviour. They encourage CEB in interactions between customers and the firm, as well as its employees. They involve customers actively participating in product development and innovation (Jaakkola & Alexander, 2014), providing information, assistance, and feedback to the firm via suggestions (Verleye *et al.,* 2014).

Prior research has not empirically examined the relationship between a firm's engagement orientation and tactical initiatives in CEB development. However, it has conceptualised engagement orientation as a cultural framework that guides managerial efforts, *i.e.*, the firm's initiatives, to foster engagement throughout the organisation (Kumar & Pansari, 2016). Building on this theoretical framework, we addressed the aforementioned research gap and proposed the following hypotheses:

H1a: Customer engagement orientation within the firm has a positive effect on the firm's initiatives in developing customer-to-customer communication behaviour.

H1b: Customer engagement orientation within the firm has a positive effect on the firm's initiatives in developing customer collaboration behaviour.
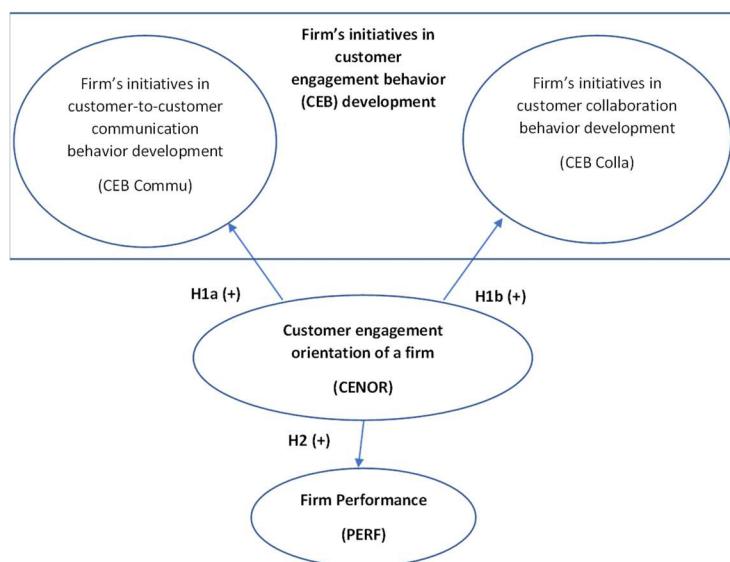
Figure 1. Causal diagram representing the nomological network
Source: own elaboration.

CENOR Impact on Performance

Customer engagement has been shown to enhance firm metrics, including sales, revenue, and profitability (Kumar *et al.*, 2025; Lim *et al.*, 2022; Wirtz *et al.*, 2013; So *et al.*, 2016). For instance, Kumar and Pansari (2016) evidenced that customer engagement, encompassing both non-transactional and purchasing behaviour, positively influences firm performance, increasing revenue and net income. However, adopting engagement marketing requires careful consideration. Firstly, negatively valenced customer engagement, such as negative word of mouth, can lead to adverse firm-level effects if not effectively managed and transformed into positive CEB (Bowden *et al.*, 2017; van Doorn *et al.*, 2010). Secondly, customer engagement, defined as the customer's contribution of resources to marketing function (Harmeling *et al.*, 2017), serves as a mechanism for interactive value formation (Echeverri & Skålén, 2021). Within this mechanism, value can be co-created, generating positive outcomes for firms, or co-destroyed, leading to negative consequences. The latter may include information overload, reduced control over strategic planning, and increased complexity in managing firm objectives (Hoyer *et al.*, 2010; Żyminkowska, 2019). Consequently, ambiguity remains in the existing literature regarding the impact of a customer engagement and firm's customer engagement orientation on performance, highlighting a research gap. Therefore, in this study, we aim to address this gap by testing the impact of CENOR on firm performance.

In doing so, we acknowledge that engaged customers have the potential to contribute to the long-term reputation and recognition of a brand. Therefore, while creating an environment that fosters greater customer engagement may entail an initial investment, it has the potential to generate higher profits over the long term (Verhoef *et al.*, 2010). Moreover, previous studies investigating the outcomes of strategic orientations in marketing have consistently shown their positive impact on firm

performance. Narver and Slater (1990) established that market orientation (MO) serves as a crucial determinant of profitability, both for commodity and non-commodity businesses. Jaworski and Kohli (1993) supported this idea by confirming that an organisation's MO is directly correlated with its business performance. Moreover, Hooley *et al.* (1990) discovered evidence that adopting MO leads to improved performance. Regarding relationship marketing orientation (RMO), Tse *et al.* (2004) and Sin *et al.* (2005b) have both reported its positive impact on market share and return on investment. Furthermore, in their replication of Sin *et al.*'s (2005b) study, Gordon *et al.* (2008) reaffirmed these same associations. Kucukkancabas *et al.* (2009) undertook further exploration of the impact of RMO on company performance. Analogously, a firm's customer engagement orientation, which encompasses long-term principles that guide marketing initiatives focused on CEB, is likely to have a positive influence on its performance. Thus, we hypothesised the following:

H2: A firm's customer engagement orientation has a positive effect on its overall performance.

RESEARCH METHODOLOGY

We followed Churchill' s procedure (1979) to create and validate the CENOR scale (Table 3). Firstly, we proposed the scale items based on insights gathered from the literature review and qualitative research (Step 1). Subsequently, the scale underwent assessment and validation through quantitative studies (Step 2). Finally, we conducted tests for nomological validity (Step 3), involving the development of a nomological network and hypotheses that outlined the relationships between the firm's CENOR and related constructs, including firm performance, grounded in the existing literature. To verify hypotheses, we utilised structural equation modelling.

Table 3. Procedure in the development and validation of the customer engagement orientation scale (CENOR)

Steps in the process	Details	Based on / effects
Step 1. Conceptualisation and operationalisation of the constructs	Conceptualisation and operationalisation of the firm's customer engagement orientation and item generation for the CENOR scale.	Literature review: a) Approaches utilised in constructing firm's strategic orientation scales in marketing. b) The managerial strategies employed by firms to foster customer engagement behaviour.
	Further operationalisation of CENOR: Expert assessment of generated items to evaluate content validity of the initial scale.	Qualitative studies – an expert review (3 scholars and 6 managers). An initial pool of 7 items was generated.
Step 2. Scale assessment and validation	Psychometric properties of scale & item selection.	Study 1: 100 companies in the household appliances industry. Reduction to 5 items.
	Cross-industry validation.	Study 2: 101 companies in financial services.
	Measurement invariance assessment.	Study 1 and Study 2: 100 companies in the household appliances industry and 101 companies in financial services.
Step 3. Nomological and discriminant validation of the scale	Nomological network development and hypotheses statement.	Literature review: Examining the connections between customer engagement orientation and associated constructs, specifically, firms' initiatives in developing customer engagement behaviour and firm performance.
	Model estimation and hypotheses testing; nomological and discriminant validity assessment.	Study 3: 201 companies in the food, beverages, and fashion industries.

Source: own study.

The following section focuses on the results achieved in each step shown in Table 3.

RESULTS AND DISCUSSION

Scale items and content validity [Step 1]

The seven initial items for the CENOR scale (Table 2) reflect the components of the firm's customer engagement orientation discussed in the preceding section. The objective was to assess the content validity of this initial scale. To achieve this, we conducted qualitative research involving both scholars and managers. Initially, we sought critical evaluations of the CENOR items from three scholars. They represented research areas crucial for understanding customer engagement orientation, including strategic orientations in marketing (1 scholar), research methodology (1 scholar), and customer experience and engagement research (1 scholar). They accepted the generated items without reservations.

Next, we interviewed managers from six companies to further clarify scale items. The nature of a company's offerings may influence customer engagement behaviour and potentially moderate its relationships with other constructs (Barari *et al.*, 2020; Behnam *et al.*, 2021; van Doorn *et al.*, 2010; Pansari & Kumar, 2017). Thus, we selected companies with distinct offerings, including tangible products (household appliances, fashion, and food and beverages) as well as financial services. By choosing these specific industries, the sample represents both low-involvement offerings (food and beverages) and high-involvement products (fashion, household appliances, and financial services) (Ratchford, 1987; Vaughn, 1986). Furthermore, we aimed to gather insights from all sizes of enterprises. We also engaged marketing executives from various management levels (Table AI – Appendix). Based on these respondents' feedback, we confirmed that the initial scale items are clear and relevant across diverse contexts.

Psychometric Properties and Cross-industry Validation of the Scale [Step 2]

We evaluated the proposed CENOR scale with regard to its psychometric properties, cross-industry validation, and measurement invariance using a survey method. Surveys offer the advantage of high external validity since data is collected in real-world settings and can capture a relatively large number of variables. However, due to their cross-sectional nature, surveys tend to have lower internal validity. We addressed this concern when assessing nomological validity.

Sample and Data Collection in Step 2

In Step 2, we conducted two surveys from companies operating in the B2C markets in Poland. Over the last decades, Poland has transitioned from a perennially backward, poor, and peripheral country to join the ranks of the world's high income countries. As the literature advocates the development of marketing theory by incorporating inputs from diverse cultures (Burton, 2002), and research results from Poland are rarely disseminated in reputed business journals, we focused on Polish companies to fill this empirical gap and to use this interesting research context.

As mentioned in the previous section, the nature of the offering may impact CEB and moderate its relationships with other constructs. Therefore, Study 1 focused on companies in the household appliances industry, while Study 2 centred on financial services companies. This aimed to validate the scale in different product contexts (Table AI – Appendix). We used probabilistic stratified sampling to ensure sample representativeness. We employed company size (*i.e.*, 5-9, 10-49, 50-249, and 250 or more employees) as a stratification variable and applied proportional sampling from the Dun & Bradstreet Bisnode database, which contains 7.4 million companies registered in Poland. We conducted data collection through computer-assisted telephone interviewing (CATI). Each interview began with a brief introduction to explain the fundamentals of a firm's customer engagement orientation. This aimed to ensure that respondents understood the components of this concept. We collected data from 100 companies in the household appliances industry (Study 1) and 101 companies in financial services (Study 2). Such sample sizes are quite satisfactory when compared with sizes offered in previous empirical research aimed at validating new scales for strategic orientations. For instance, Kohli *et al.* (1993) surveyed 102 companies, and Deshpandé and Farley (1998) surveyed 27 companies.

The respondents in both studies represented marketing executives from lower, middle, and senior management and were responsible for marketing-related activities such as relationship management,

promotion campaigns, customer complaints management, new product development, and innovation. To assess CENOR items, we used a five-point Likert scale, where 1 indicated 'strongly disagree' and 5 indicated 'strongly agree.' As we conducted the interviews in Polish, we followed a four-step translation process ensuring the accuracy, cultural sensitivity, and capturing the intended meaning in the target language (Behr & Shishido, 2016). Firstly, we translated the items from English to Polish by a professional translator fluent in both languages. Secondly, another qualified translator independently translated the items back from Polish to English, helping identify any discrepancies or misunderstandings. Thirdly, we compared the original items with the backward-translated ones, discussing discrepancies with the translators to reach a consensus on the most accurate and culturally appropriate translation. Fourthly, we tested the translated items with three executives to gather feedback on clarity and cultural relevance.

Analytical Strategy in Step 2

At the first stage of the CENOR scale assessment, we constructed the measurement model for consumer goods companies in the household appliances industry (Study 1) and evaluated the psychometric properties of the scale using confirmatory factor analysis (CFA) and F-L criteria (Fornell & Larcker, 1981). During this phase, we selected the items demonstrating the best performance in measuring CENOR.

Secondly, we validated the scale by applying the same measurement model to a sample of financial services companies (Study 2), to determine whether the scale can be replicated and generalised to different settings (Lourenço *et al.*, 2022). Furthermore, we anticipated that, similar to CEB, CENOR may be context-specific (Behnam *et al.*, 2021; Hollebeek *et al.*, 2019). Therefore, by examining the applicability of CENOR to services, we also investigated measurement invariance to ensure that we are measuring (1) the same construct (2) and in the same way across both industries. We employed multiple group confirmatory factor analysis (MGCFA) to address these issues.

CENOR is operationalised as a latent construct measured by statements representing cross-functional processes and activities that reflect customer engagement orientation. Thus, we assumed a reflective measurement model and employed CFA and CB-SEM approaches for its estimation (Jarvis *et al.*, 2003; Sarstedt *et al.*, 2016). Because of some missing values in the dataset, we opted for FIML estimation and we applied AMOS 28 software.

In assessing the scale's psychometric properties, we adhered to the Fornell and Larcker (1981) criteria for reliability and convergent validity. However, we applied cutoff values of 0.6 for reliability (Streiner, 2003; Nunnally, 1967) and an AVE close to 0.5, supplemented by a CR exceeding 0.7 (Fornell & Larcker, 1981). This is because the CENOR scale is new, and there are no well-established social (collective) representations of it in the sense defined by Durkheim (1982). Secondly, the Fornell and Larcker (1981) criteria tend to be conservative and the scale's length can influence CR (in our case, 7 items).

In step 3, we evaluated discriminant validity, which assesses whether inter-construct correlations differ from unity.

In step 2, we assessed the model fit based on criteria outlined by Sharma *et al.* (2005) due to the small sample sizes (100 and 101). For nested model comparison, we employed the chi-square difference test and ΔAFI (Chen, 2007; Cheung & Rensvold, 2002).

Results of Step 2

We initially developed a measurement tool for consumer goods companies in Study 1. However, the standardised loadings for items P.3 and P.6, were lower than 0.5, leading to a low AVE value of 0.380. Consequently, we decided to remove these items from the originally proposed scale. Finally, the CENOR scale demonstrated both reliability and validity, even when applying a more conservative criterion. We assessed convergent validity using the CR criterion, which is less conservative than the Fornell and Larcker one (1981).

Next, when validating the measurement model among consumer service companies in Study 2, the CENOR scale exhibited reliability, with a CR value of 0.771, and convergent validity. Thus, the scale may be applicable to both consumer goods and services companies (Table 4).

Table 4. Psychometric properties of the CENOR scale

Items	consumer goods companies		services companies	Assessment Criterion
	Preliminary CENOR scale	**CENOR scale**	**CENOR scale**	
	Std loadings	Std loadings	Std loadings	
P.1	0.703	0.669	0.592	> 0.5
P.2	0.716	0.720	0.531	
P.3	0.332	n.a.	n.a.	
P.4	0.647	0.690	0.593	
P.5	0.609	0.619	0.674	
P.6	0.471	n.a.	n.a.	
P.7	0.729	0.729	0.772	
CR	**0.803**	**0.816**	**0.771**	> 0.7 (0.6)
AVE	**0.380**	**0.471**	**0.407**	> 0.5 (*)

Note: In the brackets, we indicate the less conservative criterion for new scales; *close to 0.5 & CR > 0.7.
Source: own study.

Finally, we tested measurement invariance to determine whether CENOR is similarly understood across the studied industries and whether service providers react to the scale's items consistent with consumer goods companies.

We confirmed the configural measurement invariance, as the model fit reasonably well, and all factor loadings remained significant in both studied industries. Next, metric measurement invariance was supported, as the model fit did not deteriorate when we imposed restrictions on factor loadings. Regarding scalar measurement invariance, the study met two out of three criteria. To establish partial scalar invariance, we released the equality restriction for the intercept of item P.2, which displayed the most significant violations of the scalar measurement invariance (Ariely & Davidov, 2012; Putnick & Bornstein, 2016). The fit of the partial scalar model did not deteriorate compared to the metric model. Therefore, we can conclude that we achieved partial scalar measurement invariance, and meaningful comparisons of CENOR means between goods and service providers are possible (Steenkamp & Baumgartner, 1998).

Nomological and Discriminant Validation [Step 3]

We based the nomological network regarding the relationships between the firm's customer engagement orientation and related constructs on the existing literature. The structural equation model tested the hypotheses underpinning the proposed network. Moreover, we checked discriminant validity by including all constructs relevant to the firm's customer engagement orientation within the nomological network.

Measures, Sample, and Data Collection in Step 3

For assessing firm's initiatives in customer engagement behaviour development, our items are based on Bijmolt *et al.* (2010), Braun *et al.* (2016), Ho *et al.* (2020), Kumar and Pansari (2016), Muntinga *et al.* (2011), and Verleye *et al.* (2014). We employed five-point Likert scales to measure all variables (Table AII – Appendix).

To evaluate managers' assessment of performance, we used sales growth, market share, and net profit relative to main competitors (Hooley *et al.*, 1990). We adopted a subjective assessment of firm performance, aligning with the approach in Narver and Slater's (1990) study on the impact of market orientation on business performance. The prior studies have established a strong correlation between subjective assessments and objective performance indicators (Dess & Robinson, 1994). We rated the sales growth, market share, and net profit on five-point Likert scales, ranging from 1 (definitely worse than competition) to 5 (definitely better than competition (Table AII – Appendix).

In Step 3, we conducted a quantitative Study 3. The survey involved consumer goods companies in Poland that operated in food and beverages, as well as fashion industries (Table AI – Appendix). We followed the same sample design and data collection method as in Step 2, and obtained data from 201 companies. Previous research on the impact of strategic orientation on firm performance involved samples of 102 companies – Kohli *et al.* (1993), 110 business units – Narver and Slater (1990), and 130 firms – Kucukkancabas *et al.* (2009).

Analytical Strategy in Step 3

In step 3, we assessed the psychometric properties of the scales used to measure all constructs related to customer engagement orientation within the nomological network. Next, we evaluated discriminant validity, and adopted the bootstrap confidence intervals for inter-construct correlations (Bagozzi *et al.*, 1991) instead of relying solely on the commonly used AVE/SV criterion (Fornell & Larcker, 1981), which has been shown to have a high rate of false positives in detecting a lack of discriminant validity (Rönkkö & Cho, 2022). Finally, to assess nomological validity and test our hypotheses, we estimated the SEM model using the CB-SEM approach. Due to our relatively small sample size (201), we utilised model fit criteria outlined by Sharma *et al.* (2005).

Results in Step 3

The estimated measurement model displayed a good fit with $\chi^2 = 140.9$ with 98 degrees of freedom and TLI = 0.950, CFI = 0.964, RMSEA = 0.047 (90% CI for RMSEA [0.028, 0.063]). All constructs in the model demonstrated reliability, with high values of CR exceeding 0.7, and convergent validity (AVE) exceeding 0.5 (Table 5). The construct 'firm's initiatives in customer-to-customer communication behaviour development' met the less conservative criterion of AVE close to 0.5, supported by CR exceeding 0.7.

Table 5. Psychometric properties of construct scales and discriminant validity assessment

Construct			Count of items	Std. loadings range	CR	AVE
Customer engagement orientation of a firm (CENOR)			5	0.71-0.81	0.873	0.579
Firm's initiatives in customer collaboration behaviour development (CEB_colla).			4	0.60-0.79	0.807	0.512
Firm's initiatives in customer-to-customer communication behaviour development (CEB_commu)			4	0.60-0.74	0.749	0.429
Firm performance (PERF)			3	0.70-0.89	0.850	0.657
Discriminant validity assessment						
Parameter			**Correlation**	**90% bootstrap CI**		***p***
CENOR	<-->	CEB_commu	0.831	0.736	0.905	0.003
CENOR	<-->	CEB_colla	0.579	0.441	0.699	0.002
CENOR	<-->	PERF	0.419	0.272	0.528	0.004
CEB_commu	<-->	CEB_colla	0.542	0.390	0.671	0.002
CEB_commu	<-->	PERF	0.262	0.103	0.413	0.008
CEB_colla	<-->	PERF	0.212	0.032	0.385	0.045

Note: To perform the bootstrap, we excluded the missing values pairwise and estimated the model based on the covariance matrix with the use of the Monte Carlo (parametric) bootstrap. We caluclated the bias-corrected bootstrap confidence intervals (CI) on 1000 replications.
Source: own study.

We successfully established discriminant validity for all constructs within the study (Table 5). This was determined by assessing bias-corrected bootstrap confidence intervals, where none of the 90% bootstrap confidence intervals included the value of 1. Therefore, we can conclude that CENOR scale effectively distinguishes itself from other constructs.

We assessed nomological validity based on the structural model which demonstrated a good fit to the data, as evidenced by chi-square ($\chi^2 = 142.2$ with 101 degrees of freedom) and fit indices (TLI = 0.954, CFI = 0.966, RMSEA = 0.045, 90% CI for RMSEA [0.025, 0.062], Figure 1). We found the hypothesised

effects to be positive, significant, and substantial, supporting the stated hypotheses. CENOR had a positive effect on Firm's initiatives in customer collaboration behaviour development (estimate 0.582, S.E.=0.1, C.R.=5.806, p<0.001, beta=0.590, support for H1b). Moreover, CENOR had a positive effect on firm's initiatives in customer-to-customer communication behaviour development (estimate 0.796, S.E.=0.116, C.R.=6.881, p<0.001, beta=0.838, support for H1a). Finally, CENOR had a positive effect on firm performance (estimate 0.283, S.E.=0.061, C.R.=4.661, p<0.001, beta=0.411, support for H2).

Discussion

Previous research has emphasised the significance of a customer engagement focus in marketing. This is because customers' voluntary contributions through non-transactional behaviours have been identified as a valuable resource for firms (Harmeling *et al.*, 2017; Hollebeek *et al.*, 2016). Consequently, recent academic research has recognised the necessity for a framework regarding a firm's customer engagement orientation (Alvarez-Milán *et al.*, 2018; Venkatesan, 2017). Our research significantly advances these initial discussions. We clarified the nature of the firm's customer engagement orientation construct and proposed a measurement tool and framework for investigating its impact on firm performance.

Based on our research findings, we propose to conceptualise a firm's customer engagement orientation as a culture of customer engagement. This culture is reflected in cross-functional processes and activities across various levels within an organisation, including the firm's strategy and structure, all of which enable customers to interact and cultivate relationships beyond the initial purchase. Such a conceptualisation focuses on organisational culture with a long-term impact on management actions, which aligns with prior studies on strategic orientations (Hakala, 2011), particularly in marketing (Narver & Slater, 1990; Sin *et al.,* 2005b). Our approach differs from Kumar and Pansari's (2016) definition of a firm's engagement orientation, which involves policies to engage both customers and employees. While employee satisfaction, identification, commitment, and loyalty are crucial for the successful implementation of any business strategy, they fall under the domain of human resource management. In contrast, our focus is on the marketing function, specifically on customer engagement. Additionally, in our definition, we follow non-transactional views on customer engagement (Ho *et al.*, 2020; Vivek *et al.*, 2014) asserting that a firm's customer engagement orientation influences marketing initiatives to encourage customer interactions beyond purchases. In contrast, Kumar and Pansari (2016) include customer purchases as a dimension of customer engagement, which might distort the results when assessing its impact on performance. Customer purchases directly impact sales growth which is a key indicator of firm performance. By clarifying the nature of the firm's customer engagement orientation, which focuses solely on encouraging non-transactional CEB, we propose a solid foundation for demonstrating how it affects firm performance, thereby advancing existing literature.

We have developed and rigorously validated the concise, one-dimensional scale designed to measure the customer engagement orientation among firms' executives. While measuring a firm's engagement orientation, Kumar and Pansari (2016) do not provide a single score for engagement. Instead, they use an aggregate score encompassing both customer engagement (assessed among the firm's customers) and employee engagement (assessed among the firm's employees) to represent engagement within the firm. In contrast, we propose a valid and concise measure, which allows for the calculation of a single score for a firm's customer engagement orientation based on evaluations by its executives. Our method is better suited for measuring firms' strategic orientations, as it is often part of larger studies where keeping measurements concise is advantageous, as suggested in prior literature on strategic management (Hult & Ketchen, 2001; Lumpkin & Dess, 1996). Our approach focuses on executives' subjective assessments of the customer engagement orientation. This aligns with previous research on strategic orientations in marketing, where scales were developed to identify specific orientations through the subjective assessment of their components by management staff (*e.g.*, Kohli *et al.*, 1993; Sin *et al.*, 2005b).

The CENOR scale has demonstrated remarkable reliability (ranging from 0.771 to 0.873 depending on the industry), exceeding our expectations, with a cutoff point of 0.6 (Streiner, 2003). Regarding convergent validity, the scale has met the less conservative criterion. Importantly, we found that the CENOR scale is invariant across both consumer goods, such as household appliances, and financial services companies. This indicates that the scale is understood similarly in both industries and versatile companies

respond similarly to the scale's items. This result surpasses our expectations, as establishing scalar measurement invariance is less common in studies, especially when analysing such diverse industries (Putnick & Bornstein, 2016). This result indicates that the CENOR scale is an effective tool that fulfils its intended purpose across diverse contexts. The tool's effectiveness is demonstrated by its psychometric properties, including reliability and validity, which remained consistent across the industries under study. Specifically, the CENOR scale enables managers to accurately identify the firm's customer engagement orientation in various industry settings, including both tangible products and services as well as industries offering high- and low-involvement offerings, such as fashion and food and beverages, respectively.

Given that the firm's strategic orientation guides efforts to stimulate customer engagement behaviour, we anticipated a positive relationship between these constructs. Our research findings support hypotheses H1a and H1b, confirming the external and nomological validity of the CENOR scale. The relationship between the firm's customer engagement orientation and its initiatives in customer-to-customer communication behaviour development is notably strong, with a standardised effect size of 0.838. This is followed by the firm's initiatives in customer collaboration development (beta = 0.590). The stronger effect observed for initiatives in customer-to-customer communication development could be attributed to the ease of nudging customers toward communication compared to collaboration. Indeed, prior research has shown this type of consumer engagement to be a key facet of CEB (Braun *et al.*, 2016; Romero, 2018). Collaboration, being a higher level of engagement, requires more substantial incentives to overcome customer inertia. Customers tend to engage for their benefit in anticipation of securing greater value (Hollebeek & Macky, 2019; Prentice & Loureiro, 2018). Additionally, stimulating customer communication is relatively easier to implement and requires fewer resources compared to stimulating customer collaboration, which involves adapting R&D processes and production (Kunz *et al.*, 2017; Verhoef *et al.*, 2010).

In the external validation of the scale, we also supported the predictive validity of the firm's customer engagement orientation measure on performance, thereby providing support for hypothesis H2. It is worth noting that company performance is influenced by various factors, including regulatory, environmental, and economic conditions, which were not considered in our model. Nonetheless, the standardised effect of the customer engagement orientation on performance, which stands at 0.411 is substantial. Our findings align with previous research that has explored the impact of various strategic orientations on performance using a similar approach. For instance, Sin *et al.* (2005b) discovered a standardised effect of 0.34 for relationship marketing orientation on overall firm performance, including sales growth, customer retention, return on investment, and market share, in their Hong Kong sample, and an effect of 0.49 in their Mainland China sample. Similarly, Kohli *et al.* (1993) identified effects of 0.419 for market orientation dimensions related to intelligence generation and 0.426 for dimensions associated with dissemination and responsiveness. Hence, considering the customer engagement orientation as a critical factor contributing to business success is confirmed and consistent with prior research (Ho *et al.*, 2020; Shawky *et al.*, 2020). The study demonstrated a significant relationship between CENOR, viewed as a component of company culture, and firm performance relative to competitors. This finding suggests that a firm's customer engagement orientation may serve as a strategic tool for maintaining alignment with its microenvironment, thereby supporting the assumptions of the resource-based view and strategic orientation theories (Peteraf & Barney, 2003) advancing existing literature on marketing orientations.

CONCLUSIONS

This study addresses research gaps by clarifying the nature of a firm's customer engagement orientation in capturing value from non-transactional customer behaviour and by developing and validating a measurement tool for a firm's customer engagement orientation to provide evidence of its impact on firm performance. Our findings demonstrate that the CENOR scale exhibits reliability and validity across three distinct samples of companies operating in Poland, encompassing both consumer goods and services industries. In addition, a firm's customer engagement orientation is confirmed to be a

critical factor contributing to business success. The study holds significant theoretical and practical implications and opens avenues for future research.

Theoretical Implications

The theoretical contribution of our research centres on advancing the literature concerning the implementation of a firm's customer engagement orientation in marketing and the development of management systems and cultures that prioritise customer engagement.

The nature of customer engagement orientation includes five key components:

- Integration of customer engagement strategy with customer relationship management within the firm.
- Establishment of designated organisational units responsible for customer engagement.
- Implementation of effective information systems and procedures enabling direct customer communication for concerns, complaints, suggestions, or ideas.
- Creation of processes and platforms facilitating customer-to-customer communication, allowing the exchange of opinions, advice, and content.
- Measurement of the costs and effects of customer engagement.

This framework contributes significantly to the theory of customer engagement marketing, shedding light on how firms stimulate, empower, and evaluate customers' voluntary, non-transactional contributions to marketing functions.

Second, support of the reliability and validity of the CENOR scale is evidenced. This scale is a reliable means of assessing a firm's customer engagement orientation which demonstrates robust performance across both consumer goods and services industries. Moreover, the CENOR scale is invariant between sectors, enabling meaningful comparisons of mean levels and relationships across industries. This facilitates the practical application of the CENOR scale and enhances the interpretability of results across contexts.

Finally, a firm's customer engagement orientation model was validated, significant associations with specific firm initiatives in customer engagement development were evidenced. Moreover, overall business performance, indicated by sales growth, market share, and net profit is positively influenced by a firm's customer engagement orientation. This provides a robust basis for future investigations into the implementation of a firm's customer engagement orientation within firms stemming from different industries.

Managerial Implications

The developed firm's customer engagement orientation scale focuses on processes and activities essential for fostering a customer engagement-oriented approach. It offers practical guidance for implementing a customer engagement-oriented approach within an organisation and equips practitioners with tools to assess and improve their customer engagement orientation and performance systematically.

Firms aiming to harness their customers' resource contributions beyond the point of purchase might use CENOR scale for systematically gauging a firm's orientation in various industries. This tool can also function as a diagnostic instrument, enabling firms to assess the completeness of their customer engagement orientation and identify areas requiring specific adjustments.

Top-level management can utilise this framework to develop strategies and tactics for customer engagement marketing, foster a customer engagement-oriented organisational culture, and enhance customer relationships extending beyond monetary transactions. Periodic measurements of a firm's customer engagement orientation, as well as industry-level benchmarks, can further contribute to the development of a competitive advantage.

As verified in our study, a high CENOR level can contribute to the development of company performance, as the firm's customer engagement orientation places customer engagement behaviour at the core of its strategic and operational thinking.

Limitations and Future Research Directions

While this study offers substantial contributions, further research is warranted to extend the generalisability of our findings. Additionally, our current findings should be considered indicative rather than conclusive, underscoring the need for ongoing research.

One limitation pertains to the geographic scope of our study, which focused solely on testing the scale within a single post-transition market – Poland. Poland was reclassified from an emerging to a developed market by global index provider FTSE Russell in September 2018. While the three distinct samples encompassed a variety of businesses, expanding the analysis to include more mature market economies and testing CENOR in global markets is imperative. Given that respondents' perceptions and attitudes are shaped by their national cultures, replicating this study on a broader scale across diverse cultural contexts is essential to validate the generalisability of our findings.

Regarding the nomological validation of the CENOR scale, we concentrated on exploring the associations between a firm's customer engagement orientation and its outcomes, including firm's initiatives in customer engagement behaviour development and performance. The future theoretical and empirical research could incorporate the antecedents of customer engagement orientation. This would involve assessing the internal characteristics of a firm that either facilitate or hinder the development of a customer engagement orientation. Investigating organisational factors such as top management's risk aversion, interdepartmental conflicts, or centralisation could provide valuable insights into the determinants of customer engagement orientation.

Further studies are also necessary to determine whether CENOR effectiveness is contingent on environmental conditions. Subsequent research could investigate the moderating effect of environmental turbulence factors – such as technological and market turbulence, as well as competitive intensity – on the relationship between a firm's customer engagement orientation and performance.

Furthermore, our data collection focused exclusively on managers in firms operating within the business-to-consumer (B2C) market. Given suggestions by some researchers, such as Pansari and Kumar (2017), that the operational context, whether business-to-business (B2B) or B2C, may influence the impact of customer engagement orientation on performance, future research should explore the role of this moderator in the link between firm's customer engagement orientation and business performance.

In addition, because of the cross-sectional approach our results should not be interpreted as conclusive proof of a causal relationship between a firm's customer engagement orientation and business performance. Establishing a time-series database and conducting longitudinal investigations to test this relationship could offer more comprehensive insights.

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Appendix:

Table A I. Sample characteristics

Qualitative study (Step 1)				
Firm no.	**Product offered**	**No of employees**	**Management level of the respondent**	**Scope of the business**
1	Household appliances	10-49	Senior	Retailing & services
2	Household appliances	10-49	Lower	Production
3	Fashion	50-249	Middle	Production & retailing
4	Financial services	5-9	Senior	Services
5	Food and beverages	50-249	Senior	Production
6	Financial services	10-49	Middle	Services
Quantitative study				
		Step 2		**Step 3**
		Study 1	**Study 2**	**Study 3**
Industry		Household appliances	Financial services	Food, beverages, and fashion
N		100	101	201
No of employees	5-9	47%	9%	35%
	10-49	32%	49%	34%
	50-249	14%	34%	22%
	250 and more	7%	9%	8%
Management level of the respondent	Lower	8%	19%	7%
	Middle	45%	30%	31%
	Senior	47%	51%	62%

Source: own elaboration.

Table A II. The distribution of responses to scale items in Step 3

Variable	Items	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Firm's initiatives to stimulate customer-to-customer communication behaviour	We initiate discussions among consumers about our firm, brand, or products on our website and fun page.	76	39	6	32	41
	We encourage our consumers to click the 'like' button for our firm, brand, products, or posts.	37	18	8	47	85
	We encourage consumers to share the content, pictures, and videos that we provide.	73	40	8	42	26
	We collaborate with independent bloggers who initiate discussions among consumers about our products or firm.	118	33	8	16	15
Firm's initiatives to stimulate customer collaboration behaviour	We invite consumers to participate in surveys to express their preferences regarding products or ideas.	73	39	4	44	25
	We encourage consumers to submit their product designs, such as in design contests.	104	37	2	12	12
	We organise crowdfunding campaigns to finance our product prototypes.	101	32	2	9	3
	We gather consumer suggestions on products, packaging, promotions (including our website), and sales.	87	29	8	32	23

Variable	Items	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
		Definitely worse than the competition	Rather worse than the competition	Neither better nor worse than the competition	Rather better than the competition	Definitely better than the competition
Firm performance	Sales growth	6	16	85	53	14
	Market share	5	16	84	60	13
	Net profit	4	19	80	47	13

Source: own elaboration.

Authors

The contribution shares of authors: KŻ – 40%: conceptualisation, literature writing, data gathering, discussion; AP – 40%: conceptualisation, methodology, calculations, discussion; IK –20%: conceptualisation, discussion, editing and submission

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Use of Artificial Intelligence

The authors declare that they used generative artificial intelligence (GPT-5) to assist with proofreading the manuscript.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Entrepreneurial resilience in times of crisis: A bibliometric analysis

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A B S T R A C T
Objective: The study aims to map out and explore the body of knowledge related to the topic of entrepreneurial resilience in times of crisis.
Research Design & Methods: We conducted a bibliometric analysis of publications selected from Scopus. In all, we identified 291 articles concerning entrepreneurial resilience were identified, appearing in 156 journals and authored by 782 contributors affiliated with 160 institutions in 67 countries. The documents were analysed using VOSviewer software.
Findings: This study reveals an increasing trend in publications, with a notable surge from 2020 onward, likely driven by the COVID-19 pandemic's impact.
Implications & Recommendations: This study contributes to the understanding of entrepreneurial resilience during times of crisis, providing essential guidance to both researchers and practitioners. On the academic level, it highlights the distribution and current trends in research, providing a solid framework for exploring new future directions. From a practical standpoint, it offers valuable recommendations to managers and practitioners, enabling them to make informed decisions to strengthen the resilience of their businesses in a constantly evolving environment.
Contribution & Value Added: The study significantly contributes by offering a complete overview of the existing studies concerning entrepreneurial resilience, providing valuable insights and a clearer understanding of the current landscape and emerging trends.

INTRODUCTION

A number of worldwide crises, like the Great Depression of the 1930s, the 2008 financial crisis, and most recently the global COVID-19 problem, have had a significant influence on businesses (Portuguez Castro & Gómez Zermeño, 2021). Faced with the proliferation of adverse events described as 'black swans' (new and unpredictable phenomena with high impact), organisations and individuals are faced with a multitude of unpredictable potential risks in all areas (Verma & Gustafsson, 2020). These disruptions have altered the strategic aims of organisations from profit maximisation to resilience enhancement (Hamel & Valikangas, 2004).

Entrepreneurs also face a multitude of challenges, including predictable or unpredictable risks, internal or external to their activities (Chalus-Sauvannet & Ewango-Chatelet, 2022). Entrepreneurial resilience, as defined by Awotoye and Singh (2017), refers to the capacity to surmount entrepreneurial obstacles and to persevere in the entrepreneurial process despite adverse situations and unexpected

results, which plays a crucial role in this dynamic. Considered an emotional and cognitive skill, entrepreneurial resilience provides considerable benefits to the entrepreneur, particularly when bouncing back from failures related to their entrepreneurial activities (Bernard & Barbosa, 2016).

Thus, to ensure the continuity, sustainability, and future success of their business, entrepreneurs must develop and cultivate their resilience (Martinelli *et al.*, 2018). The ability to face obstacles, adapt to changes and persevere in the face of adversity is essential to overcome the challenges encountered in the entrepreneurial journey. Therefore, understanding and building entrepreneurial resilience becomes a priority for entrepreneurs seeking to thrive in often turbulent and unpredictable business environments.

Generally, researchers define resilience as the ability of an element, system, organisation, or person to withstand disruptions (Ishak & Williams, 2018), absorb changes, and return to a stable state or previous form after a disturbance (Burnard & Bhamra, 2011). It also involves the ability to adapt positively in the face of adversity, uncertainty, or adverse events (Williams *et al.*, 2017). However, despite its popularity, the concept of resilience has been criticised for being vague and unclear (Ma *et al.*, 2018; Ruiz-Martin *et al.*, 2018), due to the lack of a clear and coherent definition (Conz & Magnani, 2020; Hillmann & Guenther, 2021), as well as confusion surrounding its relationship with related, but distinct, concepts such as robustness and anti-fragility (Munoz *et al.*, 2022), which has led to varied interpretations and fragmented definitions in the literature (Duchek, 2020).

For this reason, bibliometric analysis is an effective approach to structure and clarify a scattered field of study, which promotes a more coherent and comprehensive understanding of resilience in the scientific literature. In this sense, Doern *et al.* (2019), emphasise that understanding the concept of resilience is essential, as it allows the company to continue operating reliably during the crisis (Portuguez Castro & Gómez Zermeño, 2021; Williams *et al.*, 2017).

On the other hand, the number of studies related to the crisis in entrepreneurship has increased considerably in recent years. However, scientific literature that has analysed the relationship between resilience and entrepreneurship (*e.g.*, Doern *et al.*, 2019; Korber & McNaughton, 2018), has noted the lack of studies examining how entrepreneurs learn from adverse events and how they manage crises (Portuguez Castro & Gómez Zermeño, 2021). Consequently, researchers considering the topic of resilience may find themselves faced with unanswered questions, contributing to continued confusion in this stream of research (Supardi & Hadi, 2020).

To fill these gaps, a bibliometric study focused on the subject of entrepreneurial resilience in a time of crisis becomes necessary to analyse scientific literature, in order to allow researchers and managers to better understand the current state and frontiers of research on entrepreneurial resilience. Scholars widely use bibliometric analysis is widely used to highlight the most representative results from a set of bibliographic documents (Martinelli *et al.*, 2018; Silva-Santos & Mueller, 2022). Moreover, it offers data and indicators that allow for monitoring the progress of scientific production, identifying the most influential articles and assessing their impact on the research field (Garfield, 2004). The main objective of this article is to analyse in depth the scientific production on entrepreneurial resilience, identifying and integrating the knowledge produced among the key publications while proposing perspectives to guide future research.

Thus, this article complements the bibliometric research by Linnenluecke (2017) and Silva-Santos and Mueller (2022) on resilience in the field of business and management. It provides a visual representation of the field of studies on entrepreneurial resilience by bibliometrically analysing the publications indexed in the Scopus database using the VOSviewer software, which is an effective tool in the graphical representation of bibliometric maps (Van & Waltman, 2010). Therefore, the present study stands out as one of the few systematic reviews of resilience research, based on bibliometric analysis and visual representation.

The rest of the document is organised as follows. In section 2, we illustrate our research methodology. In section 3, we present the results of the literature review. We then discuss our findings and suggest some avenues for further research on resilience in section 4. As we move towards the conclusion (section 5), we highlight a set of implications and limitations of this research.

MATERIAL AND METHODS

Traditionally, scholars interpret research findings through two main approaches: qualitative literature reviews and quantitative meta-analyses (Schmidt, 2008). Systematic reviews provide a structured and objective conceptual analysis, while meta-analyses deal with quantitative data (Linnenluecke *et al.*, 2020; Buchanan & Bryman, 2009). However, a third method, bibliographic mapping, has emerged by combining bibliometric tools to represent the structure and evolution of scientific fields (Zupic & Cater, 2015). Unlike classical approaches, bibliometric analysis allows for the processing of large volumes of data, identifying trends, influential authors, and notable publications while providing a global perspective on the past developments and future directions of a research field (Singh *et al.*, 2024; Sarango-Lalangui *et al.*, 2018).

Bibliometric analysis is a timely approach to examining the evolution of research fields, including topics and authors, based on the social, intellectual, and conceptual structures of the disciplines (Verma & Gustafsson, 2020; Donthu *et al.*, 2020). It offers a comprehensive insight into scientific research in a particular field, by pinpointing key features including references, trends, citations, authors, research institutions, and keywords (Merigó & Yang, 2017). This research took place in three stages: the determination of the research questions, the systematic search process, and the bibliometric and visualisation analysis.

Determining Research Questions

We formulated the following five research questions relating to entrepreneurial resilience in times of crisis:

RQ1: How is the chronological development of publications characterised?

RQ2: What are the most relevant journals in this area of research?

RQ3: Who are the most influential authors on this research topic?

RQ4: Which countries are the most important in this area of research?

RQ5: What are the main keywords used in this research area?

We found multiple research publications that were temporally unrestricted and indexed in the Scopus database to address the research concerns of this study. We chose this database because of its popularity in the field of scientific research. It is recommended by some bibliometricians as having broader coverage than Web of Science (Zupic & Cater, 2015). Indeed, Scopus is the most widely used database in bibliometric analyses (Singh *et al.*, 2021; Zupic & Cater, 2015). It is one of the largest curated databases, covering scientific journals, books, and conference proceedings selected through a rigorous content selection process followed by continuous re-evaluation (Singh *et al.*, 2021). Unlike Web of Science, Scopus has a single citation index and covers 66.07% more unique journals than Web of Science (Singh *et al.*, 2021). This platform offers tools such as Search (literature and author searches), Discover (identification of collaborators and data exploration via indicators), and Analysis (citation tracking and evaluation of results by country, affiliation, or field) (Singh *et al.*, 2021).

Although Scopus may not have the comprehensiveness of Dimensions or the massive reach of Google Scholar, its rigorous indexing, robust analysis features, and content quality make it a valuable tool for accurate and reliable bibliometric analyses (Singh *et al.*, 2021; Zupic & Cater, 2015).

Indeed, Google Scholar includes a wider range of publications than Web of Science or Scopus. However, it lacks a user interface or API (application programming interface) to facilitate the export of a collection of documents with cited references, which is essential for bibliometric analysis (Zupic & Cater, 2015). Furthermore, even though Dimensions stands out for its comprehensiveness (covering 82.22% and 48.17% more unique journals than Web of Science and Scopus, respectively), Scopus remains preferred for research focused on high-quality publications (Singh *et al.*, 2021). Indeed, it offers rigorous data verification, powerful analysis tools, and a user-friendly interface, making it a tool particularly suitable for demanding scientific studies (Singh *et al.*, 2021; Zupic & Cater, 2015).

Therefore, the Scopus database offers the advantage of including bibliometric and citation tracking tools, thus facilitating the analysis of scientific production. We collected documents on this database on February 5, 2024.

Process of Systematic Research

To search for articles, we came up with keywords that we thought were important to the study. These were: entrepreneurship, resilience, crisis, and crisis management. We added the asterisk (*) to find all the publications that had the words 'resilience', 'resilient', 'entrepreneur', 'entrepreneurship', or 'entrepreneur'. This allowed us to efficiently exclude pieces unrelated to the entrepreneurship literature. To find even more, we employed the Boolean operators AND and OR. This method was similar to those used in other literature studies, such as those by Korber and McNaughton (2018) or Portuguez Castro and Gómez Zermeño (2021).

We searched for the terms in the titles, abstracts, and keywords. We refined the search to only include articles published in the following three areas: Business, Management, and Accounting; Economics, Econometrics and Finance; and Social Sciences, while excluding other categories. Then, we filtered only full articles published in journals, including documents such as journal articles, reviews and conference articles. We excluded other types of materials, such as book reviews, reprints, and editorial content, were excluded. Finally, the search process continued with the removal of articles that were not written in English. We applied these filters, which resulted in the retrieval of 291 articles, which we subsequently processed for bibliometric analysis. Figure 1 illustrates the systematic research process employed in this study.
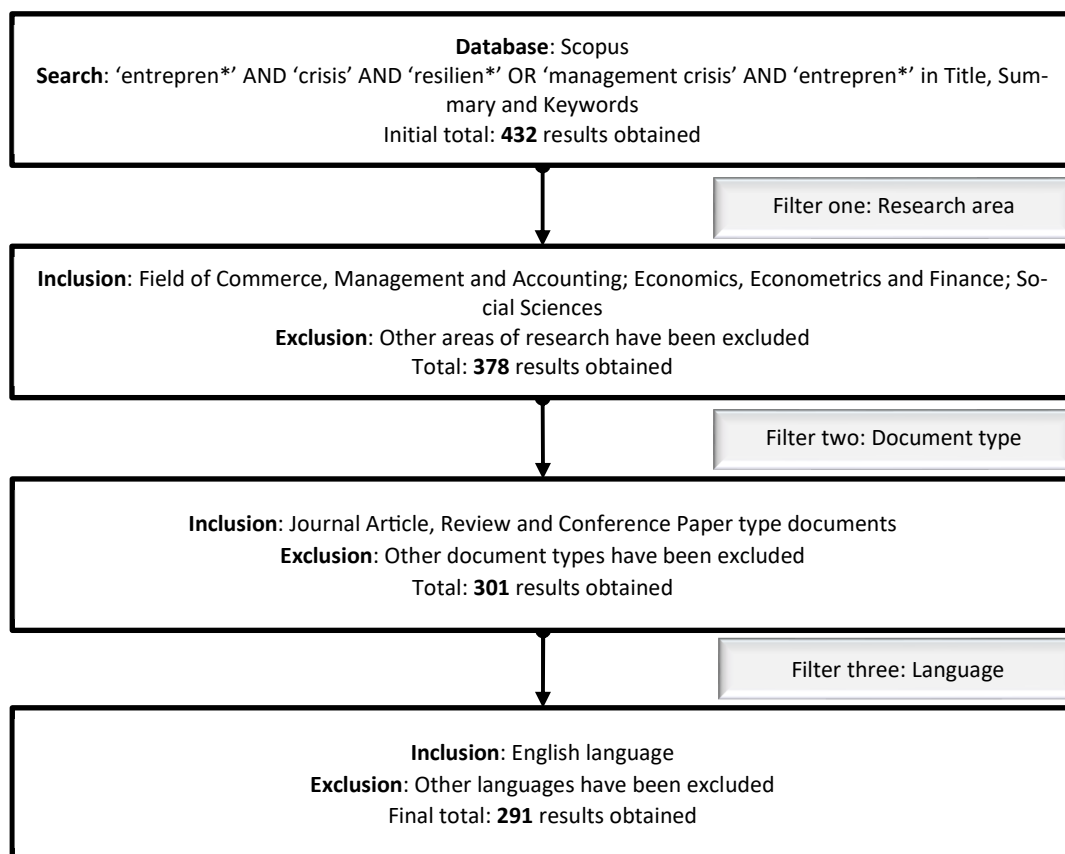
Figure 1. Summary of the systematic search process
Source: own elaboration.

Bibliometric Analysis and Visualisation

The bibliometric analysis approach proves beneficial to researchers by allowing them to grasp the scope of a topic, identify emerging trends, and observe its evolution over time (Singh *et al.*, 2020). This method provides a holistic perspective, offering more objective data than a traditional literature review, thereby reducing the subjectivity that may arise from the researcher's bias (Bhattacharyya & Verma, 2020).

Moreover, we processed the bibliographic data using the VOSviewer software (version 1.6.20). This software employs a technique called VOS (visualisation of similarities) to generate, explore, and display maps based on network data (Van & Waltman, 2010). VOSviewer software is designed primarily for bibliometric network analysis, it additionally enables the creation, visualisation, and exploration of maps for various types of network data (Van Eck & Waltman, 2023).

Although effective for visualising bibliometric maps, VOSviewer has some limitations (Van Eck & Waltman, 2023). Firstly, the complexity of the analysed data can make it difficult to capture nuances and relationships between publications, authors, or research fields. Furthermore, the interpretation of the maps is often subjective, which can lead to divergent conclusions among users. In addition, some advanced data analysis and manipulation features may be limited compared to other specialised software. Finally, the visualisation can sometimes oversimplify complex relationships, resulting in the loss of essential information. These limitations must be considered for the proper utilisation and interpretation of the findings generated by VOSviewer (Van & Waltman, 2010).

We used the VOSviewer software to create visualisation maps, exploiting bibliographic links and cartographic analyses of the keywords of the publications. These maps make it possible to highlight groupings of emerging topics linked to entrepreneurial resilience in times of crisis. We present the obtained results through tables and visual representations.

LITERATURE REVIEW

We discovered a total of 291 publications pertaining to entrepreneurial resilience in the Scopus database. These publications were disseminated in 156 periodicals and authored by 782 authors associated with 160 institutions across 67 nations. The following table shows an overview of the findings that we gathered.

Table 1. General research results

Elements	Number
Documents	291
Newspapers	156
Authors	782
Affiliation	160
Country	67

Source: own study.

Chronological Development of Publications

As shown in Figure 2, there is a notable upward trend in the number of publications produced between 1992 and 2023. During the initial period (1992-2011), the number of publications remained relatively constant, averaging one article per year. This suggests sustained but relatively limited interest within the research community. From 2011, we observed a slight increase with two publications, then peaking in 2014 with five publications. This might be a sign that interest in entrepreneurial resilience was beginning to develop.

The period from 2015 to 2019 shows a gradual increase in the number of publications, from five to 14. This suggests growing interest over time, perhaps in response to economic events or changes in the entrepreneurial landscape. The years 2020 to 2023 show a significant growth in the number of publications, going from 20 to 98. In 2024, 11 articles were published on the Scopus database until the date of this research on February 5, 2024. This marked increase suggests increased interest and recognition of the importance of entrepreneurial resilience, perhaps heightened by global events such as the COVID-19 pandemic.

Overall, research on entrepreneurial resilience demonstrates significant growth over time, with a marked increase in recent years, suggesting that this topic has become a dynamic and constantly evolving research area.
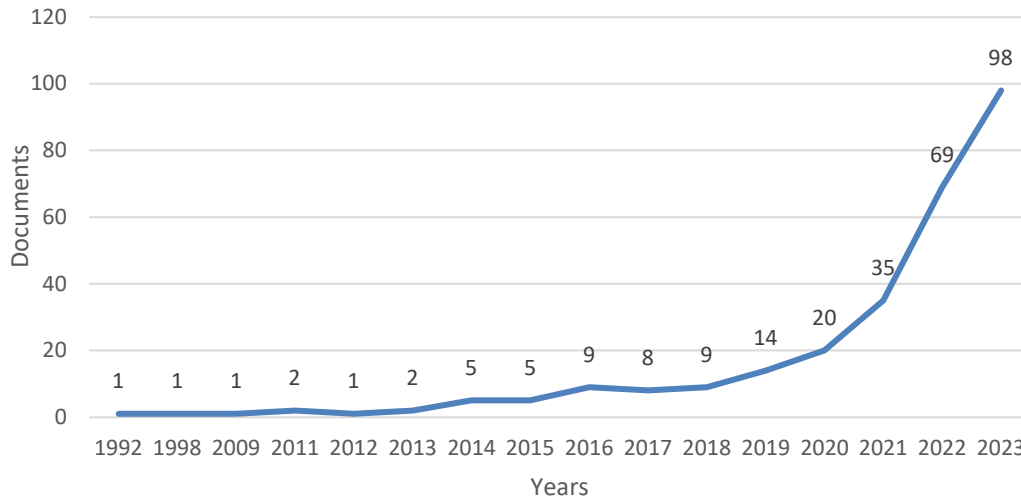
Figure 2. Chronological distribution of publications
Source: own elaboration.

Most Relevant Journals

The journal *Sustainability Switzerland* clearly stands out as a leader in the publication of articles on entrepreneurial resilience, with a significant number of 28 articles. It is followed by *Entrepreneurship and Regional Development*, which occupies the second position in terms of the number of articles published with 13 articles. The *International Journal of Entrepreneurial Behavior and Research* (10 articles) also contributes significantly to the literature on entrepreneurial resilience, although with a slightly lower number of articles.

The top three journals account for over 60% of the articles published in the top ten journals (83). These results highlight the significant contribution of these journals to the literature in general, with particular attention to research on entrepreneurial resilience. Their impact suggests that they act as journals of choice for researchers to explore and deepen this field, reflecting a growing interest in issues related to resilience in an entrepreneurial context.

Figure 3. Most relevant journals in entrepreneurial resilience research
Source: own elaboration.

The *Journal of Entrepreneurship in Emerging Economies* (seven articles) which focuses on emerging economies, provides unique perspectives on how entrepreneurial resilience manifests in these specific contexts. Although publishing fewer articles than previous journals (five articles), *Small Business Economics* remains a notable source in the field, suggesting a significant contribution to the understanding of entrepreneurial resilience in the context of small businesses. The remaining journals all contribute significantly to entrepreneurial resilience research, each with a similar number of publications (four articles each).

Table 2. Top 10 journals in entrepreneurial resilience research

Journal	TC	TP	CS 2023	Most cited article	NC	Editor
Sustainability Switzerland	362 944	54 697	6.6	'Green Closed-Loop Supply Chain Networks' Response to Various Carbon Policies during COVID-19'	82	Multidisciplinary Digital Publishing Institute (MDPI)
Entrepreneurship and Regional Development	1 267	166	7.6	'Contextualizing the knowledge spillover theory of entrepreneurship: the Chilean paradox'	6	Taylor & Francis
International Journal of Entrepreneurial Behavior and Research	3 850	388	9.9	'Artificial intelligence as an enabler for entrepreneurs: a systematic literature review and an agenda for future research'	26	Emerald Publishing
Journal of Entrepreneurship in Emerging Economies	1 578	217	7.3	'Entrepreneurial orientation and performance of SMEs: the roles of marketing capabilities and social media usage'	16	Emerald Publishing
Small Business Economics	8 511	626	13.6	'Mapping the venture capital and private equity research: a bibliometric review and future research agenda'	18	Springer Nature
Entrepreneurship Theory and Practice	3 983	215	18.5	'Happy Entrepreneurs? Everywhere? A Meta-Analysis of Entrepreneurship and Wellbeing'	37	Wiley-Blackwell
International Journal of Gender and Entrepreneurship	542	77	7.0	'Gender roles or gendered goals? Women's return to rural family business'	5	Emerald Publishing
Journal of Enterprising Communities	1 149	186	6.2	'The effects of COVID-19 on small and medium-sized enterprises: empirical evidence from Jordan'	14	Emerald Publishing
Journal of Family Business Management	943	180	5.2	'Family dynamics and relationships in female entrepreneurship: an exploratory study'	18	Emerald Publishing
Journal of Small Business and Enterprise Development	1 374	226	6.1	'Has COVID-19 pushed digitalization in SMEs? The role of entrepreneurial orientation'	17	Emerald Publishing

Source: Scopus.

As shown in Table 2, the most relevant journal in entrepreneurial resilience research, with total publications (TP) of 54 697 documents, a total citation (TC) of 362 944, and a citation score (CS) which amounts to 6.6 in 2023, is *Sustainability Switzerland* published by Multidisciplinary Digital Publishing Institute. The most cited article in this journal was 'Green Closed-Loop Supply Chain Networks' Response to Various Carbon Policies during COVID-19' with a number of citations (NC) of 82 in 2023. It was followed by *Entrepreneurship and Regional Development* published by Taylor & Francis, which had a total of 166 publications and 1 267 citations. Review 'Entrepreneurship Theory and Practice', with a

total of 215 publications and 3 983 citations, and a citation score that rises to 18.5 in 2023, was also very relevant in entrepreneurial resilience research.

Most Influential Authors

Franco Mário José Batista stands out as the most prolific author in this field, with a total of four published articles. His significant contribution suggests deep expertise and a strong interest in entrepreneurial resilience in crisis situations. Nick Williams joins Franco as the most productive author, also with four published articles. His work contributes significantly to the literature on entrepreneurial resilience, providing unique insights and substantial contributions to this area of research. Theodoraki Christina and Vorley Tim follow closely with three articles each. Their number of published articles demonstrates a notable involvement in research on entrepreneurial resilience and its impact in periods of adversity.

The other authors, such as Anderson Alistair, Apostolopoulos Nikolaos, Bishop Paul, Bosworth Gary, Bressan Alessandro and Cabras Ignazio, each contributed two articles. Although their number of articles is slightly lower than those of previous authors, their contribution remains significant, thus highlighting a diversity of expertise and perspectives in entrepreneurial resilience research.

These findings demonstrate the flexibility and receptiveness of global academics in tackling contemporary issues, including the effects of COVID-19 on enterprises. Moreover, the findings underscore that this discipline is developing and remains nascent, due to the lack of notable scholars (Verma & Gustafsson, 2020).
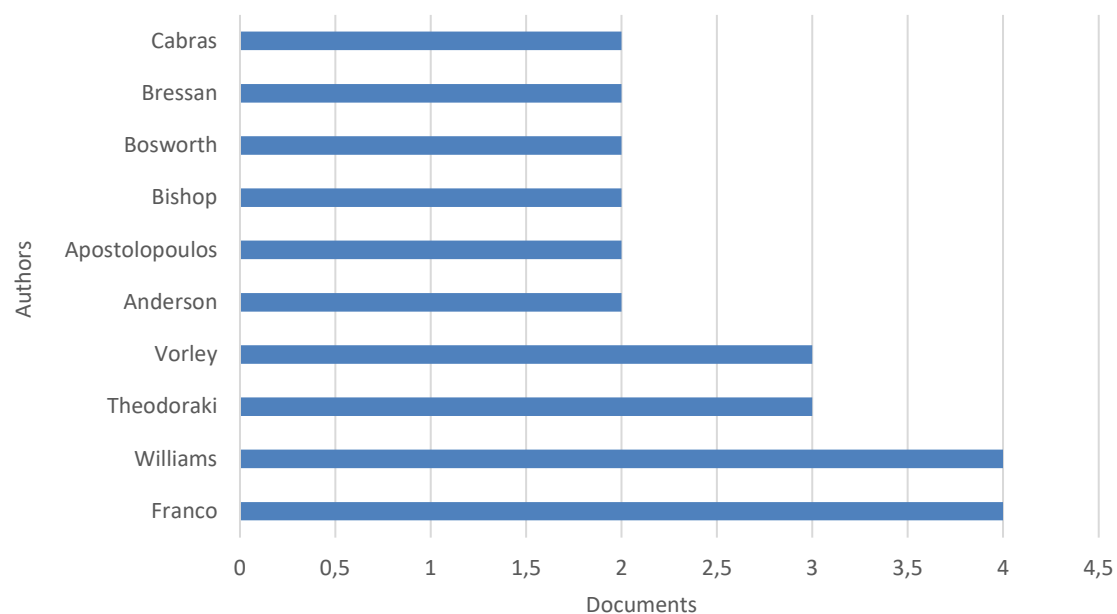
Figure 4. More productive authors in resilience research
Source: own elaboration.

As shown in Table 3, the most productive author was Franco Mário from Universidade da Beira Interior, Portugal, whose first publication in this field dates back to 2011 and which, at the time of the survey, had a total of 188 publications, 2 730 citations, an h-index of 30. The second most productive author in this area was Nick Williams, from the University of Leeds, United Kingdom, with a total of 49 publications, 1 678 citations and an h-index of 20. Among the top ten authors, Anderson Alistair, from the United Kingdom, had the highest total number of citations, at 9 158, and a total of 144 publications, with an h-index of 50.

Table 3. Top 10 authors in entrepreneurial resilience research

Author	Start of publication	TC	TP	h-index	Current Affiliation	Country
Franco, Mário José Batista	2011	2 730	188	30	Universidade da Beira Interior, Covilha	Portugal
Williams, Nick	2010	1 678	49	20	University of Leeds	United Kingdom
Theodoraki, Christina	2018	402	15	7	TBS Business School, Toulouse	France
Vorley, Tim	2010	2 019	83	23	University of Sheffield	United Kingdom
Anderson, Alistair R.	1999	9 158	144	50	Robert Gordon University, Aberdeen	United Kingdom
Apostolopoulos, Nikolaos	2017	471	38	12	Plymouth Business School, University of Plymouth	United Kingdom
Bishop, Paul	1995	816	49	15	University of Plymouth, Drake Circus, Plymouth	United Kingdom
Bosworth, Gary	2009	1 763	51	23	Northumbria University, Newcastle upon Tyne	United Kingdom
Bressan, Alessandro	2014	750	50	15	University of Western Sydney, Sydney	Australia
Cabras, Ignazio	2011	873	61	17	Northumbria University, Newcastle upon Tyne	United Kingdom

Source: own study.

Countries Most Involved in Entrepreneurial Resilience Research

Figure 5 illustrates a visualisation of the ten countries (out of a total of 67) that have most significantly contributed to the research on entrepreneurial resilience.
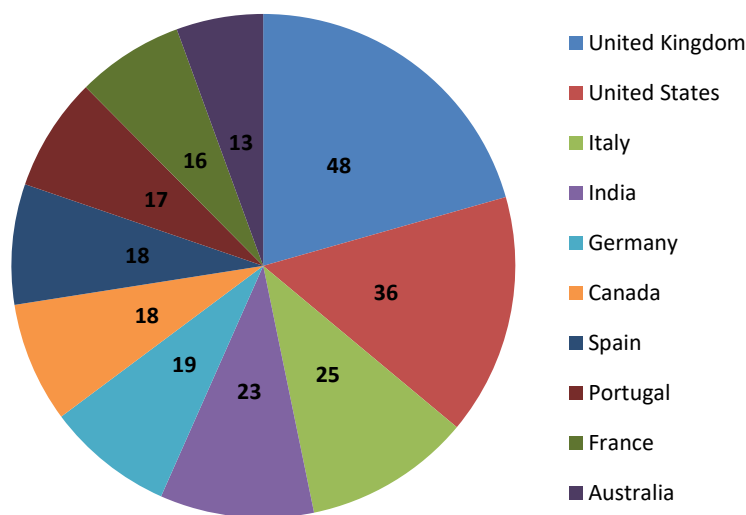
Figure 5. Top countries involved in entrepreneurial resilience research
Source: own elaboration.

Table 4 presents the ranking of these countries, according to the number of publications offered by the Scopus database, with their respective academic establishments.

The most important country in the field of entrepreneurial resilience research is the United Kingdom, with a total of 48 publications, the Goldsmiths University of London being the most significant research establishment in this field. It is followed by the United States, with a total of 36 publications, the 'Northern Arizona University' being the most significant institution. The country of Italy was ranked

third, with a total of 25 publications, and the 'Bocconi University' is its most important establishment in this area. The other most productive countries in this area of research are India with 23 publications, Germany with 19 publications, and Canada and Spain with 18 publications each.

Table 4. Top 10 countries in entrepreneurial resilience research

Rank	Country	TP	Largest academic institution
1	United Kingdom	48	Goldsmiths University of London
2	United States	36	Northern Arizona University, Flagstaff
3	Italy	25	Bocconi University, Milan
4	India	23	FLAME University, Maharashtra, Pune
5	Germany	19	Technical University Dresden, Dresden
6	Canada	18	University of Waterloo
7	Spain	18	Pablo de Olavide University, Seville
8	Portugal	17	Universidade Europeia, Lisbon
9	France	16	ICD Business School Paris, Paris
10	Australia	13	Macquarie University, North Ryde

Source: own study.

The United Kingdom and the United States dominate research on entrepreneurial resilience, with 48 and 36 publications respectively. Together, these two countries account for over 28% of the total selected articles (291), reflecting their substantial contribution to the enrichment of the academic literature in this research area. Their influence is explained by the presence of world-renowned research institutions, a strong academic tradition, and a growing interest in the issues and challenges related to business resilience to adverse events.

Keywords used in research on entrepreneurial resilience

We examined the co-occurrence of all keywords relating to the topic of entrepreneurial resilience in times of crisis. We filtered words using at least five occurrences (Oc), *i.e.*, each keyword was used by a minimum of five articles. VOSviewer calculated the total coexisting link strength (TLS) for each word. The visual representation of these words and their interrelations is shown in Figure 6. The keyword that had the highest co-occurrence (Oc) of 106 and a total link strength (TLS) of 242 was 'resilience', followed by 'COVID-19' (Oc = 83; TLS = 218). Other keywords with high co-occurrence include 'entrepreneur' with (Oc = 40 and TLS = 167), 'entrepreneurship' with (Oc = 59 and TLS = 160), 'Crisis' with (Oc = 39 and TLS = 82), 'innovation' with (Oc = 22 and TLS = 75) and 'small and medium-sized enterprise' with (Oc = 15 and TLS = 74).

We analysed keywords of 233 articles published from January 2020 to February 5, 2024, to discover central and developing topics in the latest publications. The terms were filtered based on a minimum of 10 occurrences (Oc). Consequently, we considered the terminology included in over ten articles, excluding the term 'resilience' to maintain the integrity of the results. Figure 7 shows the visual representation of these words and their interrelations. In this Figure, we may observe three sets of words, differentiated by colour: red (group 1), green (group 2), and blue (group 3). The third group is relatively small, and the keywords have fewer connections than in groups 1 and 2. The first two groups represent emerging research topics since 2020.

Group 1 (marked in red) predominantly encompasses themes pertaining to resilience during crises, featuring articles on crisis management and the ramifications of the COVID-19 pandemic (notable keywords include: COVID-19, crisis management). It also addresses resilience within the business sector and the explanatory factors influencing the resilience of small and medium-sized enterprises (keywords include innovation, SME, and sustainability). Group 2 (marked in green) contains terms often utilised in research pertaining to resilience in general (management). It includes studies that examine resilience within the framework of the COVID-19 pandemic crisis, resilience in entrepreneurship (entrepreneurial resilience), and resilience in organisations (organisational resilience).
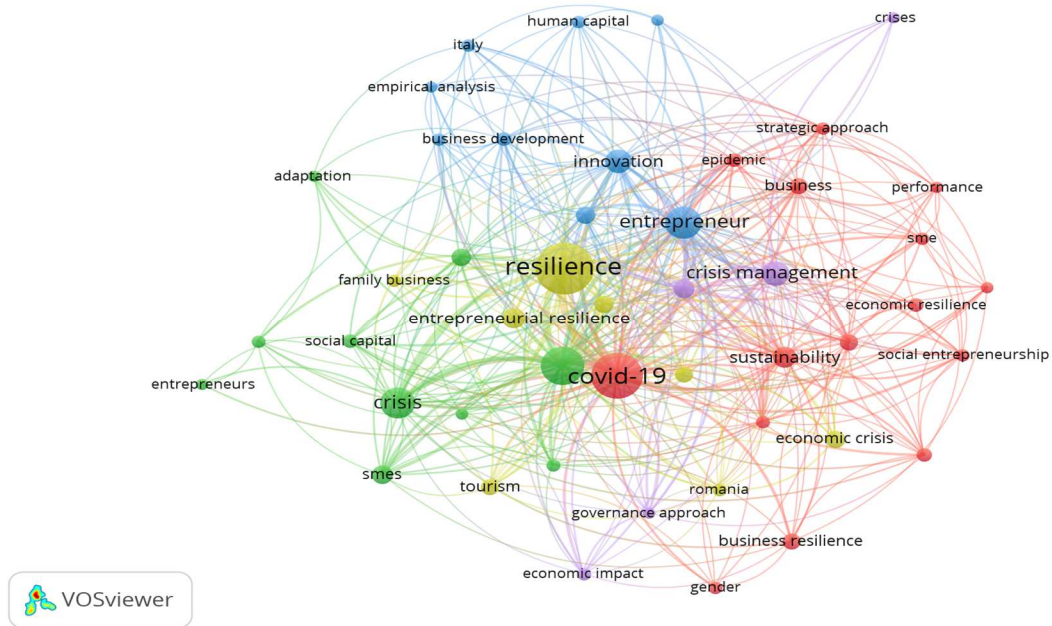
Figure 6. Co-occurrence network of all keywords
Source: VOSviewer Output.
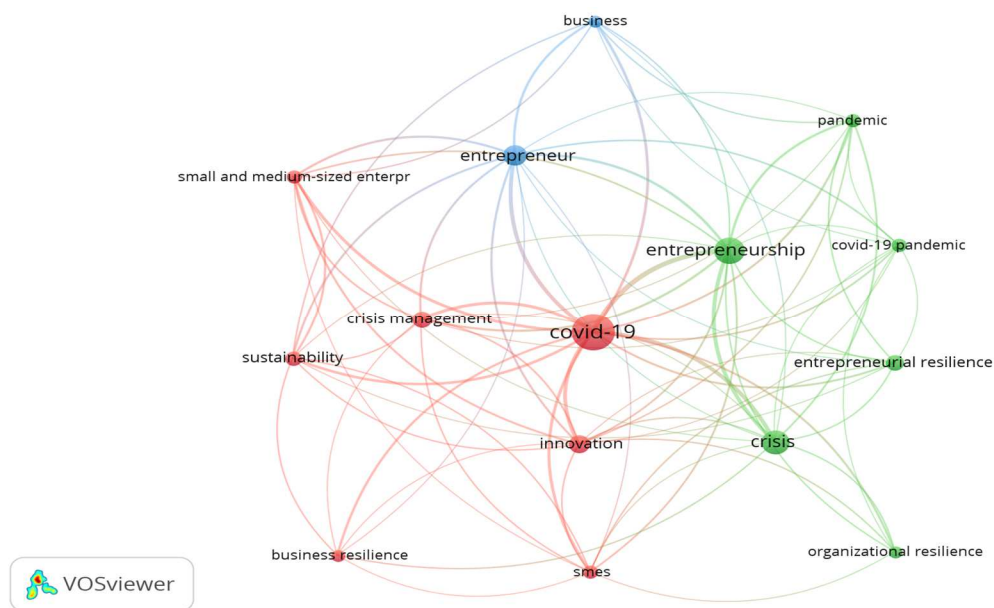
Figure 7. Keyword co-occurrence network
Source: VOSviewer Output.

DISCUSSION

Entrepreneurial resilience is frequently synonymous with individual resilience (Branicki *et al.*, 2018), regarded either as a personality characteristic of the entrepreneur (Bernard & Barbosa, 2016) or as a consequence of their experiences (De Vries & Shields, 2006). According to Doern (2016), entrepreneurs' resilience is mostly derived from experience, positive thinking, emotion management, resource

mobilisation, and perseverance. However, entrepreneurial resilience is not limited to individual resilience but also encompasses organisational resilience (Branicki *et al.*, 2018). Although individual resilience contributes to entrepreneurial success (Ayala & Manzano, 2014), it is not sufficient to explain the ability of small and medium-sized enterprises (SMEs) to overcome crises (Branicki *et al.*, 2018).

Furthermore, despite the emergence of literature on entrepreneurial resilience, entrepreneurs and SMEs are often perceived as vulnerable, especially during recessions, despite playing a key role in economic renewal and employment (Branicki *et al.*, 2018). Nonetheless, their inadequate capacity to design strategy and react to emergencies is attributed to resource limitations, including restricted access to financial resources, technologies, and skilled personnel (Ingirige *et al.*, 2008). This scarcity of resources poses a major challenge to their resilience, especially since best practice models generally come from larger companies with greater resources (Herbane, 2010). To address this challenge, SMEs lacking experience in crisis management may find it more effective to opt for flexible and adaptive approaches, rather than following rigid methods in times of crisis (Brown & Rocha, 2020).

Compared to other bibliometric research conducted on resilience in the general business and management context (Linnenluecke, 2017; Silva-Santos & Mueller, 2022), our study focuses on entrepreneurial resilience in times of crisis. Its main objective is to enrich and complement previous research by highlighting current research trends in the field of entrepreneurial resilience. These trends are positively impacted by the effects of the COVID-19 crisis (Verma & Gustafsson, 2020). As such, the present study stands out as one of the few systematic reviews of research on entrepreneurial resilience, based on bibliometric analysis and visual representation.

Study Findings

We presented a bibliometric survey of the literature on the topic of entrepreneurial resilience during times of crisis. Thus, based on the results of an analysis of documents from the Scopus database, we successively addressed all the research questions.

The chronological evolution of publications on the subject of entrepreneurial resilience in times of crisis reflects an increasing trend. Indeed, from the year 2020, the number of articles published has experienced an exponential increase compared to the previous period, going from only 58 articles between 1992-2019 to 222 documents between 2020-2023. We could attribute this sharp increase in publications could to increased awareness of the importance of entrepreneurial resilience in the face of challenges brought about by the COVID-19 pandemic. Verma and Gustafsson (2020) confirm this finding by stating that the evolution of the literature on the COVID-19 pandemic in the business field shows a distinct trend in a very short time frame. For example, in just four and a half months, no less than 107 unique documents were published in Scopus and Web of Science from 71 different journals, 272 research institutions and 61 countries (Verma & Gustafsson, 2020).

Previous studies have corroborated this observation by noting that the proliferation of resilience publications increases significantly following the occurrence of major disturbances (Williams *et al.*, 2017). In this sense, Linnenluecke (2017) states that publications on resilience in the field of business and management increased exponentially after the terrorist attacks of September 11, 2001. Annarelli and Nonino (2016) observed that the topic of resilience aroused greater interest in the literature after the financial crisis of 2008, especially regarding the strategic and operational management of resilience. Furthermore, Su and Junge (2023) indicate that the COVID-19 pandemic and Russia's aggression against Ukraine exemplify unpleasant occurrences that have led to the rising trend of publications on resilience.

Moreover, the bibliometric analysis of publications shows that the three most important journals commonly consulted as reference sources in research on entrepreneurial resilience are *Sustainability Switzerland*, Entrepreneurship *and Regional Development*, and *the International Journal of Entrepreneurial Behavior and Research* with 51 documents. In this research, these three newspapers represent more than 60% of the articles published in the ten main journals (83) and approximately 18% of the total articles selected (291). These findings suggest that these journals substantially contribute to the body of literature generally and value research on entrepreneurial resilience in particular.

Moreover, this bibliometric study indicates that the most productive author in research on entrepreneurial resilience is Franco Mário from Universidade da Beira Interior, Portugal. This author's most

frequently cited article focuses on analysing the influence of failure factors on entrepreneurial resilience in micro, small, and medium enterprises (MSMEs). In it, the authors observe that entrepreneurs attribute the failure of their businesses to external financial and environmental elements, such as the economic crisis and national legislative developments. Despite this, these entrepreneurs are perceived as being resilient, because they demonstrate sufficient capacity to face the challenges of the national market and display pronounced optimism (Franco *et al.*, 2021).

This observation is consistent with the findings of Martinelli *et al.* (2018) who argued that the resilience of retail entrepreneurs leads them to the recovery and renewal of their business activities, both internally and externally, transforming adverse conditions into new opportunities (Martinelli *et al.*, 2018). Along the same lines, Portuguez Castro and Gómez Zermeño (2021) found elements contributing to resilient entrepreneurs, including their crisis response attitudes, firm and entrepreneur traits, institutional ties, human and social capital, and strategic management practices. According to these authors, the resilience features of entrepreneurs who have encountered previous crises can be utilised to navigate the current circumstances and enhance post-COVID-19 enterprise (Portuguez Castro & Gómez Zermeño, 2021).

The second most productive researcher on the subject of entrepreneurial resilience is Williams Nick, from the University of Leeds, UK. To comprehend the connection between entrepreneurship and crises, this author's most often cited work applies specific definitions, concepts, crisis typologies, the chronology of crisis events, techniques, and empirical contexts. It looks at the relationship between entrepreneurship and crises as well as how entrepreneurship impacts crises (Doern *et al.*, 2019). This study, which highlights the mutual influence between crisis and entrepreneurship, makes a substantial contribution to the research conducted by Williams Trenton and colleagues in 2017, which highlighted the link between crisis and resilience. Williams *et al.* (2017) showed that this relationship offers a more complete understanding of the interaction between the firm and adversity, as resilience is a key entrepreneurial response to unexpected events. Doern *et al.* (2019) enhance this viewpoint by illustrating that entrepreneurs' reactions to a crisis may be influenced by several aspects, including their experience, the developmental stage of their firm, the nature or phase of the crisis impacting their organisation, and the resources at their disposal.

The analysis also revealed that the most significant countries in entrepreneurial resilience research are the United Kingdom and the United States, with a total of 48 and 36 publications, respectively. These two countries represent more than 28% of the total number of selected articles and, therefore, play an important role in research on entrepreneurial resilience, thus contributing significantly to the advancement of knowledge in this area. This finding confirms the results obtained by other researchers, which indicate that the most productive countries in the field of resilience are primarily those with developed economies, particularly the institutions of European and American countries (Silva-Santos & Mueller, 2022; Zhang *et al.*, 2022). The significant contribution of these two countries to the enrichment of academic literature in this research domain is attributable to the presence of globally recognised research institutions, a robust academic tradition, and an increased interest in the issues and challenges related to corporate resilience in the face of adverse events.

Finally, the results provided by the VOSviewer software indicate that the main keywords frequently used in research on entrepreneurial resilience in times of crisis are 'resilience', 'COVID-19', 'entrepreneur', 'entrepreneurship', 'crisis', 'innovation' and 'small and medium-sized enterprise'. These terms have very high co-occurrence (Oc) and total link strength (TLS) compared to other keywords. An in-depth analysis of articles published between January 2020 and February 2024 allowed us to highlight central and emerging themes in the most recent publications on entrepreneurial resilience. These topics constitute avenues of research to be explored by future researchers, and we will discuss their detailed analysis in the following section.

Directions for Future Studies

The findings point to two areas for further investigation into the resilience of entrepreneurs during difficult times (refer to Figure 7). Firstly, recent years have produced research focused on examining entrepreneurial resilience in the context of coronavirus. These studies have offered researchers in developed countries

the opportunity to explore certain factors that contribute to strengthening the resil-ience of SME entre-preneur owners (*e.g.*, innovation) to bounce back from challenges and changes in their environment impacted by the COVID-19 pandemic. However, the resilience of small and medium-sized enterprises (SMEs) in developing nations (DCs) must receive more focus from scholars in the future. These businesses are of vital importance in the global economy, particularly in DCs, and it is, therefore, crucial to take a closer look at how entrepreneurs and SME managers learned from the COVID-19 crisis and how they managed this crisis to ensure the survival of their businesses (Saad *et al.*, 2021; Supardi & Hadi, 2020).

Furthermore, it is important to note that entrepreneurs in SMEs in DCs often face contexts where resources are scarce and limited (Linna, 2013). In such situations, these entrepreneurs must demonstrate creativity and flexibility in combining available resources to deal with unforeseen and often surprising circumstances (Janssen *et al.*, 2018). The literature often describes this phenomenon as 'entrepreneurial bricolage', a process where entrepreneurs use innovative and adaptive solutions to solve problems encountered in their business environment (Senyard *et al.*, 2014). This practice of entrepreneurial bricolage has emerged as a promising research topic for the study of management strategies in less developed economic contexts.

The works of Baker and Nelson (2005) as well as Fisher (2012) have shed light on the importance of entrepreneurial bricolage, highlighting how entrepreneurs overcome resource constraints through their ingenuity and capacity for improvisation. Therefore, the topic offers an interesting opportunity for future research to understand how entrepreneurs in developing countries navigate challenging economic environments and how their bricolage practices impact their long-term success and sustainability (Baier-Fuentes *et al.*, 2023; Stenholm & Renko, 2016).

In this context, the results of the bibliometric analysis reveal a rise in the themes related to crisis management caused by the COVID-19 pandemic. For example, Park and Seo (2024) indicate that during this period of economic disruption, SMEs adopted various crisis management approaches, including bricolage strategies, to strengthen their resilience. Roloff (2023) focused on the reactions of SMEs to the crisis, highlighting bricolage as a key element of their ability to overcome difficulties. For their part, Kuckertz *et al.* (2020) studied how innovative startups faced the challenges posed by the pandemic, highlighting the strategic importance of bricolage in strengthening entrepreneurial resilience.

Indeed, several studies have explored the link between bricolage and resilience from various perspectives, but without fully establishing their causal relationship (Lee & Yeh, 2024). For example, Coutu (2002) noted the etymological link between bricolage and resilience but did not examine the causal relationship between these factors. Weick (1993) qualitatively showed that bricolage promotes resilience, while Park and Seo (2024) quantitatively demonstrated that SMEs adopting bricolage are more resilient, although their study was limited to developed countries. However, the relationship between entrepreneurial bricolage and resilience in poor nations remains unexplored (Aaouid *et al.*, 2024).

Next, the results of this bibliometric analysis indicate that other research has focused on topics related to resilience generally in the field of business and management, including entrepreneurial resilience and organisational resilience. Despite the advances made in understanding resilience in this stream of research, substantial opportunities remain to conduct in-depth theoretical studies, and importantly, longitudinal empirical research. This work could aim to deepen the conceptualisation and measurement of resilience itself, as highlighted by researchers such as Linnenluecke (2017) or Hillmann and Guenther (2021). Moreover, given the lack of consensus on the definition of resilience, the term is often used to encompass various related concepts, such as robustness, adaptability, agility, flexibility, suppleness, and anti-fragility (Munoz *et al.*, 2022; Ruiz-Martin *et al.*, 2018; Ma *et al.*, 2018). These authors propose to clarify what resilience does not represent in order to better understand its true nature. Therefore, future research should shed light on this distinction in order to allow for a more nuanced understanding of these concepts.

Furthermore, there is a crucial need to deepen the understanding of the antecedents of resilience, an under-explored aspect in the current literature, as mentioned by Su and Junge (2023). Further exploration of these antecedents could shed more light on the factors that contribute to resilience capacity in different contexts. Moreover, assessing resilience impacts and outcomes remains a key area requiring increased attention. Research such as that of Silva-Santos and Mueller

(2022) and Ma *et al.* (2018) high-lights the importance of comprehensively analysing how resilience impacts individual and organisational outcomes, thereby enabling us to better understand its true impact in varied and difficult situations.

Theoretical and Managerial Implications

Our bibliometric analysis of studies on entrepreneurial resilience in periods of crisis generates valuable information for both researchers and managers that will help them understand research trends, assess the impact of existing work and identify opportunities to build resilience.

From an academic perspective, this bibliometric study holds significant importance in allowing researchers to explore current research trends in the field of entrepreneurial resilience. By identifying the most researched topics, gaps in the literature, and emerging areas, it provides an in-depth understanding of the dynamics of this ever-evolving field of study. Furthermore, this study makes it possible to assess the impact and influence of different publications, authors, institutions and countries in the field of entrepreneurial resilience. This assessment allows researchers to distinguish the most influential works and key contributors to research, providing valuable benchmarks for future explorations and collaborations.

Furthermore, visualising the relationships between different concepts and research themes is another crucial dimension of this study. By mapping knowledge in the field of entrepreneurial resilience, it helps researchers understand the links between different concepts and identify new research perspectives. This visualisation also promotes better communication and interdisciplinary collaboration by allowing researchers to see how ideas and fields overlap and interact.

From the perspective of managerial implications, the results of this bibliometric analysis are of considerable importance in providing entrepreneurs and managers with valuable information to make informed decisions and better prepare their companies to face unforeseen challenges. By identifying the most relevant research trends in the area of entrepreneurial resilience, these findings provide business leaders with the opportunity to learn about the most effective practices to strengthen the resilience of their organisations. They can therefore rely on the most cited and influential research to guide their management strategies and decision-making.

Furthermore, this bibliometric study allows business managers to stay abreast of the most recent and relevant developments in the field of entrepreneurial resilience. By mapping current research trends, it provides entrepreneurs with the opportunity to ensure their strategies and practices are aligned with the latest advances, which is essential to remaining competitive in the market and anticipating future challenges. This knowledge of emerging trends can also help entrepreneurs identify new opportunities and adjust their approach based on changes in the business environment.

According to a systematic review of the literature on empirical studies concerning entrepreneurship, resilience, and crises, Portuguez Castro and Gómez Zermeño (2021) identified the main elements of resilience for entrepreneurs in crises. These elements include the attitudes adopted in the face of the crisis, the characteristics of the business and the entrepreneur, interactions with institutions, human and social capital, as well as strategic management. The two authors suggest that these elements can be taken into account when designing training programs aimed at strengthening entrepreneurs' resilience and preparing them to face potential crises (Portuguez Castro & Gómez Zermeño, 2021).

Along the same lines, Park and Seo (2024) point out that entrepreneurs and SMEs with little experience in crisis management may benefit more from a flexible, spontaneous, and adaptive approach, rather than rigid methods that are often unsuitable in a crisis context (Brown & Rocha, 2020). This strategy involves an agile reconfiguration of internal resources, the integration of external resources, as well as the adjustment of operational procedures that are usually effective in normal times (Kuckertz *et al.*, 2020).

The results of this study can also guide public policies by identifying the specific needs of entrepreneurs according to the different phases of crisis, by strengthening their access to resources, innovation and networks, and by adapting regulatory frameworks to facilitate their adaptation. They highlight the importance of targeted support, particularly for vulnerable start-ups and small businesses, and encourage initiatives that promote diversification and the entrepreneurial ecosystem.

Based on the findings of this bibliometric analysis, policymakers can develop tailored interventions to help entrepreneurs overcome crises and emerge stronger.

For example, the COVID-19 pandemic has highlighted the challenges faced by entrepreneurs and SMEs, thereby underscoring their critical dependence on external support to ensure their resilience (Juergensen *et al.*, 2020). In this context, the policy measures implemented by the government play an essential role in safeguarding economies during times of crisis, particularly by providing support to SMEs facing financial and operational difficulties (Juergensen *et al.*, 2020). These measures primarily aim to ensure access to the resources needed to ensure their survival and economic contribution (Park & Seo, 2024).

Furthermore, Kuckertz *et al.* (2020) highlighted the speed of government interventions, including immediate institutional arrangements to counter falling revenues and rising costs. These measures include financial support (interest rate cuts, easier access to loans, wage subsidies, direct payments) and operational support (tax relief, repayment deferrals, reduced operating costs). An OECD (2020) analysis reveals that the majority of governments combined these approaches, offering subsidies, wage subsidies, and social security contribution deferrals in order to lessen the blow that the crisis has dealt on SMEs (Park & Seo, 2024).

Study Limitations

Despite the valuable information on research trends in entrepreneurial resilience during times of crisis provided by this bibliometric analysis, it is important to note the methodological limitations that could restrict the generalisability of its conclusions.

First, the data used in this article come from the Scopus database, recognised for its high reliability and academic authority (Singh *et al.*, 2021). However, the exclusivity of this source may result in a limitation in terms of coverage of the relevant literature, as some key publications may be located in alternative databases, including Web of Science, Elsevier, ScienceDirect or EBSCOhost. By combining multiple databases, it would be possible to broaden the scope of the search and reduce the risk of omitting important works, especially in varied disciplines where relevant sources are dispersed.

Therefore, restriction to a single database, even though Scopus is known for its broad coverage, may introduce selection bias. Some relevant publications may be missed if not listed in this particular database. Important perspectives on entrepreneurial resilience may not be fully represented in the analysis.

Second, the decision to limit the study to certain fields, notably business and management, economics and social sciences, as well as to certain types of documents, such as journal articles and conference articles, constitutes a significant limitation. This approach could result in a partial view of entrepreneurial resilience by neglecting insights and advances from other disciplines and publication types, such as books, reports, or journal articles in related fields.

Finally, the restriction to a single language, in this case English, may limit the representativeness of the articles used in the study. Significant research conducted in other languages has been excluded, which could lead to a distortion of the overall understanding of the concept of entrepreneurial resilience. It is therefore important to recognise that this analysis may not fully reflect the diversity of perspectives and knowledge available in different languages.

Overall, the future integration of multiple databases, combined with research conducted in different languages and across distinct disciplines, could thus offer more complete and nuanced coverage of the available studies on entrepreneurial resilience.

CONCLUSIONS

This article offers a bibliometric analysis of 291 articles addressing the theme of entrepreneurial resilience in crisis contexts. These articles were selected without temporal constraints from the Scopus database. The analysis was conducted using the VOSviewer software, and the results of this study revealed several significant findings.

Firstly, there is a significant increase in the volume of publications on entrepreneurial resilience, indicating the rising acknowledgement of the significance of this topic. This rapidly increasing trend

since 2020, with 233 publications recorded as of February 2024, suggests a continued expansion of research in this crucial area. Secondly, the results highlight that a large proportion of the relevant journals were published by Emerald Publishing, which thus made a substantial contribution to the domain of entrepreneurial resilience research. Furthermore, the most productive author to date is Franco Mário, affiliated with the Universidade da Beira Interior in Portugal, with an impressive total of 2 730 citations and an h-index of 30 since his first publication in this field in 2011.

Thirdly, the nations exhibiting the highest levels of entrepreneurial resilience are predominantly those with advanced economies, such as the United States and the United Kingdom. They are responsible for more than a quarter of the total number of documents selected for this study (84 articles). This finding highlights their key role in promoting understanding and practices related to entrepreneurial resilience nationally and globally. Fourth, the most frequent keywords in recent publications are 'COVID-19', 'entrepreneurship', 'crisis', 'innovation' and 'small and medium-sized enterprise'. These keywords reflect the main themes addressed in research on entrepreneurial resilience in adverse times. Bibliometric analysis enabled the generation of keyword co-occurrence networks, thereby providing insight into dominant trends and emerging research avenues in this vital area.

These findings make significant contributions to both academic research and managerial practice. Academically, this bibliometric analysis offers researchers the opportunity to identify research trends, gaps, and emerging areas, thereby facilitating a better understanding of the field's evolution. In this context, our findings highlight the need for further research on entrepreneurial resilience, emphasising the crucial role of longitudinal empirical studies in less developed economic contexts, intending to deepen the study of the elements that promote this capacity for resilience.

From a managerial perspective, this study provides entrepreneurs and managers with essential information to adapt their strategies to market developments and unforeseen challenges, thus ensuring better preparation for future crises. In this sense, our findings highlight the important role of innovation, creative problem-solving, and the development of improvisational and entrepreneurial bricolage skills as necessary entrepreneurial skills during periods of crisis.

Moreover, the results of this bibliometric analysis also provide valuable guidance for public policies by identifying entrepreneurs' needs according to crisis phases. They highlight the importance of targeted support, particularly for startups and small businesses, by facilitating access to resources and networks. Based on these findings, policymakers can develop tailored interventions to help entrepreneurs overcome crises and strengthen their resilience.

Ultimately, this study's findings elucidate the distribution of literature and factors on entrepreneurial resilience, offering academic insights to identify current research gaps and explore future paths. Furthermore, this work is notable as one of the few systematic evaluations of entrepreneurial resilience studies, utilising bibliometric analysis and visualisation.

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Use of Artificial Intelligence

During the preparation of this manuscript, the authors employed DeepL to enhance the clarity and linguistic quality of their writing.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Does international orientation intermediate in the relationship between entrepreneurial orientation and firm performance?

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A B S T R A C T
Objective: This article aims to augment the literature on entrepreneurial business primarily by assessing how the synergies between international orientation (IO) and entrepreneurial orientation (EO) promote the overall performance of Portuguese exporting companies after controlling for the effect of several firm and country characteristics commonly cited in the literature.
Research Design & Methods: The study considers the impact on overall firm performance of aggregated and individual dimensions of EO and IO using survey data collected from 341 companies through online questionnaires in 2015. We validated the proposed hypotheses using covariance-based structural equation modelling (CB-SEM).
Findings: We found three main relationships: (1) the positive impact of EO on firm performance is greater than the influences through the IO pathway; (2) the effect of firm innovativeness is noticeably higher than the proactiveness and risk-taking components of EO; and (3) IO positively and significantly reinforces the relationship between EO and firm performance.
Implications & Recommendations: Taken together, the results indicate that innovations to improve the international positioning of Portuguese exporters will make the greatest contribution to their overall performance. Thus, it is recommended that managers adopt governance structures that motivate and reward employees with novel ideas on how to foster penetration into new overseas markets.
Contribution & Value Added: This study fills the gap in the literature by emphasising: (1) the importance of combining IO with EO to boost the overall performance of risk-averse Portuguese exporters, and (2) the differential effects of the several EO dimensions on IO and overall firm performance.

Article type:	research article
Keywords:	entrepreneurial orientation; international orientation; performance; exporting firms; structural equation modelling
JEL codes:	L25, L26

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INTRODUCTION

Although the literature evidences a strong link between entrepreneurial orientation (EO) and corporate performance, scholars have paid little attention to the hypothetically intermediating effects of internationalisation on the relationship between EO and firm performance. Therefore, we aimed to fill this gap in the entrepreneurship literature by investigating whether international orientation (IO) is an effective mediator in the relationship between EO and the overall performance of Portuguese exporting firms. As a small open economy with a growing export sector, Portugal provides an ideal setting to explore these interactive relationships. To the best of our knowledge, there are no empirical studies that considered international alignments as a controlling factor in the relationship between these two variables in the

Portuguese context. Our findings should illustrate how intangible non-substitutable resources, such as entrepreneurship and internationalisation, bestow competitive advantage on exporting firms in small open economies like Portugal. Such information should inform managers on whether efforts made to develop such idiosyncratic firm characteristics are worthwhile. Then, too, given the poor economic climate in Portugal, we argued that a company's capability to proactively participate in product-market innovation is most crucial to exploiting new overseas business opportunities.

The remainder of this article is structured as follows. Section 2 reviews the literature on intrapreneurship and overall firm performance. Section 3 describes the research design involving the data collection process and the characteristics of the estimation techniques employed. Section 4 presents the results of our structural equation model analysis. The final section concludes with the policy implications of our main empirical results while recognising areas for further research and limitations of this study.

LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

McDougall and Oviatt (2000) used the concept of international entrepreneurship (IE) to describe how a combination of innovation, proactiveness, and risk inherent in foreign markets influences the direct relationship between entrepreneurship and internationalisation. Hence, Autio (2017) noted that entrepreneurship and internationalisation complement each other to strengthen a company's competitive advantage with associated growth in market share. Evidence on the important role that entrepreneurship and its components play in the development of countries at different economic stages is widely recognised in the literature (Brás & Soukiazis, 2019; Lumpkin & Pidduck, 2021). Further, Parker (2011) and Vatavu *et al.* (2022) differentiated between the types of entrepreneurial activities undertaken by firms.[1] They suggested that intrapreneurship applies to the exploitation of endogenous resources by organisations to develop new business ventures. By contrast, when new initiatives are endorsed outside an organisation, the firm is said to be engaged in entrepreneurship. Hence, we may define corporate entrepreneurship as a process of creating new businesses through the modernisation of existing products/services and/or processes to improve the organisations' competitive position (Di Vaio *et al.*, 2022). Moreover, Ireland *et al.* (2009) characterised intrapreneurship as a strategy to continuously rejuvenate an organisation's governance systems to identify innovative products and market opportunities.

Nevertheless, whether the emphasis is on the internal and external regulatory conditions that support entrepreneurship within a company to engage in innovation (intrapreneurship), it is important to understand how variations in entrepreneurial orientation across organisations are reflected in their overall performance (Antoncic & Hisrich, 2003). Therefore, scholars have identified entrepreneurship as a firm-level phenomenon –more commonly known as EO (Covin & Miller, 2014) – to reflect the extent to which firms are innovative, proactive, and risk-averse in their management philosophies (Anderson *et al.*, 2009).[2] However, Rutherford and Holt (2007) observed that not all EO dimensions have a direct and positive effect on corporate performance and that innovativeness is the most influential factor in determining profitability. Hernández-Perlines *et al.* (2019) underline this evidence. They found that innovativeness is a necessary and sufficient condition for strategic EO to differentiate a firm from its competitors. Moreover, Čović *et al.* (2023) and Yaqub *et al.* (2024) recognised that EO is a critical factor influencing both internal organisational dynamics and external market strategies. Internally, EO manifests through managerial philosophies that prioritise innovation, risk-taking, and proactivity (Surin *et al.*, 2023), while externally it is reflected in sustainable competitive behaviours and market entry strategies (Wales *et al.*, 2023). This implies that EO is an endogenous resource, shaped by several contextual factors, including a firm's level of innovation, proactiveness, risk appetite and IO (Abu-Rumman *et al.*, 2021; Gull

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[1] Scholars have used different concepts to describe entrepreneurship within organisations, such as: intrapreneurship (Pinchot, 1986), corporate entrepreneurship (Zahra, 1991), corporate venturing (Macmillan *et al.*, 1986), entrepreneurial orientation (Covin & Slevin, 1989), internal corporate venturing (Zajac *et al.*, 1991) or internal corporate entrepreneurship (Schollhammer, 1982).

[2] To preserve the academic authenticity, we chose to maintain the author's terms throughout the literature review (intrapreneurship or corporate intrapreneurship) rather than to standardise in one term. Whether referring to corporate entrepreneurship or to intrapreneurship, the focus is on the extension of entrepreneurial capabilities within the firms, that is EO.

et al., 2021). It follows that one should examine the relationship between EO and firm performance from the perspective of resource-based theorists (Barney, 1991; Peteraf, 1993), which recognizes the role of a firm's unique set of rare, valuable and non-substitutable tangible and intangible assets in achieving and sustaining its competitive advantages (Campbell & Park, 2017).

The theory of international new ventures (INVs), initially developed by Oviatt and McDougall (1994), illustrates how benefits from resource endowments enable firms to introduce innovative products/services ahead of competitors. Various studies focused on the dimensions of EO that significantly positively influenced the speed at which a firm internationalised using the INV approach (Gull *et al.*, 2021; Lim & Kim, 2022). In contrast, the stage theory of internationalisation, for which the Uppsala model is the main reference, proposes a positive product positioning achieved through continuous employee training (Pellegrino & McNaughton, 2017) and the gradual commitment of an appropriate share of the firm's resources to growing foreign markets (Vahlne & Johanson, 2017). The implication is that the speed of internationalisation is crucial in determining whether (or not) a firm follows the INV approach from the outset (Hennart *et al.*, 2021). Therefore, regardless of the pace of international firms' commitment, from these prior conclusions on the favourable impact of EO on firm internationalisation, we hypothesised that:

H1: EO has a direct and positive effect on the IO of Portuguese exporters.

Scholars have approached research on the effect of EO on firm performance from a variety of business management disciplines (Lin *et al.*, 2011; Nudurupati *et al.*, 2021; Schwens *et al.*, 2018). However, the argument lacks a coherent body of theory. For example, whereas Elango (2006) suggested a positive linear relationship between the two concepts, Luu *et al.* (2023) concluded that the connection was negative. Moreover, some authors supported a nonlinear relationship between internationalisation and firm performance in diverse contexts, involving different countries, markets, and organisational structures, ranging from S-shaped (Contractor, 2007; Lu & Beamish, 2004), M-shaped (Almodóvar & Rugman, 2014), W-shaped (Fernández-Olmos *et al.*, 2016; Zhou, 2018), U-shaped (Rossmannek & Rank, 2019) and inverted U-shaped (Brida *et al.*, 2016; Fernández Olmos & Díez-Vial, 2015). For the current study, IO was reported to lead to higher firm performance (Moen *et al.*, 2016), either through the influence of international expertise (Billing *et al.*, 2010), greater export cooperation (Racela *et al.*, 2007), innovation (Boermans & Roelfsema, 2016), CEO attributes (Hsu *et al.*, 2013), or the expansion into new high-growth geographic and product markets (Colpan *et al.*, 2013).

To reconcile the disagreement in the literature on the relationship between IO and overall firm performance, Rezaei and Ortt (2018) underline the interacting positive influence of idiosyncratic firm attributes, including access to critical resources and absorptive capacity. That is, firms with greater access to resources and the ability to formulate strategies to develop and manage diverse networks in both domestic and international markets will experience a stronger IO effect on firm performance. Thus, based on the theoretical framework developed by Rezaei and Ortt (2018), we proposed that:

H2: IO has a direct and positive effect on the performance of Portuguese exporters.

Scholars study firm performance not only due to its relationship with internationalisation, but also because of its relationship with entrepreneurial behaviour. Specifically, some authors proposed that EO can have a moderating or interactive effect on corporate international characteristics, with consequent performance improvements including sales growth, market share and new product development (Lumpkin & Dess, 1996; Rezaei & Ortt, 2018). Indeed, an earlier study by Felício *et al.* (2012) commented on the interceding role of intrapreneurship in the relationship between EO and business performance for Portuguese firms. Then, too, Rezaei *et al.* (2012) noted that a firm's entrepreneurial capability is positively associated with competitive advantages to facilitate positive performance outcomes. This prediction is consistent with the RBT that successful firms gain competitive advantages through knowledge creation and access to high-quality scarce resources (Ray *et al.*, 2004). In this regard, Urbano *et al.* (2013) emphasised the importance of access to critical resources to help firms develop intrapreneurship to engender positive performance outcomes. Consequently, we proposed that:

H3: EO has a direct and positive effect on the performance of Portuguese exporters.

To resolve the confusion surrounding the relationship between EO and firm performance, several authors considered the role of various internal or organisational variables that intermediate in the hypothesised EO-Performance relationship. They consist of functional performance (Rezaei & Ortt, 2018), absorptive capacity and improvisation (Hughes *et al.*, 2018), product quality (Yang & Ju, 2017), governance structure (Lee & Chu, 2017) knowledge intensity (Schwens *et al.*, 2018) and corporate entrepreneurship (Lim & Kim, 2020).

Other studies on the IE assessed the impact of strategies designed to extend firm entrepreneurship across national borders by combining innovation, proactiveness, and risk-taking behaviour (McDougall & Oviatt, 2000). Using the same conceptual framework, Zahra and George (2002) argued that firms that creatively internationalise their operations tend to achieve significant gains that go beyond financial performance. However, Etemad (2018) cautioned that the IE approach is a multi-layered and multi-dimensional process, hence requiring extensive research. Previously, Zehir *et al.* (2015) examined the mediators of the EO-Performance relationship, focusing on factors related to international alliances. Their research builds on the study by Kollmann and Stöckmann (2014), which recognises innovation as an effective intermediating factor.

Further, Wang (2008) analysed the mediating factors in the EO-performance through a learning orientation paradigm. Other authors, including Boso *et al.* (2013) and Johanson and Mattsson (2015), have considered the mediators in the EO-Performance using models that include resources acquired through international connections. Thus, we may predict that those Portuguese exporters who cultivate inter-organisational relationships through international ventures should strengthen the link between their entrepreneurial activities and overall performance outcomes. Several international business researchers support this anticipated positive intermediation effect of IO (Brouthers *et al.*, 2015; Semrau *et al.*, 2016). Consequently, we hypothesised that:

H3': IO positively intermediates the connection between EO and the performance of Portuguese exporting firms.

Figure 1 presents the structural model (base) to be tested with the respective research hypotheses.
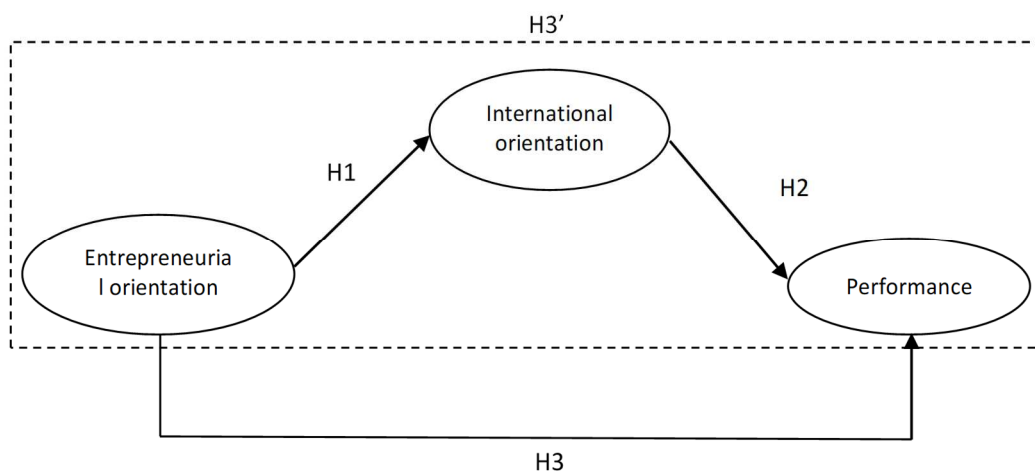
Figure 1. Entrepreneurial orientation
Source: own elaboration.

RESEARCH METHODOLOGY

Despite the economic challenges of recent decades, including the financial crisis and the COVID-19 pandemic, the number of Portuguese exporting firms has risen steadily, reflecting the government's commitment to promoting global trade. Moreover, Carreira *et al.* (2024) and (Leitão, 2023) recognised that the implicit improvement in Portuguese firms' international competitiveness was underscored by the country's trade policy stability and subsequent economic growth. Broadly speaking,

the traditional sectors of textiles, footwear, and cork have dominated exports to three main desti-nations, including Spain, France, and Germany (AICEP, 2023).

Figure 2 shows the sectoral distribution of Portuguese exporting firms in 2022. Manufacturing is the leading sector, accounting for 23% of Portuguese exports since 2013, highlighting its long-standing importance in the national economic activity (Informa – Dun & Bradstreet, 2024).
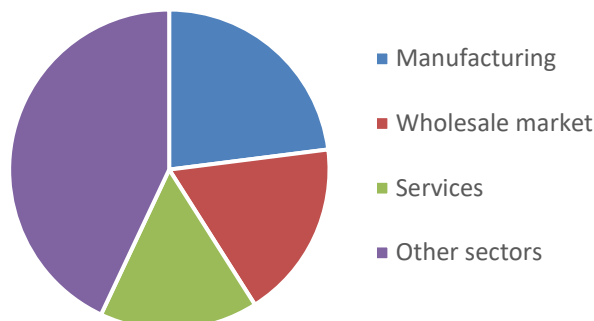
Figure 2. Sectoral distribution of Portuguese exporter firms in 2022
Source: own elaboration based on Informa – Dun and Bradstreet (2024).

According to Informa Dun and Bradstreet – Portugal's official data, 46 562 Portuguese firms exported in 2013. We requested a randomly selected sample of 8 002 firms (17% of all exporters) for analysis to ensure representativeness in size, international experience, strategy, sales, and in-ter-organisational relationships. Due to issues such as incorrect emails and company protections, we excluded 827 firms, resulting in a final sample of 7 175 firms.

To test the appropriateness of the questionnaires, we conducted a pilot test by sending pre-addressed stamped envelopes to 200 randomly selected managers responsible for their firm's in-ternationalisation strategy, ensuring responses came from those with relevant business knowledge. Based on feedback from 16 firms, we made minor changes before publishing the final questionnaire on the LimeSurvey platform between 15 February and 15 March 2015, a period when firms typically have validated data. The questionnaire comprised four sections: (i) company profile, (ii) EO, (iii) IO, and (iv) overall firm performance. We received a total of 527 responses, but we deemed only 350 as valid, as respondents either completed all items or omitted just one. We applied the Mahalano-bis distance method (alpha level of 0.001; (Kline, 2011) to detect and remove outliers, further re-ducing the sample to 341 Portuguese exporting firms.

Figure 3 compares the sectoral distribution of Portuguese exporting firms in 2013, 2015 (sam-ple), and 2022 with our 2015 dataset for 341 firms. The close alignment of our 2015 sample with the dominant companies confirms its representativeness. Moreover, a chi-square goodness of fit test showed no statistically significant difference between the universe and our final sample at the 0.05 level (p-value $\{\chi_{12}^2 = 12.332\}$ = 0.419). Based on the final dataset, we collected information on: (i) company size, (ii) business sector, (iii) share of foreign sales in total revenue and (iv) years in operation before entering the foreign markets (internationalisation speed). Table 1 presents the distribution of firms across these characteristics.

The first part of the questionnaire (company profile) consisted of questions on: (i) the average number of employees in 2014 and (ii) the firm's business activity. We used Likert scales (1-5 points) for all items in the second, third, and fourth sections. It is standard practice to include both reversed and non-reversed items in multi-item Likert scales (Swain *et al.*, 2008). We presented reverse-polarity items in the IO and EO factors adapted from Knight and Kim (2009) and Kreiser *et al.* (2002), respec-tively. To ensure consistency, we retained the original EO and IO scales, measuring agreement levels from (1) strongly disagree to (5) strongly agree. Likewise, the performance scale assessed corporate outcomes from (1) very poor to (5) very good.

Table 1. Characteristics of the respondents (number of firms)

Company size[3]	Business sector	Share of foreign sales in total revenue[4]	Internationalisation speed[5]
Microenterprise– 166	Manufacturing – 173	1-20% – 112	Less than 3 years – 31
Small enterprise – 111	Wholesale & retail – 88	21-40% – 62	Up to 3 years – 122
Medium-sized enterprise – 59	Services – 38	41-60% – 40	Up to 8 years – 180
Large enterprise – 14	Others[6] – 51	61-80% – 41	More than 8 years – 146
		More than 81% – 92	

Source: own study.
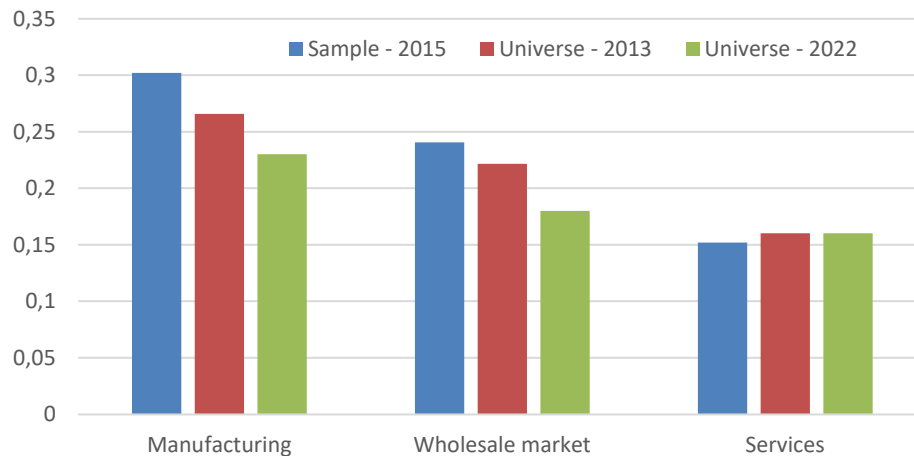
Figure 3. Share of the top three Portuguese exporting sectors by sample (2015) and universe (2013-2022)
Source: own elaboration based on Informa – Dun and Bradstreet (2015) and Informa – Dun and Bradstreet (2024).

The scale proposed by Covin and Slevin (1989), though frequently adapted, remains the most widely used for assessing a company's EO. To maintain its structure, we adopted a multidimensional approach as confirmed by Kreiser *et al.* (2002).[7] In contrast, we chose a unidimensional scale publicised by Knight and Kim (2009) to measure a firm's IO due to its broader scope, encompassing 11 items. Following previous studies (Baker & Sinkula, 1999; Slater & Narver, 2000), we employed both multifaceted and unidimensional scales to capture five key areas of corporate performance: (i) customer loyalty, (ii) new product success, (iii) sales growth, (iv) return on investment and (v) overall performance.

We conducted a first-order factor analysis to determine the effects of firm characteristics on five key variables: innovation, risk, proactiveness, IO and performance. A second-order factor analysis then examined how the latent variables (innovation, risk and proactiveness) influence the aggregated EO series. We used covariance-based structural equation modelling (CB-SEM) to validate the relationships between exogenous and endogenous latent variables. Consistent with (Hair *et al.*, 2005) and (Ripollés *et al.*, 2012), we selected CB-SEM due to the complexity of the model, which involves multiple simultaneous variables and latent traits.

Appendix I shows the summary statistics for all the variables used in our CB-SEM. Notably, the two risk-taking items (Risk1 and Risk2) exhibited the lowest average values across all observable variable categories. Five items (Inov2, IO1, IO2, IO11, Perf1) had average values above four, while six (Pro3,

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[3] Micro firms employ less than 10 employees, small firms employ 10-50 employees, medium-sized firms 51-250 employees, and large firms more than 250 employees.
[4] Three missing values were reported.
[5] All incomplete questionnaires from firms that answered this question were also considered.
[6] Activities related to the primary sector, gas, electricity and water, construction, transports, housing and restauration, retail, financial activities, real estate activities and telecommunications.
[7] As proposed by Kreiser *et al.* (2002), the 9th item from original scale measuring bold posture was dropped.

Risk1, Risk2, IO5, IO6, IO7) fell below three. We analysed data dispersion using the coefficient of variation, with six items exceeding the threshold of 30% threshold proposed by Brown (1998), indicating relatively high dispersion. Moreover, normality tests confirm that the variables in Appendix I follow a normal distribution with skewness between -2 and +2 and kurtosis between -7 and +7 (Byrne, 2013). To mitigate potential bias from multiple data sources, we employed a bootstrap resampling method with 1000 replications, aligning with the 500 to 1 000 range proposed by Cheung and Lau (2008). Following Marôco (2010), we used the maximum likelihood estimator to test the indirect effects of aggregated and EO dimensions on overall performance, ensuring a 95% confidence interval.

RESULTS AND DISCUSSION

Descriptives

The descriptive statistics in Table 1 show that circa 9.5% of the Portuguese exporters were start-ups, while 45% entered overseas markets after eight years in operation. Given that nearly half of these firms internationalised later in their business cycles, the results suggested that Portuguese exporters align more closely with the Uppsala Model than the INV approach. Additionally, the EO dimension with the lowest mean values was risk-taking (Risk1 and Risk2) (Appendix I), supporting the argument that Portuguese exporters are considerably risk-averse (Ribeiro *et al.*, 2018). Compared to firms in other countries, Portuguese firms adopt more conservative strategies when entering new overseas markets (Ferreira *et al.*, 2017). Carvalho *et al.* (2012) attributed this to a national culture that discourages risk-taking, leading to committing fewer resources to foreign markets perceived as having a significant risk of costly failure in order to protect their reputations.

Measurement Model

Given that the internal consistency measures based on Cronbach's alpha and the Kaiser-Meyer-Olkin (KMO) models revealed unsatisfactory results for the proactiveness and risk dimensions, we concluded that the multidimensionality of the EO variable was not accurately defined. Therefore, we rescaled these latent items (innovation, proactiveness, and risk) as unidimensional components. Further, two proactiveness items (Pro1 and Pro3), two risk-taking items (Risk1 and Risk2), three IO factor items (IO5, IO6, and IO7) and the Perf2 variable from the performance construct were removed from the model. Table 2 displays the estimation results of the measurement model after these adjustments.

As shown in Table 2, all items had high factor weights (FW> 0.5) and showed adequate individual reliability (SMC> 0.25).

Concerning composite reliability (CR) based on Dillon-Goldstein criterion, all factors exhibited strong reliability, with values ranging from 0.7 to 1 (Tenenhaus *et al.* (2005). Given that the AVE values for all factors in our model exceed 0.5, we concluded that all items demonstrated convergent validity and construct reliability (Fornell & Larcker, 1981; Hair *et al.*, 2005)

Regarding discriminant validity, the AVE values for the three factors consistently exceed the square of the construct's correlations, confirming their discriminant validity. This is reinforced by the heterotrait-monotrait ratio of correlations (HTMT) matrix, where all values remained below the 0.85 threshold suggested by Kline (2011) (Appendix II). Moreover, the Cronbach's alpha values listed in Table 2 (fourth column) fell within the internal consistency ranges proposed by George and Mallery (2010). Thus, we concluded that the scales for EO, IO, and Performance met the accepted theoretical standards.

The sampling adequacy was rated as good to excellent, as the KMO measure for all the factors exceeded the 0.7 threshold (Kaiser, 1974). Moreover, Harman's single-factor test indicated that our six factors explained 62.90% of the total variance, confirming that the dataset was not affected by common method bias. Moreover, following Mardia's (1970) standardised coefficient of multivariate kurtosis, we obtained a value of 22.2 for our sample, which is considerably above the usual cutoff of 3. Thus, we concluded that the hypothesis of multivariate normality in our empirical model cannot be rejected.

Finally, an assessment of the validity of our measurement model based on various adjustment indexes/parameters confirms a good overall fit, notably (χ^2/gl = 1.734; RMSEA = 0.046; PCFI = 0.800; CFI = 0.970; TLI = 0.964; NFI = 0.932).

Consistent with the findings of Ferreira (2007) for the Portuguese manufacturing industry, along with other studies in different contexts (Sorama & Joensuu-Salo, 2023; Wach *et al.*, 2023), our results do not support the multidimensionality of EO in Portuguese firms. Consequently, we treated EO as a unidimensional construct in our subsequent analyses.

Table 2. Estimation results: The measurement model

Factor	CR[8]	AVE[9]	α[10]	KMO[11]	Items	FW[12]	SMC[13]
Entrepreneurial orientation Adapted from Kreiser *et al.* (2002)	0.83	0.56	0.74	0.74	(Inov1) In general, the top managers of my firm favour a strong emphasis on R&D, technological leadership, and innovations.	0.58	0.33
					(Inov2) In the past five years, my firm has marketed many new lines of products or services.	0.69	0.47
					(Inov3) My firm usually promotes significant changes in product lines/services offered.	0.77	0.59
					(Pro2) My firm is very often the first business to introduce new products/services, administrative techniques, and operating technologies, among others.	0.59	0.35
International orientation Adapted from Knight and Kim (2009)	0.92	0.59	0.87	0.89	(IO1) Top management tends to see the world, instead of just Portugal, as our firm's marketplace.	0.54	0.29
					(IO2) The prevailing organisational culture at our firm (management's collective value system) is conducive to active exploration of new business opportunities abroad.	0.71	0.50
					(IO3) Management continuously communicates its mission to succeed in international markets to firm employees.	0.79	0.63
					(IO4) Management develops human and other resources for achieving our goals in international markets.	0.77	0.59
					(IO8) Our top management is experienced in international business.	0.63	0.40
					(IO9) Management communicates information throughout the firm regarding our successful and unsuccessful customer experiences abroad.	0.61	0.37
					(IO10) Top management is willing to go to great lengths to make our products succeed in foreign markets.	0.69	0.48
					(IO11) Vision and drive of top management are important in our decision to enter foreign markets.	0.68	0.46
Performance Adapted from Farrell *et al.* (2011)	0.92	0.74	0.86	0.80	(Perf1) Customer retention.	0.53	0.28
					(Perf3) Sales growth.	0.84	0.71
					(Perf4) Return on investment.	0.85	0.72
					(Perf5) Overall performance.	0.91	0.83

Source: own study.

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[8] Composite reliability.
[9] Average variance extracted.
[10] Cronbach's alpha.
[11] Kaiser-Meyer-Olkin.
[12] Factor weights (standardised).
[13] Squared multiple correlation.

Structural Model and Hypothesis Testing

Table 3 summarises the main results from our base structural model, obtained using the bootstrap resampling method, with all results available in Appendix III. For comparison, Appendix IV provides the results without bootstrap resampling. Moreover, Figure 4 illustrates the estimated standardised coefficients and significance levels for the estimated relationships between the key latent variables of interest.

Table 3. Results of the estimation of the standardised parameters of the model

Relationships	Standardised coefficients	*p*-value	Hypotheses	Results
EO → IO	B1 = 0.677***	0.002	H1	**Supported**
IO → Performance	B2 = 0.326***	0.002	H2	**Supported**
EO → Performance	B3 = 0.189**	0.047	H3	**Supported**
EO → IO → Performance	B3' = 0.221***	0.001	H3'	**Supported**

Notes: **The coefficient is significant at the 0.05 level; ***the coefficient is significant at the 0.01 level.
Source: own study.
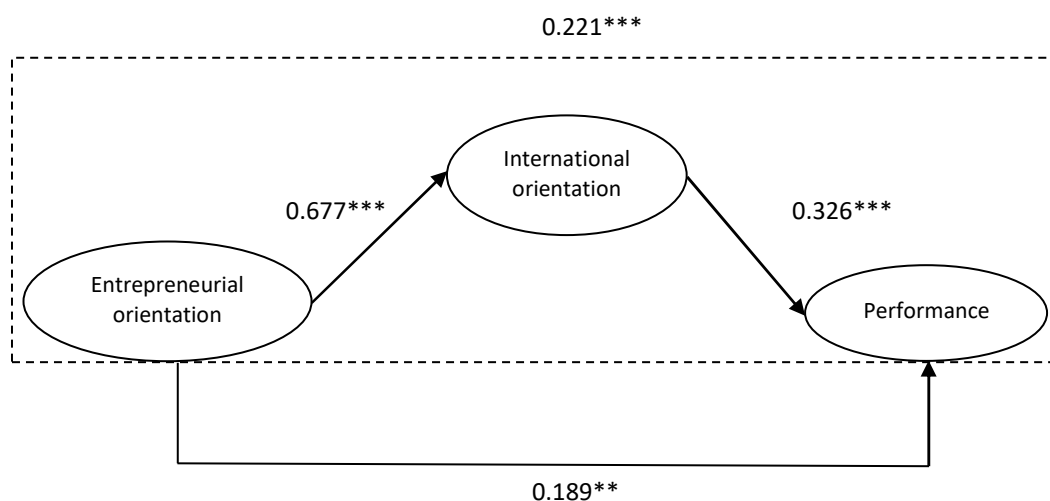
Figure 4. Structural model results (base model)
Notes: **The coefficient is significant at the 0.05 level; ***the coefficient is significant at the 0.01 level.
Source: own elaboration.

Collectively, the results in Table 3 and Figure 4 support all the hypotheses proposed in our structural model, showing a good overall fit (χ^2/gl = 1.715; RMSEA = 0.048; PCFI = 0.801; CFI = 0.963; TLI = 0.954; NFI = 0.929).

Most specifically, the EO-IO pathway has the greatest impact, followed by the IO-Performance route, with both being statistically significant at the 1% level. These results imply that the impact of EO on the overall performance of Portuguese exporters is influenced by their degree of internationalisation. This conclusion aligns with the evidence from Brás and Preto (2024) on Portuguese technology firms, underscoring the importance of fostering EO to enhance international market growth (Solano Acosta *et al.*, 2018). Moreover, the strong interrelationships with IO align with previous findings for SMEs (Pangarkar, 2008) and multinational enterprises (Loncan & Nique, 2010).

The EO-Performance path was statistically significant at the 5% level, meaning that we could not reject hypothesis 3. Moreover, with a statistical significance level of 1%, we concluded that the impact of the EO was intermediated by the IO dimension, exerting an indirect and positive effect on the overall firm performance,[14] thereby, supporting hypothesis 3'. Thus, the total effect of EO on firm performance was 0.41 points (0.189 + 0.221).

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[14] The product of the standardised coefficients measures this indirect effect (0.677 x 0.326 = 0.221) and it is statistically significant at the 1% level (Appendix V).

For Portuguese exporters, this finding implies that the indirect effect of EO, when reinforced by IO, is stronger than its direct effects on overall performance. Similarly, Karami and Tang (2019) acknowledged the management implications of such aggressive international ventures and their interplay with EO and overall firm performance. Besides, Gull *et al.* (2021) advocated that managers of Portuguese exporting firms should focus on maximising the potential EO-IO synergies through targeted staff training programs.

Finally, our study reveals that innovativeness contributes to raising corporate performance. Hence, we argue that Portuguese exporters should accentuate the innovative dimension of their EO to optimise overall performance.

CONCLUSIONS

Our study contributes to the existing EO literature in three important ways.

Firstly, it confirms that Portuguese exporters exhibit high risk aversion, favouring conservative strategies based on the Uppsala framework to mitigate the risks associated with internationalisation.

Secondly, it highlights that the innovativeness dimension of EO is particularly effective in fostering IO within the Portuguese export sector, leading to enhanced overall performance beyond the direct positive impact of IO.

Thirdly, it validates the hypothesis that intrapreneurship plays a critical role in leveraging internationalisation. Hence, we should view the attempts of Portuguese exporters to develop these strategic areas as an investment in business functions, ultimately driving future performance outcomes.

Overall, we confirmed IO as a reliable link in the relationship between EO and the overall performance of Portuguese exporters. Following Cumming *et al.* (2015), we considered IO as a strategic endogenous resource that firms should cultivate to enhance their competitive advantages. Accordingly, authorities should implement policies to support Portuguese exporters in optimising their entrepreneurial and international orientations. From a government policy perspective, this may include providing financial assistance to develop and maintain governance systems that (i) foster and reward creativity and (ii) facilitate training in international business management and networking. From a corporate viewpoint, managers should be encouraged to prioritise initiatives that (i) boost R&D investments in international business ventures and (ii) leverage institutional resources such as AICEP Portugal Global to navigate the complexities of the international business landscape.

Finally, we recognise the limitations arising from the low response rate to our survey questionnaires. Besides, as our study covers only a specific period, a longitudinal study is needed to validate the findings. We also recognise that the analysis relies on a dataset from 2015, which may have affected the reliability of the EO constructs in our model. Thus, we recommend that future researchers collect updated data from E-Informa Dun & Bradstreet – Portugal to validate the robustness of our findings in light of changes in the entrepreneurial and internationalisation orientation of Portuguese firms and their overall performance. Moreover, scholars should conduct sensitivity tests to authenticate the results of our CB-SEM model across different product and service exporting firms in various international markets. This would help determine whether our conclusions remain applicable to the emerging global challenges faced by Portuguese exporters in the post-COVID pandemic era.

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Appendixes:

Appendix I. Descriptive statistics

Variables	N	Minimum	Maximum	Mean	Std. deviation	Skewness	Kurtosis	Coeff. variation
Inov1	341	1	5	3.57	1.008	-0.804	0.169	0.282
Inov2	341	1	5	4.04	0.839	-1.189	1.758	0.208
Inov3	341	1	5	3.62	0.911	-0.729	0.067	0.252
Pro1	341	1	5	3.48	0.925	-0.322	-0.666	0.266
Pro2	341	1	5	3.21	0.942	-0.165	-0.419	0.293
Pro3	341	1	5	2.83	1.191	0.07	-1.146	0.421
Risk1	341	1	5	2.25	0.804	1.43	2.324	0.357
Risk2	341	1	5	2.28	0.95	0.673	-0.198	0.417
IO1	341	1	5	4.03	0.95	-1.101	0.986	0.236
IO2	341	2	5	4.09	0.673	-0.807	1.684	0.165
IO3	341	1	5	3.77	0.93	-0.919	0.724	0.247
IO4	341	1	5	3.76	0.866	-0.794	0.693	0.230
IO5	341	1	5	2.54	0.902	0.727	-0.36	0.355
IO6	341	1	5	2.33	0.796	1.092	0.935	0.342
IO7	341	1	5	2.4	0.988	0.561	-0.53	0.412
IO8	341	1	5	3.81	0.899	-0.985	0.913	0.236
IO9	341	1	5	3.4	1.012	-0.562	-0.452	0.298
IO10	341	1	5	3.93	0.777	-1.129	2.261	0.198
IO11	341	1	5	4.13	0.631	-0.951	3.766	0.153
Perf1	341	2	5	4.03	0.778	-0.73	0.527	0.193
Perf2	341	1	5	3.75	0.771	-0.538	0.332	0.206
Perf3	341	1	5	3.36	0.983	-0.393	-0.309	0.293
Perf4	341	1	5	3.27	0.867	-0.232	-0.206	0.265
Perf5	341	1	5	3.6	0.794	-0.494	-0.043	0.221

Source: own study.

Appendix II. HTMT matrix

–	EO	IO	Performance
EO	1	–	–
IO	0.688	1	–
Performance	0.444	0.466	1

Source: own study.

Appendix III. Standardised regression weights (with bootstrap)

Parameter			Estimate	Lower	Upper	P
IO	<—	EO	0.677	0.557	0.785	0.001
Performance	<—	IO	0.326	0.079	0.546	0.003
Performance	<—	EO	0.189	-0.045	0.434	0.047
Innov1	<—	EO	0.577	0.447	0.681	0.001
Innov2	<—	EO	0.687	0.578	0.771	0.002
Innov3	<—	EO	0.770	0.665	0.853	0.001
Pro2	<—	EO	0.593	0.468	0.699	0.001
IO1	<—	IO	0.537	0.413	0.636	0.001
IO2	<—	IO	0.706	0.608	0.780	0.001
IO3	<—	IO	0.791	0.715	0.855	0.001
IO4	<—	IO	0.765	0.679	0.833	0.001
IO8	<—	IO	0.631	0.516	0.716	0.002

Parameter			Estimate	Lower	Upper	P
IO9	<—	IO	0.606	0.489	0.704	0.001
IO10	<—	IO	0.693	0.598	0.772	0.001
IO11	<—	IO	0.675	0.579	0.759	0.001
Perf1	<—	Performance	0.526	0.414	0.633	0.001
Perf3	<—	Performance	0.841	0.782	0.888	0.001
Perf4	<—	Performance	0.848	0.790	0.890	0.002
Perf5	<—	Performance	0.908	0.861	0.946	0.001

Source: own study.

Appendix IV. standardised regression weights (without bootstrap)

Parameter			Estimate	P
IO	<—	EO	0.677	***
Performance	<—	IO	0.326	***
Performance	<—	EO	0.189	0.044
Inov1	<—	EO	0.577	–
Inov2	<—	EO	0.687	***
Inov3	<—	EO	0.770	***
Pro2	<—	EO	0.593	***
IO1	<—	IO	0.537	–
IO2	<—	IO	0.706	***
IO3	<—	IO	0.791	***
IO4	<—	IO	0.765	***
IO8	<—	IO	0.631	***
IO9	<—	IO	0.606	***
IO10	<—	IO	0.693	***
IO11	<—	IO	0.675	***
Perf1	<—	Performance	0.526	–
Perf3	<—	Performance	0.841	***
Perf4	<—	Performance	0.848	***

Source: own study.

Appendix V. Indirect effects: Two-tailed significance (BC) by bootstrapping

–	EO	IO	Performance
IO	…	…	…
Performance	**0.001**	…	…
Perf5	0.001	0.003	…
Perf4	0.001	0.003	…
Perf3	0.001	0.003	…
Perf1	0.001	0.002	…
IO11	0.001	…	…
IO10	0.001	…	…
IO9	0.001	…	…
IO8	0.001	…	…
IO4	0.001	…	…
IO3	0.001	…	…
IO2	0.001	…	…
IO1	0.001	…	…
Pro2	…	…	…
Inov3	…	…	…
Inov2	…	…	…
Inov1	…	…	…

Source: own study.

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The contribution share of authors was equal and amounted to ⅓ for each of them
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Long-run effects of fiscal policies on environmental pollution

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A B S T R A C T
Objective: This study aims to investigate the long-run effects of fiscal policy instruments, including environmental taxes, environmental protection expenditures and renewable energy incentives on environmental pollution, measured as ecological footprint, in a sample of European Union countries and Turkey using annual data for the period 1996-2018.
Research Design & Methods: The conventional literature generally suggests that fiscal policy instruments can affect environmental pollution in the long run. To examine whether fiscal policy instruments will be effective on pollution in the long run, we employed both fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) methods.
Findings: The estimation results showed that renewable energy incentives are the most effective policy instrument to mitigate pollution. We also found that environmental taxes have negative and statistically significant effects on pollution. However, the relationship between environmental protection expenditures and pollution is not robust and changes with respect to the estimation method.
Implications & Recommendations: The findings of this study indicate that fiscal policy instruments can reduce environmental pollution. In this vein, renewable energy incentives and environmental tax tools appear to be the most effective fiscal policy instruments. Therefore, policymakers can use fiscal policy instruments to deal with environmental pollution problems.
Contribution & Value Added: Given the limited research on the combined effects of fiscal policy instruments, we aimed to contribute to the literature by employing FMOLS and DOLS estimation procedures. These methods allowed us to examine the long-run relationship between fiscal policy instruments and the ecological footprint. To examine the long-run relationship between fiscal policy instruments and ecological footprint, we prefer to employ FMOLS and DOLS methods which consider potential autocorrelation and some degree of heterogeneity. Therefore, we aimed to contribute to the literature by investigating the effectiveness of fiscal policy instruments on environmental pollution in our sample of countries.

Article type:	research article
Keywords:	environmental pollution; fiscal policies; environmental protection expenditures; environmental taxes; renewable energy resources
JEL codes:	E62, H23, Q28

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INTRODUCTION

Structural change, industrialization, urbanization and rapid population growth have led to a series of environmental problems such as global warming, climate change, and deterioration of air, soil and water quality. All these have contributed to the rapid rise in environmental pollution. Environmental problems are expected to be addressed through the joint participation of countries and the shared responsibility to deal with pollution. In this line, many countries contribute to the formation of environmental laws and try to implement environment-friendly policies.

United Nations member countries adopted Sustainable Development Goals in 2015 to reduce the environmental damage of economic activities. By 2030, it is planned to achieve the goals by adopting

objectives such as ensuring universal access to cheap, reliable, and modern energy services, increasing the share of renewable energy sources, encouraging investments in clean energy areas and incorporating climate change-related actions into national policies. In this vein, this article aims to examine whether fiscal policy instruments can serve to mitigate pollution to achieve the Sustainable Development Goals.

Conventional wisdom maintains that fiscal policy aims to adjust public expenditures and revenues to achieve macroeconomic and social objectives. In addition to these classical duties, the state also aims to produce solutions when the market is insufficient in justice, health, education, and environmental protection. In this context, fiscal policy in a broad framework may also involve the use of fiscal policy tools to achieve sustainability in resource allocation. In this context, environmentally compatible fiscal policies are considered to be an effective policy instrument in reducing environmental pollution. For instance, government incentives for renewable energy investments can support clean energy production capacity and play a crucial role in achieving sustainable development goals. Moreover, economic activities with negative externalities can be internalized by selective taxation policy. This can reduce environmental pollution by transforming producer and consumer behaviour patterns in favour of the environment. In this context, we may define fiscal policy for environmental protection as a set of instruments implemented by the state to prevent environmental damage and contribute to environmental sustainability.

Fiscal policy instruments, such as renewable energy incentives, environmental taxes, and environmental protection expenditures, play a significant role in reducing the ecological footprint. Renewable energy consumption is reduced primarily through the substitution effect. This substitution reduces carbon emissions, air pollution, and resource depletion, significantly mitigating environmental damage. Moreover, renewable energy consumption decreases reliance on non-renewable resources, further conserving resources and minimizing degradation caused by fossil fuel extraction. Environmental taxes reduce pollution by internalizing the social costs of polluting activities, incentivizing both producers and consumers to adopt more sustainable behaviours. By increasing the cost of polluting activities, these taxes promote energy efficiency and promote the use of renewable energy, reducing carbon emissions and environmental harm. Environmental protection expenditures involve direct government investments in projects that conserve natural resources, improve air and water quality, protect biodiversity, and manage waste. When effectively managed, these investments can significantly reduce pollution, although their success may depend on the efficient allocation of funds and the feasibility of environmental protection projects.

These fiscal policy instruments align with the broader objective of fiscal policy to promote sustainability in resource allocation. As noted, fiscal policy is not only concerned with achieving macroeconomic goals but also with addressing market failures in areas such as health, education, and environmental protection. In this regard, environmentally compatible fiscal policies – such as renewable energy incentives, selective taxation, and government-funded environmental protection projects – serve as effective tools for reducing environmental pollution. By incentivizing clean energy production, internalizing negative externalities, and investing in sustainable environmental initiatives, fiscal policies contribute to achieving sustainable development goals and promoting environmental sustainability.

In line with all these explanations, the main objective of this study was to examine whether environmental protection expenditures, environmental taxes and renewable energy incentives, which are among the fiscal policy instruments, have a reducing effect on environmental pollution. In analyzing the impact of these fiscal policy instruments on pollution, we also considered real income per capita, which is the main determinant of environmental pollution as stated by Grossman and Krueger (1995). We applied fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) estimation methods for the sample of 21 European Union (EU) countries and Turkey during the 1996-2018 period. We preferred these estimation methods because they consider potential autocorrelation and some degree of heterogeneity by incorporating leads and lags of first differenced regressors and provide the long-run impacts of fiscal policy instruments on ecological footprint.

The empirical results show that the most effective fiscal policy instrument to reduce pollution is renewable energy incentives. Moreover, environmental taxes also have negative and significant effects on pollution. However, the relationship between environmental protection expenditures

and pol-lution is statistically positive and significant according to the DOLS estimation method while it is negative and statistically insignificant according to the FMOLS estimation method. In this context, it is possible to say that environmental protection expenditures are the least effective fiscal policy instrument to reduce environmental pollution.

The remainder of the article is organized as follows: The next section will present a brief overview of the recent studies in environmental economics. Then, we will report the methodology, data set, and definition of variables. We will present the empirical results derived from the DOLS and FMOLS methods in the findings section. Finally, this study concludes with a discussion of the results and policy recommendations for encouraging the adoption of environmentally friendly fiscal policies.

LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

Grossman and Krueger (1995) explored the relationship between environmental pollution and economic growth and made a pioneering contribution to the environmental economics literature. Their empirical findings show that there is an inverted-U relationship between pollution and per capita income. Accordingly, pollution first increases with income, then reaches a maximum level and then decreases. In the literature, this relationship is represented by the Environmental Kuznets Curve (EKC). 'Scale effect, structural (composition) effect, and technological effect' arguments serve to explain the inverted-U relationship. The scale effect refers to the increase in production leading to negative effects on the environment (Grossman & Krueger, 1991). The structural (composition) effect refers to the pollution-reducing effect of the structural change with the shift from manufacturing to the services sector. The technical effect refers to the reduction in pollution by the use of environmentally friendly technologies in the production process. Therefore, the scale effect argument serves to explain the positively sloped EKC, while the structural and technical effect arguments explain the negatively sloped part of EKC.

Following the study by Grossman and Krueger (1995), the literature often examines the validity of EKC for different countries and periods. However, there is no consensus on the validity of EKC in the literature. For example, some studies argue that an inverted-U relationship is valid (Dinda, 2004; Hilton & Levinson, 1998; Stern *et al.*, 1996), while some studies show that there is an N-shaped (Torras & Boyce, 1998; Moomaw & Unruh, 1997), while the others find that a reverse-J-shaped (Selden & Song, 1994) relationships. According to some studies, environmental pollution is positively related to economic growth (Barra & Zotti, 2018; Şentürk *et al.*, 2020; Taşdemir, 2022a). Furthermore, the results by Stern (2004) suggest that there is no statistically significant association between pollution and income.

In addition to the argument that real income per capita is the main driver of pollution, environmental economics literature also indicates that literacy rate, civil liberties, political rights (Torras & Boyce, 1998), labour/capital ratio (He & Wang, 2012), population density, returns to scale, the share of industry (as a per cent of income), and governance (Apergis & Öztürk, 2015) are important variables to explain pollution. Moreover, scholars also consider the following factors important: energy consumption, foreign direct investment and urbanization (Shahbaz *et al.*, 2019), renewable energy consumption (Zhang & Cheng, 2009; Bloch *et al.*, 2012; Soytas *et al.*, 2007; Shahbaz *et al.*, 2011), sectors' share in income (Taşdemir, 2022b), foreign direct investment (Cole, 2004), renewable energy consumption (Apergis *et al.*, 2010; Bento & Moutinho, 2016; Chen *et al.*, 2019; Tiwari, 2011), environmental tax (Jeffrey & Perkins, 2015; Morley, 2012) and environmental protection expenditures (Bostan *et al.*, 2016; Huang, 2018). Since the environment is a global public good, it is emphasized that public policies are necessary to solve the environmental externalities caused by pollution. In this context, the literature states fiscal policy can play an effective role in reducing environmental pollution.

Studies examining the relationship between environmental pollution and environmental policies more specifically indicate that fiscal policy instruments such as taxes, incentives, and public expenditures will have an impact on pollution. Theoretical model results by Gupta and Barman (2009) indicate that fiscal policies play a significant role in reducing environmental pollution. Morley (2012) concludes that environmental taxes negatively affect greenhouse gas emissions by using the generalised method of moments (GMM) method for EU countries and Norway during the 1995-2016 period. López and Palacios (2014) found that public expenditure composition and energy taxes significantly improve air quality in 12

European countries. The study by Jeffrey and Perkins (2015) reveals that there is a negatively significant relationship between energy taxes and total carbon emissions by using the panel data for 27 EU countries during the 1996-2009 period. Kartal (2024) analyzes the effects of disaggregated and aggregated environmental taxes on the ecological footprint in EU5 countries from 1995-Q1 to 2021-Q4 using a nonlinear quartile estimation method. The study found that energy taxes are effective only in Germany and Italy, while there is no significant impact of transportation taxes on pollution. The results by Rafique *et al.* (2022) suggest that environmental taxes reduce the ecological footprint in the long run. Telatar and Birinci (2022) employed nonlinear regression analysis for Turkey during the 1994-2019 period and found that there was no significant impact of environmental taxes on ecological footprint. The empirical results by Postula and Radecka-Moroz (2020) suggest that environmental taxes lead to a faster and more effective decline in pollution in the long run.

Among the studies investigating the relationship between environmental pollution and environmental protection expenditures, Bostan *et al.* (2016) using data for Switzerland, Turkey, and 18 EU countries for the period 1995-2013, conclude that environmental protection expenditures lead to a reduction in air pollution. Similarly, using panel data for China during the 2008-2013 period, Huang (2018) found that environmental protection expenditures reduce environmental pollution. Akdağ *et al.* (2024) found that environmental protection expenditures are nearly twice as effective as environmental taxes in reducing greenhouse gas emissions in 26 EU countries during the 1995-2019 period by using system GMM method. However, the studies by Moshiri and Daneshmand (2020) and Ma *et al.* (2023) suggest that environmental protection expenditures are not significantly effective in reducing environmental pollution.

Studies on renewable energy consumption (REC) examine the effect on carbon dioxide emissions. For example, Tiwari (2011) reports that REC decreases carbon dioxide emissions. In a similar vein, Bento and Moutinho (2016) found that REC reduces carbon dioxide emissions in Italy. The results by Chen *et al.* (2019) suggest that REC reduces carbon emissions in the long run. On the other hand, Apergis *et al.* (2010) found that REC does not have a mitigating effect on carbon dioxide emissions. Usman *et al.* (2021) report that REC tends to reduce ecological footprint. Similarly, Wang *et al.* (2024) analyzed the impact of renewable energy on the ecological footprint in 14 developing EU economies between 1995 and 2020 by using augmented mean group and common correlated effect mean group methods, finding that renewable energy mitigates environmental degradation and enhances sustainability. According to the results by Bozatlı and Akça (2023) and Ali and Kirikkaleli (2024), environmental taxes and REC reduce the ecological footprint. However, Appiah *et al.* (2023) found that REC increases the ecological footprint, suggesting that in some countries, renewable energy policies may be insufficient or implemented alongside fossil fuel consumption, limiting the expected environmental benefits.

The literature often investigates the individual effects of fiscal policy instruments on environmental pollution excluding the studies by Postula and Radecka-Moroz (2020), Zahra *et al.* (2022) and Villanthenkodath *et al.* (2024). Postula and Radecka-Moroz (2020) remark that the most effective solution for environmental pollution is the employment of mixed fiscal policy instruments. Zahra *et al.* (2022) found that tax revenues and social expenditures mitigate pollution while Villanthenkodath *et al.* (2024) report that fiscal policy instruments are ineffective on pollution. The research gap identified in the cited literature suggests a limited number of studies examining the joint effect of fiscal policy instruments on environmental pollution. We consider environmental protection expenditures, environmental taxes and renewable energy incentives as fiscal policy instruments. Our measure of environmental pollution is ecological footprint, a comprehensive indicator that quantifies the total environmental impact of human activities, including carbon emissions, land use, water consumption, and resource depletion. Thus, given there are limited studies in the literature on the joint effects of fiscal policy instruments, we aimed to contribute by examining their effectiveness in reducing ecological footprint. Considering the policy changes will be effective in the long run, this article investigates the effects of fiscal policy instruments on ecological footprint by employing FMOLS and DOLS estimation procedures which allowed us to investigate the long-run relationship between our variables of interest. These estimation methods also consider potential autocorrelation and some

degree of heterogeneity by including leads and lags of first-differenced regressors as briefly explained by Kao and Chiang (2000), Saikkonen (1991), and Stock and Watson (1993).

In this study, we considered the following research hypotheses:

H1: There is a negative relationship between renewable energy incentives and environmental pollution.

Renewable energy sources are expected to significantly lower environmental pollution as compared to fossil fuels. These energy types include biomass, hydroelectric, solar, wind, and geothermal energy sources. The literature often finds that renewable energy lowers environmental pollution by decreasing carbon emissions. Renewable energy incentives promote the use of renewable energy sources, enabling them to replace fossil fuels, thereby reducing the pressure on the environment. This hypothesis is based on the assumption that investments and incentives in renewable energy are expected to be effective in reducing environmental pollution. These will accelerate the adoption of clean energy technologies in the energy sector, thus helping to reduce the ecological footprint.

H2: There is a negative relationship between environmental taxes and environmental pollution.

Environmental taxes are fiscal instruments used to reduce pollution. These taxes aim to encourage producers and consumers to adopt more environmentally friendly behaviours by increasing the cost of polluting activities. Based on Pigou's theory of externalities, environmental taxes serve to internalize the social costs of pollution. Increasing tax rates raises the cost of polluting activities, thus encouraging avoidance of such behaviours. The literature often maintains that environmental taxes are effective in reducing carbon emissions and other environmental damages. These taxes will serve as an effective tool to increase energy efficiency, promote the use of renewable energy, and foster a more environmentally conscious model of production and consumption.

H3: There is a negative relationship between environmental protection expenditures and environmental pollution.

Environmental protection expenditures include direct investments by governments to protect the environment and reach sustainable development goals. These expenditures can be directed towards areas such as the preservation of natural resources, improvement of air and water quality, biodiversity protection, and waste management. Although the effectiveness of environmental protection expenditures in reducing environmental pollution is debated in the literature, there is evidence that these expenditures play a significant role in reducing pollution when managed effectively. However, the effectiveness of these expenditures may vary depending on how governments utilize these funds and the feasibility of implementing environmental protection projects.

RESEARCH METHODOLOGY

Data and Variables

The main goal of this study was to empirically examine whether fiscal policy instruments are effective in reducing environmental pollution in a sample of 21 EU[1](Germany, Austria, Croatia, Belgium, Greece, Denmark, Luxembourg, Estonia, Czechia, France, Netherlands, Italy, Latvia, Lithuania, Poland, Romania, Portugal, Slovakia, Slovenia, Spain, Sweden) countries and Turkey using annual data for the 1996-2018 period. For this purpose, we constructed the following regression model:[2]

$$\log(\text{EF})_{it} = \alpha_0 + \alpha_1 \log(\text{GDPpc})_{it} + \alpha_2 \text{EPE}_{it} + \alpha_3 \text{ET}_{it} + \alpha_4 \text{REC}_{it} + u_{it} \qquad (1)$$

In equation (1), sub-indices i and t represent countries and years, respectively. The log(EF) is the logarithm of the ecological footprint (in global hectares), log(GDPpc) is the logarithm of real GDP per capita, EPE is the share of environmental protection expenditures in income, ET is the share of total

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[1] We were unable to include Bulgaria, Cyprus, Finland, Hungary, Ireland and Malta because of the data unavailability.

[2] We also consider the square term of log(GDPpc) to investigate the validity of EKC. We appreciate the anonymous referees for highlighting this important point. Our preliminary results suggest that the square term of log(GDPpc) is statistically insignificant. We did not report the results to save the space but available on request.

environmental taxes in income, and REC is the share of renewable energy consumption in total energy consumption. We maintained that REC can serve as a proxy for public incentives,[3] as the indirect promotion of renewable energy through government fiscal policies may reduce pollution. In this vein, we suggest that the pollution-reducing effect of REC may prompt fiscal authorities to consider public incentives to increase renewable energy use. Table 1 gives the main data sources for the variables.

Table 1. Definition of variables and data sources

Abbreviation	Variable	Data source
Log(EF)	Global ecological footprint in hectare (in log.)	Global Footprint Network
Log(GDPpc)	Real income per capita (in log.)	World Bank, World Development Indicators
EPE	Environmental protection expenditures (as a per cent of income)	International Monetary Fund (IMF)
ET	The share of environmental taxes as a per cent of income	Eurostat
REC	The share of renewable energy consumption as a percent of total energy consumption	World Bank, World Development Indicators

Source: own study.

Table 2. Basic descriptive statistics

Statistics	$\log$(EF)	$\log$(GDPpc)	EPE	ET	REC
Mean	5.678	10.086	16.214	2.653	7.20
Median	5.330	10.072	13.484	2.510	6.80
Maximum	17.778	11.626	52.892	5.300	18.83
Minimum	2.346	8.471	1.148	0.860	0.30
St. Deviation	2.364	0.716	11.159	0.703	3.40

Note. Abbreviations for variables: log(EF): natural logarithm of ecological footprint, log(GDPpc): natural log. of real income per capita, EPE: environmental protection expenditure, ET: environmental taxes, REC: renewable energy consumption. Source: own study.

Table 2 presents descriptive statistics for our variables. The mean value of the ecological footprint was 5.68. The average real income per capita was 10.09. The share of REC in total energy consumption was 7.2. The average environmental tax (share of income) was 2.65. The minimum and maximum values of environmental tax may imply that some countries impose relatively high tax rates. The mean value of environmental protection expenditure was 16.21. The standard deviation of environmental protection expenditure was much higher than the rest of the variables. This may be related to an argument that environmental taxes as compared to environmental protection expenditure are a more common policy instrument to mitigate pollution.[4]

RESULTS AND DISCUSSION

To investigate the long-run effect of fiscal policy instruments on ecological footprint, we first investigated the stationary degrees of the variables. In this vein, we employed Levin, Lin, and Chu (LLC, 2002) and Im, Pesaran, and Shin (IPS, 2003) panel unit root tests. To employ panel unit root tests, we considered the following equation:

$$\Delta Y_{it} = \alpha_0 + \alpha_1 Y_{i,t-1} + \sum_{i=1}^{m} \alpha_i \Delta Y_{i,t-1} + u_{it} \tag{2}$$

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[3] It is conventionally assumed that government interventions – such as subsidies, tax credits, and public investments – play a significant role in shaping renewable energy markets. These fiscal measures reduce the cost of renewable energy production and consumption, thereby incentivizing its adoption. Consequently, renewable energy consumption (REC) may, to some extent, reflect the impact of fiscal policies aimed at promoting cleaner energy sources. Moreover, we may consider REC an indirect outcome of energy policies or incentives. Unfortunately, data on renewable energy incentives are not available for most of the countries in our sample, which has led us to use REC as a proxy. We appreciate the anonymous referee for highlighting this important point.

[4] For detailed information on environmental taxes applied in EU countries, see: European Commission, 2017, 2021.

We also included the lagged dependent variable in equation (2) to tackle the potential autocorrelation. The LLC and IPS tests maintain these hypotheses:

$H_0 : \alpha_1 = 0$, Y variable is non-stationary.

$H_A : \alpha_1 < 0$, Y variable is stationary.

Table 3 reports the unit root test results. According to the results, our variables appeared to be stationary in the first difference.

Table 3. Unit root test

Variables	Levin, Lin, and Chu test results		Im, Pesaran, and Shin test results	
	Level	1st Difference	Level	1st Difference
log(GDPpc)	-0.699 [0.242]	-6.357 [0.00]	2.078 [0.981]	-15.734 [0.00]
REC	3.204 [0.990]	-11.635 [0.00]	4.646 [0.778]	-17.939 [0.00]
ET	-0.173 [0.431]	-16.783 [0.00]	0.601 [0.726]	-15.660 [0.00]
log(EF)	-1.013 [0.156]	-5.491 [0.00]	-1.074 [0.142]	-11.787 [0.00]
EPE	1.011 [0.844]	-12.119 [0.00]	-1.708 [0.143]	-20.080 [0.00]

Note. Abbreviations for variables: log(GDPpc): natural log. of real income per capita, EPE: environmental protection expenditure, ET: environmental taxes, log(EF): natural log. of ecological footprint, REC: renewable energy consumption; Unit root test equations include a constant term and [.] denotes the p-value corresponding to the relevant test; The Akaike Information Criterion (AIC) is used to select the lagged value.
Source: own study.

To investigate the validity of the long-run relationship between our variables of interest, we utilized the panel cointegration test by Pedroni (1999). We used Pedroni cointegration test because it allows for testing whether cointegration is valid in a multiple regression model. Pedroni cointegration test includes seven different tests (Panel V, Panel rho, Panel PP, Panel ADF, Group rho, Group PP, Group ADF).

Table 4. Panel cointegration test

Pedroni panel cointegration results	
(Within-dimension= In-group approach)	
	t-statistic
Panel v-Statistics	0.956
Panel rho-Statistics	-1.219*
Panel PP-Statistic	-5.660***
Panel ADF-Statistic	-5.673***
(Between-dimension=Inter-group approach)	
Group rho-Statistics	0.819
Group PP-Statistic	-7.807***
Group ADF-Statistic	-6.774***

Notes. ***, **, * indicate significance at the 1%, 5% and 10% levels, respectively.
Source: own study.

Table 4 shows the Pedroni cointegration test results. According to the cointegration test results, the Panel v-statistic in the within-group approach and the Group rho statistic in the between-group approach indicated that the null hypothesis stating that cointegration is not valid should not be rejected. The remaining cointegration test results (Panel rho, Panel PP, Panel PP, Panel ADF, Group PP, Group ADF) indicate that the null hypothesis should be rejected. Except for Panel v and Group rho statistics, the remaining five test statistics indicate that there was a cointegration. This implies that there was a long-run rela-tionship between the variables included in the regression. Since our variables were stationary in first-order differences and cointegration is valid, we could employ FMOLS and DOLS estimation methods.

DOLS Estimation Results

The DOLS method allows parameter estimation by considering potential autocorrelation and some degree of heterogeneity by including leads and lags of first-differenced regressors (Kao & Chiang, 2000; Saikkonen, 1991; Stock & Watson, 1993). Kao and Chiang (2000) argue that the DOLS estimation method is superior to the other panel cointegration methods. Pedroni (1999) states that the DOLS estimation method allows for consistent parameter estimates even if the sample size is small.

Table 5. DOLS estimation results

Variables	Equation (1)
$\log(GDPpc_{it})$	0.526***
	(0.023)
EPE_{it}	-0.034*
	(0.021)
ET_{it}	-0.017*
	(0.009)
REC_{it}	-0.017***
	(0.001)
R^2	0.976
LRV	0.003
N	21
NT	445

Note. Abbreviations for variables: log(GDPpc): natural log. of real income per capita, EPE: environmental protection expenditure, ET: environmental taxes, REC: renewable energy consumption; LRV denotes long-run variance, N and NT represent, respectively, the number of countries and observations. (.) values denote the standard error. ***, ** and * denote 1%, 5% and 10% significance level, respectively.
Source: own study.

Table 5 shows the DOLS estimation results of equation (1). Accordingly, there was a positive and significant relationship between real income per capita (GDPpc) and pollution. The income elasticity of pollution was estimated at 0.5. This coefficient implies that an increase in real income per capita leads to an increase in pollution. This empirical result aligns with the scale effect argument proposed by Grossman and Krueger (1995). There was a negative and statistically significant relationship between environmental protection expenditure (EPE) and ecological footprint. This result is consistent with the empirical findings by Huang (2018) and Akdağ *et al*. (2024). Environmental taxes also tend to mitigate pollution. We also found that there was a negative and statistically significant relationship between renewable energy consumption (REC) and ecological footprint. This was in line with the results by Bento and Moutinho (2016), Chen *et al*. (2019), Usman *et al*. (2021), Wang *et al*. (2023) and Tiwari (2011). According to Table 5, real income per capita, environmental protection expenditure, environmental tax and REC are among the important determinants of pollution. Consistent with the findings by Gupta and Barman (2009), López and Palacios (2014) and Postula and Radecka-Moroz (2020), our empirical results suggest that fiscal policy instruments are effective in reducing ecological footprint.

Table 6 shows the country-specific DOLS estimation results of Equation (1). The income elasticity of pollution was estimated at 0.526 in the whole sample. It was much higher in Austria, Italy, Netherlands, Slovakia, and Spain as compared to the other countries. However, the income elasticity of pollution was relatively lower in Denmark, Germany and Turkey. The results in Table 6 reveal that the income elasticity of pollution differed with respect to the countries in our sample. This may related to the argument that the adoption of environmentally sensitive production processes takes time.

Table 6. DOLS results of equation (1) by country

Countries	log(GDPpc)	ET	REC	EPE
Austria	1.078***	-0.079**	-0.012***	0.101
	(0.098)	(0.035)	(0.002)	(0.105)
Belgium	0.184***	-0.012	-0.035***	0.156
	(0.013)	(0.062)	(0.007)	(0.099)
Croatia	0.491***	-0.028	-0.015***	-1.026***
	(0.105)	(0.039)	(0.002)	(0.216)
Czechia	0.503**	0.033	-0.034***	0.068
	(0.218)	(0.078)	(0.010)	(0.047)
Denmark	0.169***	0.058	-0.006***	0.112
	(0.013)	(0.036)	(0.001)	(0.173)
Estonia	0.192***	0.125	-0.021	0.290
	(0.036)	(0.129)	(0.016)	(0.278)
France	0.226***	-0.121	-0.019**	-0.336*
	(0.022)	(0.086)	(0.009)	(0.166)
Germany	0.161***	-0.008	-0.011*	0.111
	(0.028)	(0.074)	(0.006)	(0.186)
Greece	0.272*	-0.149***	0.006	-0.098
	(0.154)	(0.045)	(0.010)	(0.071)
Italy	1.733***	0.030	-0.009**	-0.523**
	(0.426)	(0.050)	(0.003)	(0.157)
Latvia	0.447***	0.002	0.006	0.178
	(0.127)	(0.063)	(0.011)	(0.154)
Lithuania	0.491***	-0.036	-0.002	-0.052
	(0.103)	(0.034)	(0.005)	(0.054)
Luxembourg	0.195***	0.172	0.002	0.030
	(0.020)	(0.098)	(0.011)	(0.189)
Netherlands	0.998***	-0.008	-0.068***	0.229
	(0.298)	(0.158)	(0.017)	(0.180)
Poland	0.177***	-0.024	-0.020***	0.123
	(0.011)	(0.034)	(0.006)	(0.087)
Portugal	0.231***	-0.058*	-0.025***	-0.181
	(0.020)	(0.031)	(0.003)	(0.179)
Romania	0.310*	-0.078*	-0.008	-0.209**
	(0.170)	(0.046)	(0.010)	(0.080)
Slovakia	1.026***	-0.116	-0.050***	0.195
	(0.230)	(0.086)	(0.015)	(0.114)
Slovenia	0.514***	-0.048***	-0.018***	0.064
	(0.074)	(0.016)	(0.003)	(0.051)
Spain	0.630***	-0.357**	-0.050***	-0.912**
	(0.095)	(0.099)	(0.002)	(0.316)
Sweden	0.237***	-0.157	-0.014**	0.606
	(0.054)	(0.147)	(0.006)	(0.453)
Turkey [5]	0.076**	0.100	-0.032*	1.507**
	(0.005)	(0.021)	(0.006)	(0.092)
Panel overview:	**0.526*****	**-0.017***	**-0.017*****	**-0.034***
	(0.023)	**(0.009)**	**(0.001)**	**(0.021)**

Note. Abbreviations for variables: log(GDPpc): natural log. of real income per capita, EPE: environmental protection expenditure, ET: environmental taxes, REC: renewable energy consumption; ***, ** and * denote 1%, 5% and 10% significance level, respectively.
Source: own study.

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[5] There are only 9 observations for Turkey.

We observed the pollution-reducing effect of environmental taxes in Austria, Greece, Portugal, Romania, Slovenia, and Spain. As indicated by the European Commission (2017), taxes in Austria (landfill tax, Vienna tree protection law), Portugal (charging for water resources, ecological fiscal transfers), Spain (landfill tax), Slovenia (private forest management), Romania (packaging fees and taxes) may have a reducing effect on the ecological footprint. The relationship between environmental taxes and pollution varies across countries because environmental taxes are often implemented for fiscal purposes rather than for pollution prevention. Moreover, the share of environmental taxes in both GDP and total tax revenues[6] may imply that there is no consensus among EU countries on the harmonization of environmental taxes at a sufficient level. Therefore, environmental taxes may have a significant effect on pollution in some countries, while it is insignificant in some other countries.

The pollution-reducing effect of renewable energy consumption seems to be held in most countries excluding Estonia, Greece, Latvia, Lithuania, Luxembourg and Romania. The ecological footprint-reducing effect of environmental protection expenditure is valid for Croatia, France, Italy, Spain and Romania. From Turkey's perspective, it is local governments that mostly conduct environmental protection services. Conventionally, environmental protection expenditures are often considered a cost item and have a very low share of income. Therefore, local governments may not have sufficient and necessary financial resources to fulfil environmental protection activities. Because of these reasons, environmental protection expenditures may lead to an increase in pollution in Turkey.[7]

FMOLS Estimation Results

To investigate the long-run effect of fiscal policy instruments on pollution, we also employ a fully modified ordinary least squares (FMOLS) estimation method developed by Pedroni (2001) and Phillips and Hansen (1990). In a similar vein to DOLS, the FMOLS method considers autocorrelation and some degree of heterogeneity among our variables. Pedroni (2001) suggests that the FMOLS method provides super-consistent parameter estimation.

Table 7. FMOLS estimation results

Variables	Equation (1)
$\log(GDPpc_{it})$	0.468***
(0.016)
EPE_{it}	-0.008
(0.013)
ET_{it}	-0.027***
(0.007)
REC_{it}	-0.017***
(0.001)
R^2	0.949
LRV	0.003
N	22
NT	471

Note. Abbreviations for variables: $\log(GDPpc)$: natural log. of real income per capita, EPE: environmental protection expenditure, ET: environmental taxes, REC: renewable energy consumption; LRV denotes long-run variance, N and NT represent, respectively, the number of countries and observations. (.) values denote the standard error. ***, ** and * denote 1%, 5% and 10% significance level, respectively.
Source: own study.

Table 7 presents FMOLS estimation results of Equation (1). According to Table 7, there is a positive and statistically significant relationship between real income per capita and ecological footprint. This empirical result aligns with the scale effect argument proposed by Grossman and Krueger (1995).

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[6] In the EU, the share of environmental tax revenues in total tax revenues varies from country to country (4%-10%) but averages around 6.15% (Eurostat, 2022).
[7] The result obtained for Turkey should be evaluated by considering the fact that we conducted the analysis with only nine observations.

There is no statistically significant relationship between environmental protection expenditure and ecological footprint. Increasing environmental taxes results in a reduction in the ecological footprint.

Table 8. FMOLS results of equation (1) by country

Countries	log(GDPpc)	ET	REC	EPE
Austria	1.179***	-0.285*	-0.138	0.375
	(0.132)	(0.153)	(0.204)	(0.230)
Belgium	0.208***	-0.074**	-0.026***	0.052
	(0.009)	(0.035)	(0.003)	(0.033)
Croatia	0.737***	-0.017	-0.021***	-0.016
	(0.068)	(0.018)	(0.002)	(0.209)
Czechia	0.540***	0.084	-0.029***	0.075
	(0.089)	(0.095)	(0.006)	(0.045)
Denmark	0.533***	-0.058*	-0.016***	0.057
	(0.161)	(0.029)	(0.002)	(0.128)
Estonia	0.210***	0.053	-0.017	0.221
	(0.027)	(0.090)	(0.014)	(0.148)
France	0.237***	-0.154**	-0.015*	-0.449***
	(0.019)	(0.073)	(0.008)	(0.144)
Germany	0.152***	0.015	-0.012**	0.172
	(0.028)	(0.068)	(0.005)	(0.209)
Greece	0.233*	-0.107**	-0.015*	0.007
	(0.127)	(0.040)	(0.009)	(0.056)
Italy	0.818***	-0.086***	-0.014***	-0.080
	(0.203)	(0.029)	(0.002)	(0.120)
Latvia	0.419**	-0.017	0.281	0.274
	(0.160)	(0.184)	(0.284)	(0.211)
Lithuania	0.459***	-0.065*	-0.004	-0.058
	(0.098)	(0.034)	(0.004)	(0.049)
Luxembourg	0.398*	0.098	-0.005	-0.038
	(0.223)	(0.058)	(0.004)	(0.155)
Netherlands	1.377***	0.304	-0.403*	0.258
	(0.177)	(0.270)	(0.212)	(0.151)
Poland	1.860***	-1.449***	-1.784***	0.075
	(0.093)	(0.149)	(0.154)	(0.267)
Portugal	0.178***	0.030	-0.020***	0.114
	(0.022)	(0.031)	(0.003)	(0.199)
Romania	0.369**	-0.089**	-0.008	-0.278***
	(0.155)	(0.041)	(0.010)	(0.074)
Slovakia	0.908***	-0.125	-0.049***	0.070
	(0.195)	(0.080)	(0.013)	(0.093)
Slovenia	0.942***	-0.418*	0.005	-0.583**
	(0.149)	(0.213)	(0.110)	(0.226)
Spain	0.544***	0.041	-0.043***	0.074
	(0.072)	(0.041)	(0.001)	(0.089)
Sweden	0.225***	-0.139	-0.012*	0.577
	(0.055)	(0.147)	(0.006)	(0.443)
Turkey	0.081***	0.040	-0.011*	1.173***
	(0.009)	(0.024)	(0.005)	(0.141)
Panel Overview:	**0.468*****	**-0.027*****	**-0.017*****	**-0.008**
	(0.016)	**(0.007)**	**(0.001)**	**(0.013)**

Note. Abbreviations for variables: log(GDPpc): natural log. of real income per capita, EPE: environmental protection expenditure, ET: environmental taxes, REC: renewable energy consumption; ***, ** and * denote 1%, 5% and 10% significance level, respectively.
Source: own study.

Consistent with the results by Bento and Moutinho (2016), Chen *et al.* (2019), Tiwari (2011), and Rafique *et al.* (2022), our results suggest that a rise in REC reduces ecological footprint.

Table 8 shows the FMOLS estimation results of Equation (1) with respect to the countries in our sample. According to the empirical results, the positive relationship between real income per capita and ecological footprint was much higher for Austria, the Netherlands, and Poland. Austria, Belgium, Denmark, France, Greece, Italy, Lithuania, Poland, Romania and Slovenia were the countries where environmental taxes led to a decrease in pollution. We found REC to be effective in reducing ecological footprint in Belgium, Denmark, Croatia, France, Czechia, Greece, Germany, Netherlands, Italy, Portugal, Poland, Slovakia, Sweden, Spain, and Turkey. The negative effect of environmental protection expenditures on ecological footprint was statistically significant in France, Romania and Slovenia, while this parameter was estimated as statistically insignificant across the panel. In Turkey[8], an increase in environmental protection expenditure led to an increase in ecological footprint.

CONCLUSIONS

This article investigated whether fiscal policy instruments can solve environmental problems. These instruments may include environmental taxes, environmental protection expenditures, and renewable energy incentives. The conventionally used fiscal policy instrument in practice is environmental taxes. Environmental taxes serve to restrict, prevent, or reduce pollution-intensive economic activities. Renewable energy incentives may support clean energy production and enable producers to compete with firms using fossil fuels. Environmental protection expenditures may also serve to reduce environmental pollution. In this context, this article examines the long-run effects of fiscal policy instruments on the ecological footprint in our sample including 21 EU countries and Turkey during the annual sample of the 1996-2018 period.

To study the long-run effects of fiscal policy instruments on ecological footprint, we prefer to use DOLS and FMOLS estimation methods. The empirical results show that the most effective fiscal policy instrument to mitigate the ecological footprint is renewable energy incentives. Both DOLS and FMOLS estimation results suggest that renewable energy consumption tends to reduce ecology-ical footprint. Renewable energy incentives appear as a pollution-reducing factor in almost all countries included in the analysis. To compete with cheap and polluting fossil fuels, renewable energy consumption needs to be supported by the government. A renewable energy incentive policy that prioritizes the employment of renewable energy is expected to contribute to the countries achieving their sustainable development goals.

In addition to renewable energy incentives, we found that environmental taxes reduce pollution in most of the countries in our sample. However, environmental taxes may also serve other purposes than environmental protection. We suggest that revenues from environmental taxes could be directly used to address environmental problems.

Environmental protection expenditures appear to be the least effective fiscal policy instrument. Although environmental protection expenditures have a small share in income, they are very important in dealing with environmental problems, protecting natural life and achieving sustainable development goals. Therefore, allocating more resources to environmental protection services will contribute to making it an effective policy instrument.

Policy implications derived from these findings emphasize the necessity of a well-coordinated approach that integrates environmental taxation, renewable energy incentives, and strategic environmental expenditures to achieve sustainability goals effectively. Environmental taxes should be structured not only as revenue-generating instruments but also as mechanisms to incentivize cleaner production and innovation in green technologies, ensuring that tax revenues are reinvested into environmental projects. Similarly, increasing renewable energy incentives can accelerate the transition towards low-carbon energy systems, enhancing energy security while fostering technological advancements. Furthermore, environmental protection expenditures should be strategically allocated to

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[8] This result require cautious evaluation because there were only nine observations for Turkey.

targeted, results-oriented pro-jects, such as green infrastructure, waste management, and R&D in clean technologies, to maximize their effectiveness in reducing pollution. Policymakers should also prioritize cultivating environmentally responsible behaviours to reinforce the long-term sustainability of policy interventions.

A holistic and well-designed policy framework that aligns taxation, incentives, and expenditures can ensure that environmental policies mitigate ecological damage. By adopting such an approach, governments can balance the financial burden of environmental taxes with renewable energy incentives and direct the revenue generated from these taxes towards environmental protection expenditures. This strategic alignment and coordination will create a more effective policy framework not only for reducing environmental pollution but also for achieving sustainable development goals. Therefore, policymakers must plan and implement various fiscal policy tools in an integrated and strategic manner to enhance environmental policies' effectiveness.

Future studies should focus on using more recent data, exploring different pollution indicators, and examining the combined effects of fiscal policies through advanced econometric models to assess the effectiveness of environmental policies comprehensively. It would also be interesting for future studies which investigate the short- and long-run effects of fiscal policy instruments on environmental pollution by employing the autoregressive distributed lag (ARDL) model. Moreover, future studies may benefit from a comparative analysis across countries with varying levels of economic development and environmental regulations to better understand the heterogeneous impacts of fiscal policies on pollution.

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Use of Artificial Intelligence

The manuscript is free of AI/GAI usage.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Human-centric approach to creating sustainable innovation in the context of Industry 5.0

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A B S T R A C T
Objective: The article aims to explore how human-centric organisational practices, combined with employee dynamic capabilities (EDC), can drive sustainable innovation in the Industry 5.0 concept.
Research Design & Methods: We conducted an empirical study to verify hypotheses regarding human-centric organisational practices and their impact on sustainable innovation. We conducted a questionnaire-based study among 462 organisations from Poland. We tested research hypotheses with a linear regression analysis with a mediator using the Macro Process for IBM SPSS.
Findings: The critical literature review and empirical verification of the proposed hypotheses indicated that human-centric organisational practices influence sustainable innovation through EDC. Organisational employees are not mere resources but dynamic change agents who, supported by appropriate practices, drive innovation among organisations exhibiting characteristics of the Industry 5.0 concept. Human-centric organisational practices enable EDC, allowing organisations to benefit from them because of the strengthened ability to generate sustainable innovations.
Implications & Recommendations: Organisations seeking to implement sustainable innovation should adopt a more dynamic and human-centric approach to human resource management, prioritizing practices that enhance EDC such as adaptability, critical thinking, and creativity. The results confirm that achieving sustainability through innovation requires investments that go beyond technology and infrastructure. Future research could focus on different geographical or cultural contexts. Moreover, scholars could analyse in detail specific employee-centric practices and their impact on EDC and sustainable innovation and extend the proposed model to include new concepts.
Contribution & Value Added: The study's results extend the resource-based view and the dynamic capabilities framework by demonstrating that human-centric organisational practices are critical in enhancing EDC for fostering innovations among organisations exhibiting characteristics of the Industry 5.0 concept. They also contribute to the sustainable innovation literature by showing that sustainable innovation is not solely a product of top-down initiatives or rely mainly on technological advancements but also critically depends on the dynamic capabilities of employees that are supported by human-centric organisational practices. Leaders pursuing sustainability through innovation should focus on investing in human-centric practices, particularly those related to the enhancement of EDC.
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INTRODUCTION

In a world of accelerating technological advancement, organisations increasingly seek ways to innovate sustainably while responding to societal expectations. However, the key to unlocking such innovation

lies not only in the technological advancements themselves – such as AI, cloud, or renewables – but also in how organisations empower their people. Therefore, this paper focuses on the role of human-centric organisational practices (HOCP) in triggering employee dynamic capabilities (EDC), which in turn enhance the organisation's capacity for sustainable innovation (SI).

Although scholars have given much attention to emerging technologies and industrial paradigms like Industry 5.0, the literature places less emphasis on the mechanisms through which organisations can enable their human potential to drive innovation that is both socially and ecologically responsible. Such innovation, called sustainable innovation, is increasingly in demand among consumers who, besides expecting fast-paced change, are also aware of the broader impact of the products and services they choose (Ansu-Mensah, 2021; Zeynalova & Namazova, 2022; Lubowiecki-Vikuk *et al.*, 2021; de Sousa, 2023). As noted by Trendwatching (2024), sustainability is one of the prominent characteristics in current consumer trends, reflecting a deeper societal shift in expectations. Therefore, the question should concern not only whether organisations can meet sustainability goals through technological advancements, but whether they can foster internal conditions that allow their employees to contribute meaningfully to those goals. The article considers human-centric organisational practices that place employees at the centre of strategic and operational decisions, as the trigger of EDC, allowing employees to adapt, innovate, and align with evolving organisational needs. This dynamic capability becomes critical in turbulent environments, where responsiveness and resilience are strategic imperatives. Although Industry 5.0 provides a useful context for framing human-centricity, sustainability, and resilience as organisational priorities (Breque *et al.*, 2021), this study does not focus solely on this paradigm. Rather, it seeks to contribute to a broader discussion on how internal human-oriented strategies can catalyse innovation outcomes aligned with sustainability and long-term competitiveness. As Acemoglu and Johnson (2023) emphasize the need for external regulation to ensure inclusive innovation, this article highlights the complementary role of internal managerial support and leadership.

This study aims to fill a gap in the literature by examining the mediating role of EDC in the relationship between human-centric organisational practices and sustainable innovation, a relationship yet to be fully explored, particularly in dynamic and innovation-intensive environments, such as Industry 5.0. Furthermore, by incorporating the dynamic capabilities framework (Teece *et al.*, 1997; Bieńkowska & Tworek, 2020) into the resource-based view (RBV) (Wernerfelt, 1984; Barney, 1991), the research connects traditional resource-focused approaches to innovation with contemporary human-centred organisational strategies. To fulfil such aim, we performed the critical literature review to establish theoretical hypotheses and next, we conducted empirical research to verify them in the context of organisations developing into the Industry 5.0 framework.

LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

Sustainable Innovation

The debate on how to combine economic, environmental and social benefits while aiming for sustainable development has intensified over the last two decades (Boons & Lüdeke-Freund, 2013; Leal Filho *et al.*, 2022). This has increased the pressure on organisations to respond intensively to the challenges of climate change, environmental degradation, and social inequalities by embedding the concept of sustainability into their business practice (Hermundsdottir & Aspelund, 2021; Cataldo *et al.,* 2024; Adams *et al.*, 2016). Moreover, regulatory changes and increasing customer and stakeholder demands have driven the need to conduct sustainable actions, accompanied by proper monitoring and reporting of their outcomes (Provasnek *et al*., 2017; Xie *et al*., 2019). Nowadays, the pressure to comply with existing regulations is believed to be the key driver for organisations to move towards sustainability, especially if the target markets include European Union member states (Chan *et al*., 2016).

Sustainable innovation is a generalised term for sustainable business development, responding to social and environmental concerns. Combining the concepts of sustainability and innovation offers a meaningful approach to a new paradigm, where innovation is rooted in sustainable development and guided by the principles of ethical, social, economic and environmental responsibility (Cataldo *et al*.,

2024). At the intra-organisational level, the importance of factors such as uncertainty acceptance, social awareness, environmental competence, (Longoni & Cagliano, 2018), and leadership or knowledge management strategies (Adams *et al.*, 2016) is highlighted for sustainable innovation.

In the literature, scholars often use the term 'sustainable innovation' interchangeably with 'eco-innovation' (Boons & Lüdeke-Freund, 2013), 'green innovation,' 'environmental innovation' (Ben Arfi *et al.*, 2018; Hojnik & Ruzzier, 2016), despite the slight differences between these issues. However, the general trend demonstrates that there is already a consensus around the three-dimensional view on both the process and the result with an emphasis on the overall human well-being. Tello and Yoon (2008), state that 'sustainable innovation in a broad sense is defined as any improvement in the quality of products, services, and technologies that benefit a firm and institutionally improve human well-being at large.' In contrast, Clark and Charter (2007) define it as 'a process where sustainability considerations (environmental, social, and financial) are integrated into company systems from idea generation through to research and development (R&D) and commercialization.' In this article, the authors will focus on three dimensions of sustainable innovation: economics, environmental, and social.

Economic Dimension of Sustainable Innovation

Since the Schumpeterian approach to innovation, which identified innovation as the main driver of economic development, innovation has become a central economic term, affecting organisations, sectors, and societies. For a long time, sustainability innovation has been perceived as a cost factor for the organisation (Hermundsdottir & Aspelund, 2021; Adams *et al.*, 2016), initially requiring significant investments, a long payback time, and no guarantee of social or environmental benefits (Hermundsdottir & Aspelund, 2021; Hojnik & Ruzzier, 2016). However, from an economic perspective, sustainable innovation is crucial to support long-term growth and sustainability (Aguilera-Caracuel & Ortiz-de-Mandojana, 2013), as well as to achieve sustainable competitive advantage (Christmann, 2000; Caracuel, de Mandojana, 2013; Hermundsdottir & Aspelund, 2021). Sustainable innovation often leads to significant savings and performance improvements, *e.g.* by adopting energy-efficient technologies in the industry, organisations reduce energy consumption and lower operating costs (Christmann, 2000; Aguilera-Caracuel & Ortiz-de-Mandojana, 2013). Moreover, the shift toward sustainability opens new markets causing an increase in demand from consumers focused on ecology and environmental protection (Christmann, 2000; Aguilera-Caracuel & Ortiz-de-Mandojana, 2013).

The environmental Dimension of Sustainable Innovation

In its environmental dimension, sustainable innovation involves the introduction of a new or significantly improved product, service, production process, management approach, or marketing solution that minimizes environmental impact. This includes reducing pollution, conserving natural resources, and lowering the overall environmental footprint (Carrillo-Hermosilla *et al.,* 2009; Kemp, 2010). Environmentally sustainable innovation can imply reducing greenhouse gas emissions by using solar, wind, and bioenergy (Ramus, 2001; Chaudhry *et al.*, 2022), resource efficiency and waste management, *e.g.*, through a circular economy model, and biodiversity conservation, through, *e.g.,* precision agriculture or agroecology (Adams *et al.*, 2016; Zhang *et al.*, 2019). Sustainable innovation is an integral part of solving environmental problems, by increasing resource efficiency and promoting environmental sustainability (Abbas & Sağsan, 2019) throughout the product life cycle. They are now considered, as one of the most important factors affecting the image and reputation of companies (Gallardo-Vázquez *et al.*, 2019), as well as its competitive position (Abbas & Sağsan, 2019). However, organisations will only invest in activities that will impact their bottom line (Zhang *et al.*, 2019), so it is important that these are in line with the long-term goals of the organisation. For this reason, environmental legislation is also important and leads to improved environmental performance in terms of innovation (Kagan *et al.*, 2003; Chan *et al.*, 2016).

The Social Dimension of Sustainable Innovation

The social dimension of sustainable innovation focuses on improving quality of life, bridging inequalities, and addressing social exclusion. Sustainable innovations respond to social challenges and contribute to the overall well-being of a community or individual (Hölsgens *et al.*, 2018; Leal Filho *et al.*, 2022). The

implementation of sustainable innovations enables the collaboration of various actors – private, public, social organisations or households – allowing them to align and act on each other's interests (Beers & Geerling-Eiff, 2014). Sustainable innovation in the social dimension also encompasses practices such as employing people at risk of social exclusion, improving workers' living and working conditions (*i.e.*, work-life balance, health protection, and occupational safety), promoting professional development, maintaining, and improving living standards, supporting social causes, and preventing discrimination and human rights violations (Martin-Castejón & Aroca-López, 2016; García-Piqueres & García-Ramo, 2018). Johnson and Acemoglu (2023) highlight the need for a human-centric approach toward innovation. They use the term 'useful machines' to refer to innovations which, in the first place, complement human capabilities and empower people, creating new job opportunities as opposed to simply automating processes and replacing people. Moreover, implementing sustainable innovations can affect an organisation's reputation (García-Piqueres & García-Ramo, 2018), increasing an individual's ability to recruit the most skilful and innovative talents (Guerrero-Villegas *et al.*, 2018; García-Piqueres & García-Ramo, 2018).

Building awareness of sustainability should precede driving sustainable innovation. This will contribute to higher expectations toward sustainable innovations from all the stakeholders enhancing their development and deployment by organisations while transitioning to Industry 5.0.

Influence of I5.0 Human-centric Practices on Sustainable Innovation I5.0 Human-centric Practices

The human-centric approach of Industry 5.0 is consistent with the human resource approach, which regards employees as the organisation's key resource, essential for achieving competitive advantage and organisational goals (see Alves *et al.*, 2023). As Saikia (2023) notes, 'Industry 5.0, envisions an industry that is innovative, resilient, socio-centric, and competitive while minimizing negative environmental and social impacts, respecting people, the planet, and prosperity.' Consequently, both approaches view employees as an 'investment,' rather than a 'cost' (Breque *et al.*, 2021). Furthermore, the human-centric approach in Industry 5.0 'needs to consider societal constraints, aiming not to leave anyone behind. This has several implications, pertaining to a safe and beneficial working environment, the respect of human rights, and the skills requirements for workers (Breque *et al.*, 2021).

These assumptions translate into human-centric organisational practices for Industry 5.0 (I5.0 human-centric organisational practices), which refer to solutions adopted in an organisation which, on the one hand, respond to the above-described challenges of the Industry 5.0 concept and, on the other hand, place the human being as the main axis of the organisation's activity as a key factor of organisational success. At the same time, they do not only relate strictly to the field of human resources but also to the organisation as a whole. In particular, they concern intra-organisational practices related to:

— Improvements in working conditions, both in terms of reducing workplace accidents, particularly in contact with high-tech machinery and equipment, and ensuring the mental health of workers (Breque *et al.,* 2021). 'Security is a challenge for Industry 5.0 as it is critical to establish trust in ecosystems' (Adel, 2022, p. 9). These efforts aim to improve overall workplace safety while also considering the role of ethics in Industry 5.0 (Longo *et al.*, 2020), ensuring safety at work, and reducing work-related risks.

— Continuous employee development (providing training and development programmes), particularly in deepening digital competences, to achieve synergies in human-machine collaboration (cf. Breque *et al.*, 2021; Grosse *et al.,* 2023; Ivanov, 2022). This aligns with the vision where 'human and machine reconcile and work in perfect symbiosis with one another' (Longo *et al.*, 2020, p. 1). Moreover, enhancing these competencies helps reduce and eliminate risks associated with working environments where humans collaborate with increasingly intelligent machines (cf. Breque *et al.*, 2021; Ivanov, 2022).

— Development of soft competences such as: 'skills linked to creative, entrepreneurial, flexible, and open-minded thinking' (Breque *et al.*, 2021, p. 19).

Creation of an inclusive working environment that embraces employee diversity and supports their development; considering the individual approach to employees' needs and expectations, providing programmes to increase sensitivity to diversity, and individualising incentive schemes in a broad sense (Breque *et al.,* 2021; Ivanov, 2022; Calzavara *et al.,* 2020) to build employee involvement and proactive

attitude in the work process. As a result of the application of I5.0 human-centric organisational practices, an organisation can achieve its goals corresponding to the assumptions of the Industry 5.0 concept, including, in particular, those related to innovation in a broad sense. However, employee dynamic capabilities play a special role in this process as they allow employees to proactively adapt to changes occurring both within the organisation and in its surroundings.

I5.0 Human-centric Practices' Role in Shaping EDC

Both practitioners and management theorists emphasise the significant role of employee dynamic capabilities (EDC) (Bieńkowska & Tworek, 2020) in contemporary organisations (cf. Bieńkowska & Tworek, 2024; Tworek *et al.,* 2023; Al Wali *et al.,* 2023; Wang *et al.,* 2024). It appears that the contemporary theory of the resource-based view (RBV) (Wernerfelt, 1984; Barney, 1991) regarding both the organisation as a whole and its employees is insufficient. Therefore, the dynamic capabilities concept developed by Teece *et al.* (1997) complements the resource approach. It responds to the need for a dynamic view of the resources in response to changes in the organisation's environment. Thys, the dynamic capabilities in relation to the organisation as a whole mean 'the firm's ability to integrate, build, and reconfigure internal and external competencies to address rapidly changing environment' (Teece *et al.*, 1997). Transferring Teece *et al.'s* (1997) concept to the employee level, one can speak of EDC (Bieńkowska & Tworek, 2020), which are a critical complement to employees' existing qualifications and competencies and enable them to perform their work in accordance with the changing conditions of the work environment in which that work is performed. In this context, EDC mean 'abilities to integrate, build, and reconfigure employees' competencies to address rapidly changing environment, which is directly influencing the performance of tasks in the workplace' (Bieńkowska & Tworek, 2020). As understood here, EDC include four dimensions: 'ability to be sensitive to changes in the environment (the ability to see changes, recognize opportunities and risks potentially affecting the performance of work at the workplace), ability to adapt to changes in the environment (the ability to undertake preventive actions, avoiding the occurrence of problems in the workplace), ability to proactively solve problems arising in the workplace (if they occur), and include innovations in the workplace, as well as the ability for continuous personal development and learning' (Bieńkowska & Tworek, 2020).

Given the critical importance of EDC, it is important to develop them effectively. As in the case of employee qualifications and competences, human resources management practices and other organisational solutions serve to shape the level of EDC (cf. Salvato & Vassolo, 2018; Bingham *et al.*, 2015). Regarding the Industry 5.0 concept, human-centric organisational practices may be a natural and sought-after solution that should influence the level of EDC in an organisation This is due to their alignment with the principle of prioritising people as a core of organisations' goals and activities, as well as their role in creating a safe and beneficial working environment (Breque *et al.,* 2021).

As noted above, human-centric practices primarily promote and prioritise employees' skill development, create training opportunities, especially related to new technologies, and actively consider the impact of digital transitions on employees during strategy development. In particular, the above has an almost obvious impact on the potential ability of employees to proactively solve problems arising in the workplace – EDC component. That is because an update in terms of knowledge and skills regarding job requirements, including digital competences, is essential to fully exploit the synergistic effect of human-machine collaboration (Grosse *et al.,* 2023) while mitigating job-related risks. Moreover, a proactive attitude of employees toward solving problems arising in the workplace is fostered by creating a workplace that is safe (in the sense of preventing workplace accidents and ensuring mental health) and that respects the human rights of the employee. In such a workplace the efforts to jointly achieve organisational goals are valued and mistakes are not seen as a reason to punish employees, but as an inspiration for continuous improvement, all while prioritizing the well-being of employees. Furthermore, the promotion of employee skill development arises from the necessity of continuous improvement in response to the changing environment. Therefore, the human-centric approach emphasises the creation of opportunities for continuous employee development (Giniuniene & Jurksiene, 2015; Schilke *et al.,* 2018, Ingram, 2019; Al Wali *et al.*, 2023), which is critical in the EDC concept.

Moreover, the human-centric promotion of diversity as an element of workforce strategy (also reflected in the areas of hiring and promotions) sensitizes employees to the changing and diverse needs of both the organisation and its business environment, which in turn enables the employee to recognize changes, identify opportunities and risks potentially affecting the performance at the workplace, which is also an important component of the EDC. Furthermore, a human-centric approach aims to leave no one behind, meaning that the actions taken within the organisation affect all its employees and are not limited to certain groups, *e.g.*, the best or most committed employees. Inclusiveness has a positive impact on raising dynamic capabilities in the organisation (cf. Salvato & Vassolo, 2018). Therefore, it is possible to underline the systemic impact of human-centric organisational practices on the individual components of EDC, with the simultaneous assumption of reaching every employee in the organisation. In this context, we hypothesised:

H1: Human-centric organisational practices have a positive influence on EDC.

The role of EDC in Shaping Sustainable Innovation

Employee dynamic capabilities encompass innovative thinking and idea generation on behalf of the employees, thereby enhancing innovation development and deployment. The core question is whether EDC can foster sustainable innovation. When applied to sustainable innovation, EDC should enable the organisation and its employees to not only respond to the vulnerability of the environment with new products, services or operational processes, but also ensure that these innovations simultaneously create economic, social, and environmental benefits, generating shared impact beyond mere shareholder value.

A proactive attitude in employees, considering the needs central to the concept of Industry 5.0, is critical for the effective development and implementation of innovations in modern organisations. Sensitivity to changes occurring in the environment draws attention to emerging or anticipated needs, which are a determinant of development, and which set the direction of innovative changes. Employees with dynamic capabilities are adept at identifying emerging trends and opportunities related to sustainability. According to Abcouwer and Takacs (2020), in a vulnerable environment with an unpredictable future, organisations require flexibility and adaptive capabilities of their employees to achieve a person/future fit to succeed in innovations. Such employees can anticipate market shifts and regulatory changes, positioning the organisation to innovate sustainably. This aligns with the growing consumer demand for sustainable products and services, as highlighted by recent research (Ansu-Mensah, 2021; Zeynalova & Namazova, 2022).

Once opportunities are identified, employees can mobilize resources and align organisational processes to seize these opportunities. This involves developing new products or services that meet sustainability criteria, optimizing existing processes to reduce environmental impact, and leveraging advanced technologies to enhance efficiency and reduce waste. Sustainable innovation often requires significant changes in organisational structures and processes. Employees with dynamic capabilities can lead these transformations, ensuring that the organisation not only adapts to sustainable practices but also embeds them into its core operations. This transformation is essential for maintaining a competitive advantage in a market increasingly focused on sustainability (Lubowiecki-Vikuk *et al.,* 2021). Moreover, employees with well-developed EDC can identify risks related to digital process innovations and job loss, anticipating the potential social tension in the community. Such employees are then capable of introducing labour-friendly solutions.

However, to a large extent require, sustainability initiatives specialised knowledge and expertise. The rapidly evolving technologies to address upcoming issues, such as automation and eco-efficiency solutions, necessitate another dynamic capability, *i.e.*, continuous learning. Continuous personal development and learning are prerequisites for having the ability to develop innovative solutions based on the latest scientific achievements. Thus, companies invest in training programs for their leaders and employees permanently to facilitate sustainability decisions at large scales (Polman & Bhattacharya, 2016). Outperforming companies have employees with skills and functional expertise focused on customers and the external ecosystem, who can demonstrate quick reaction to change and realize value

very quickly within the innovation and transformation processes (Bohlin *et al.*, 2023).

Based on the above, we hypothesised:

H2: EDC have a positive influence on sustainable innovation.

I5.0 Human-centric Organisational Practices' Influence on Sustainable Innovation Through EDC

Advocates of Industry 5.0 note that Industry 4.0, focused on productivity and technology, is not the right structure to achieve sustainability goals and sustainable innovation. It is Industry 5.0, representing a paradigm in which workers play a central role in cyber-physical systems (Grabowska *et al.,* 2022) that emphasizes the importance of synergy between humans and machines (Grosse *et al.*, 2023; Özdemir & Hekim, 2018; Grabowska *et al.,* 2022). According to Horvat *et al.* (2024), 'this synergy leads to more robust ideation processes, enhancing both explorative and exploitative knowledge capabilities, which are crucial for generating innovative solutions to complex problems.' The synergy between competent employees and advanced technologies will be key to bearing the innovative capacity of companies (Adel 2022; Mikalef *et al*., 2020), through the active involvement of employees in the innovation process (Weigt-Rohrbeck & Linneberg, 2019; Horvat *et al.,* 2024), their enhanced capabilities related to knowledge creation and analysis (Horvat *et al.,* 2024), a proactive approach (Weigt-Rohrbeck & Linneberg, 2019), and an attitude that fosters creativity and exploratory thinking (Park *et al.*, 2014). Competent workers are a valuable resource for solving complex challenges in sustainability-oriented innovation (Hector & Cameron, 2023). They understand the environmental and social challenges and can therefore implement innovations in line with sustainability goals by means of modern technological solutions, *e.g.*, giving them the ability to process huge amounts of data (Ramus, 2001; Weigt-Rohrbeck & Linneberg, 2019).

Sustainable innovation often lies beyond the scope of employees' operational activities. According to Weigt-Rohrbeck and Linneberg (2019), 'employees who are satisfied with their allocated tasks will be more likely to take on additional tasks.' Therefore, human-centric practices leading to higher job satisfaction enforce sustainable innovation in the organisation. Job satisfaction and employee engagement will depend on the right work environment, in which talent and diversity management, employee experience, and organisational culture based on trust, inclusion and collaboration are important (Ramus, 2001; Hector & Cameron, 2023; Ingram, 2019). As a result, without diminishing the role of technology for economic growth and value creation, Industry 5.0 provides a framework for integrating economic and social goals through workplace safety and optimal human-machine relations in the work environment and social and environmental responsibility – in the outside surroundings (Gorodetsky *et al.,* 2019; Ivanov, 2022).

Hence, we hypothesised:

H3: Human-centric organisational practices have a positive influence on sustainable innovations.

Human-centric organisational practices, through the construction of an appropriate work environment, are a key element in the development of EDC (Nold, 2019; Hector & Cameron, 2023). Recent research indicates that innovation is, as it were, a consequence of EDC (Giniuniene & Jurksiene, 2015; Schilke *et al.,* 2018; Ingram, 2019; Al Wali *et al.,* 2023), which contributes to an organisation's innovation capacity (Al Wali *et al.,* 2023). Supported by human-centric management and favourable working conditions, EDC facilitate an organisation's recognition of potential technological change but also strengthen its ability to adapt to change through innovation (Hill & Rothaermel, 2003; Mousavi *et al.,* 2018). EDC facilitate managers' ability to effectively perceive changes in the internal and external environment of the organisation and enhance the ability to purposefully combine, allocate and develop internal and external resources, contributing to the long-term success of the organisation (Mousavi *et al.,* 2019; Mishra *et al.,* 2022). The mediating role of EDC in implementing sustainable innovation is highlighted by Mousavi *et al.* (2018), who are optimistic about the potential of EDC in shaping a deeper understanding of sustainability innovation management. According to Longoni *et al.* (2014), the conceptualisation of employees and dynamic capabilities are linked to social and environmental sustainability outcomes.

Given the above considerations, we posed a complementary hypothesis:

H3m: Human-centric organisational practices positively influence sustainable innovations through EDC.

Hence, the proposed hypotheses form a model presented in Figure 1.
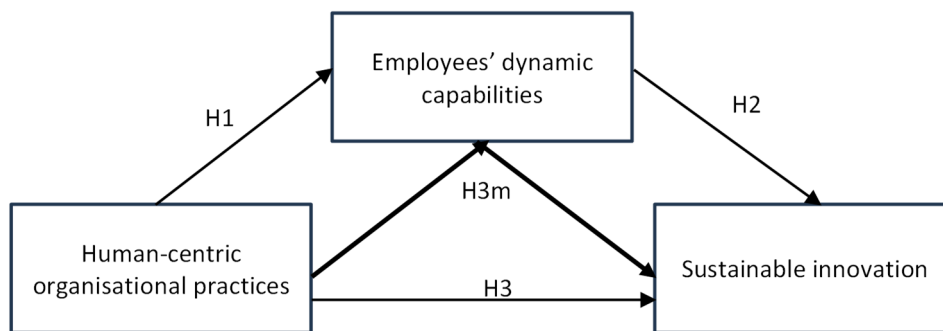
Figure 1. Model of hypotheses
Source: own elaboration.

RESEARCH METHODOLOGY

We applied a two-phase empirical study to validate the theoretical framework and examine and confirm hypotheses concerning human-centric organisational practices and their effects on sustainable innovation. Initially, we conducted a pilot study to validate the measurement tool, followed by the main research phase. To collect primary data, we used a questionnaire, which included newly developed measurement scales along with previously validated scales for various model variables and control variables.

Top-level managers from Polish organisations completed this questionnaire. Each provided a single response per organisation due to their thorough understanding of organisational operations. The pilot study aimed to assess the questionnaire quality, including all proposed measurement scales, and involved 25 purposefully selected senior managers acting as judges. Their feedback helped refine several questions to ensure they were clear and understandable. The main research phase, conducted in the first quarter of 2024, focused on analysing and verifying the proposed hypotheses. We conducted it using the computer-assisted web interview (CAWI) method, based on a purposively selected and bought respondents panel consisting of top-level managers employed in organisations in Poland, which exhibited some characteristics from the Industry 5.0 concept. We obtained 462 fully filled-in questionnaires and included them in the sample for this study. Table 1 shows the characteristics of the sample, which includes a diverse mix of organisations, differing in case of size, industry, and technological advancement. While the sample was not representative, the diversity of the participating organisations supports meaningful conclusions. Including various sectors strengthens the findings' robustness. Moreover, we calculated the Kaiser-Meyer-Olkin (KMO for each variable and model to confirm that the sample size and diversity were adequate for the planned statistical analyses.

Table 1. Sample description: Organisation size

Size of employment	Number of organisations
Less than 10 people	15.32%; 70
10 and more people, but less than 50 people	23.19%; 106
50 and more people, but less than 250	32.60%; 149
250 and more	28.88%; 132
Total	457

Source: own study.

Variables

To verify the formulated hypotheses, we utilized the following variables:
Human-centric organisational practices (HCOP) underwent assessment using six items related to employee support initiatives.

Employee dynamic capabilities (EDC) included eight items across four dimensions: sensitivity to changes, ability to adapt to those changes, capacity to solve problems and innovate within the workplace, and potential for continuous personal development (Bieńkowska & Tworek, 2020).

Sustainable innovation (Sinn) variable was based on 13 items concerning economic, environmental, and social aspects of sustainable innovation.

We evaluated all items in the above variables on a 5-point Likert scale.

We constructed the questionnaire in SurveyMonkey in English. It consisted of several sections concerning questions about various aspects of organisations operations. Appendix A gives specific items for each variable.

To verify the proposed hypotheses, we rigorously analysed and validated all measurement scales, using the IBM SPSS. We confirmed the data's normal distribution, which was followed by three statistical tests to check for the reliability and validity of the measurement scales. Cronbach's alpha analysis assessed the coherence and reliability of the measurement scale. Obtained numbers above 0.7 (for EDC) indicate average reliability, while values above 0.8 (for HCOP and SInn) are more satisfactory (Drost, 2011). We conducted confirmatory factor analysis (CFA) using IBM SPSS. This test verified the coherence and internal consistency of the measurement scale. The average variance extracted (AVE) value should exceed 0.5. We evaluated model fit statistics with the following criteria: $\chi^2/df < 5.000$, TLI > 0.800, CFI > 0.800, GFI > 0.800, and RMSEA < 0.2 (Hopwood & Donnellan, 2010). Kaiser-Meyer-Olkin (KMO) test assessed the adequacy of the sample size. All values accede 0.5 and therefore the size of the sample was sufficient (Field, 2000; Kaiser, 1974).

Table 2 presents the results, showing that the scales were internally consistent, reliable, and coherent, hence, allowing for a robust hypothesis verification. We also utilized the heterotrait-monotrait ratio (HTMT) to assess discriminant validity. The obtained values were below 0.65 (Hamid *et al.*, 2017), indicating the variables' suitability for further analyses. The variables were first-order latent variables.

Table 2. Variables overview

Variable	Number of items	AVE	K-M-O	Cronbach's alpha	N
HCOP	6	0.523	0.856	0.822	455
EDC	5	0.531	0.811	0.778	452
SInn	13	0.547	0.962	0.931	445

Source: own study.

Moreover, we utilized Harman's single-factor test (Aguirre *et al.*, 2019) to confirm the absence of the common method bias, as we used the same questionnaire to collect all the primary data. Through IBM SPSS and the dimension reduction procedure, we checked if any of the factors explained more than 50% of the variance among variables, which would indicate bias. The confirmatory factor analysis, with factors fixed at one, revealed that the single factor explained only 32.0% of the variance. This indicates that the sample did not have a common method bias. Moreover, we undertook various steps at the time of survey development to limit common methods bias: (1) we separated items measuring independent and dependent variables in the questionnaire, (2) we used different formats and sometimes different scales for each variable, (3) we avoided ambiguous, vague, or complex questions were avoided.

RESULTS AND DISCUSSION

Research Results

We used a linear regression analysis incorporating a mediator, run in Process Macro for IBM SPSS to examine the formulated hypotheses. As outlined by Saks (2006), three conditions must be met to establish mediation. Firstly, there must be a significant association between independent variables and mediators. Secondly, the mediator must exhibit a significant relationship with the dependent variables. Thirdly, when the mediator is accounted for, the effect of the independent variables on the dependent variables should either diminish (indicating a partial mediation) or disappear (indicating full mediation).

To verify the first two criteria, we conducted Pearson's correlation analysis using IBM SPSS. The findings, presented in Table 3 support the fulfilment of these conditions. There were statistically significant and strong correlations among all the analysed variables and the strongest correlation appeared between human-centric organisational practices and EDC (r = 0.732).

Table 3. Results of correlation analysis

Variable		HCOP	EDC	Sinn
HCOP	r-Pearson	1	–	–
	p	–	–	–
EDC	r-Pearson	0.732	1	–
	p	<0.001	–	–
SInn	r-Pearson	0.376	0.366	1
	p	<0.001	<0.001	–

Source: own study.

Such findings provide a basis for proceeding with hypothesis testing related to EDC through a mediated linear regression analysis. We developed a mediation model, positioning human-centric organisational practices as the independent variable and sustainable innovation as the dependent variable, with EDC serving as the mediator. For the regression model to be valid, it must demonstrate statistical significance, and the total effect must exceed the direct effect observed between the variables. Table 4 summarises the outcomes of this analysis.

Table 4. Results of mediation analysis

Mediator	Direct effect value	Indirect effect value	Boot LLCI	Boot ULCI	R2
EDC	0.4046	0.2512	0.0784	0.4282	0.541

Source: own study.

The results of the mediated linear regression analysis indicate that the model is statistically significant (F (1.439) = 517.548, p<0.001 and corrected R2= 0.464). The overall fit of the model is more than satisfactory for the social science empirical research, as R2 = 0.541, which shows that a significant portion of dependent variable variance is explained by the independent variable and mediator. Furthermore, we confirmed EDC to be a statistically significant mediator within the model (p<0.001, coeff. = 0.3442, se = 0.1130). The mediating effect is also statistically significant, as we conclude from Table 4, as it shows that there is an indirect effect within the given model, and both Boot LLCI and ULCI remain above 0, which renders the results statistically significant. Since the model includes both direct and indirect effects, this supports the presence of partial mediation. These findings support the acceptance of both hypotheses, demonstrating that human-centric organisational practices have a positive impact on sustainable innovation, with EDC mediating this relationship.

Discussion

This study offers significant contributions to the growing body of literature on sustainable innovation, dynamic capabilities, and the emerging paradigm of Industry 5.0 by empirically demonstrating the mediating role of EDC in the relationship between human-centric organisational practices and sustainable innovation. Building on the resource-based view (RBV) concept and extending it with the dynamic capabilities (DC) framework, our study enables a broader theoretical understanding of several key research areas. Traditionally, the RBV has focused on the static resources available to organisations, without focusing on the opportunities to develop such resources, whereas the dynamic capabilities framework, proposed by Teece, Pisano, and Shuen (1997), emphasizes the adaptive nature of an organisation's ability to integrate, build, and reconfigure internal and external competencies in response to environmental change.

Firstly, our findings contribute to the development of theory on Industry 5.0 by confirming that its human-centric pillar is not merely philosophical or ideological, but can indeed be operationalized in terms of specific organisational practices that influence innovation outcomes. While the Industry 4.0 literature has emphasized the importance of automation and productivity growth, this study shows

that human-centred organisational design – centred on employee well-being, development, inclusion, and safety – creates the right environment to support EDC, but also actively unlocks these dynamic capabilities. This activation of employee potential is key to generating sustainable innovation that is aligned with economic, environmental, and social goals, and that leads to sustainable development in the long term. To remain competitive and responsible in the era of Industry 5.0, organisations must adopt a holistic, human-centric approach that promotes a culture of adaptation, continuous learning and proactive problem-solving. This is underlined by the results of the study, which indicate the need to change traditional innovation strategies based on technology or costs.

Secondly, the study responds to calls for more empirically grounded research on how employee-level capabilities drive innovation in turbulent, technologically advanced environments. The study provides robust evidence that EDC are a central mechanism through which human-centric practices translate into innovation outcomes. This is especially important in contexts aligned with Industry 5.0, where innovation must deliver shared value for multiple stakeholders, including employees, communities, and the environment. The results provide a more nuanced understanding of how organisational practices influence sustainability outcomes. Previous research has often focused on the direct effects of organisational culture or leadership on sustainable innovation (Boons & Lüdeke-Freund, 2013; Hermundsdottir & Aspelund, 2021). However, this study adds to this by illustrating the mediating role of EDC in this relationship. It suggests that sustainable innovation is not solely a product of top-down initiatives but also depends critically on the dynamic capabilities of employees – capabilities that are unlocked and nurtured within an environment intentionally designed by human-centric organisational practices. Moreover, EDC enable the organisation to identify and capitalize on new opportunities related to sustainability-oriented innovation, which in turn are essential to maintaining a competitive edge amid growing pressure for sustainability. Human-centric orientation in an organisation will also be important in creating sustainable business models or finding new ways to implement eco-innovation. The involvement of employees in organisational processes and their high creativity allows organisations to respond flexibly and adaptively to changing market conditions, resulting in higher efficiency of innovations introduced. This finding bridges the gap between high-level strategic initiatives and individual employee behaviours, highlighting the importance of aligning organisational practices with employee development to achieve sustainability goals.

Thirdly, the research contributes to the sustainable innovation literature by reinforcing that such innovation is not merely a function of technological investment or leadership commitment. Instead, the ability to generate sustainable outcomes lies in the distributed, bottom-up capabilities of employees, who can sense, adapt, and respond proactively to changing needs. This people-centred perspective shifts the focus of innovation from being solely a top-down strategic imperative to an organisation-wide competency, nurtured by supportive practices that trigger and develop EDC.

The results of this study also provide several practical implications for business leaders, policy-makers, and organisational designers who want to align their organisations with Industry 5.0 principles and deliver on sustainability targets through sustainable innovation. The first is the need for strategic investments in human-centred practices. Organisations striving for sustainable innovation should prioritise policies that improve employee experience, safety, well-being, and inclusion. These should not be mere ethical or compliance measures but should be viewed as strategic enablers of innovation through the development and activation of EDC. Human-centred practices create an environment for the development of dynamic employee competencies. The second one concerns human resources as a driver of innovation. The findings underscore the critical role of fostering a dynamic workforce, one that continuously learns, adapts, and contributes creatively. HR departments should evolve from administrative units into strategic partners in innovation by designing systems that promote agility, resilience, and employee-led problem-solving to enhance their EDC. The third one is linked to reframing technology implementation. As organisations adopt new technologies (for example AI, IoT, and robotics), the focus should be on complementing human capabilities rather than replacing them to establish an environment conducive to innovativeness. This shift requires the development of human-machine collaboration skills, which human-centric practices can effectively cultivate. Finally, there are also policy and organisation-level considerations. The study reinforces the value of incentivizing human-centric

innovation practices, *e.g.*, through subsidies, regulatory frameworks, or recognition schemes that reward organisations demonstrating social and environmental impact via employee-driven innovation.

CONCLUSIONS

This article aimed to explore how human-centric organisational practices, in conjunction with EDC, can drive sustainable innovation within the framework of Industry 5.0. Industrial transformation increasingly forces organisations to change values, employees and technologies. An extensive literature review provided the basis for the hypothesis that human-centred practices, which are the central point of Industry 5.0, influence sustainable innovation through the development of EDC, but also enable the construction of an environment for the development of EDC. We empirically confirmed the mechanism and the mediation model showed that EDC significantly strengthened the relationship between human-centred organisational practices and sustainable innovation. Therefore, this study contributes to the literature by combining the human-centred approach, which is the operating philosophy of Industry 5.0, with the RBV and dynamic capabilities frameworks, showing that human-centred organisational practices enhance EDC, which in turn drive sustainable innovation.

The study results confirm that the human-centric pillar of Industry 5.0 can be effectively translated into organisational practices that support the dynamic employee capabilities necessary to drive sustainable innovation across economic, environmental, and social dimensions. Through robust empirical analysis on a diverse sample of Polish organisations, it demonstrates that these capabilities serve as a key mechanism linking human-centric design to innovation outcomes, especially in rapidly evolving environments. Ultimately, the research reframes sustainable innovation as a distributed, employee-driven process, highlighting the need for inclusive, bottom-up strategies rather than solely top-down initiatives.

The article demonstrates that human-centric organisational practices are not only aligned with Industry 5.0 aspirations but are essential to their implementation. The study empirically confirms that these practices are a direct, powerful driver of sustainable innovation by building an environment for enabling and developing EDC. As organisations move beyond the automation-driven mindset of Industry 4.0, the need for a more inclusive and sustainable approach becomes evident. Hence, from a practical perspective, it shows that fostering human-centric environments that nurture employee adaptability, creativity, and continuous learning, while bearing EDC, is essential for achieving sustainable innovation – economically, socially, and environmentally. It highlights the need for organisations to move beyond traditional innovation strategies that are technology- and cost-driven. A holistic approach that prioritizes human-centric practices is essential to fostering a culture of continuous learning, adaptability, and proactive problem-solving – key components of sustainable innovation that remain at the heart of Industry 5.0. Combining human-centric Industry 5.0 practices with sustainable innovation by exploring the intermediary role of EDC allows for the practical operationalization of organisational activities and the strengthening of the employee's role as an innovator.

While this study provides valuable insights into the relationship between human-centric organisational practices, EDC, and sustainable innovation, it is not without its limitations. Firstly, the research was conducted within a specific geographic context, focusing on organisations in Poland. Secondly, the study relies on self-reported data collected through questionnaires completed by top-level managers. While this approach ensures that respondents have a thorough understanding of organisational operations, it also introduces the potential for response bias. The self-reported data may introduce common method bias and social desirability effects, potentially inflating the observed relationships between variables. While we addressed this through statistical controls (*e.g.*, Harman's single-factor test), the reliance on a single-source, cross-sectional design limits the generalizability of the findings. Future research could address this by incorporating multi-source data (*e.g.*, combining employee and managerial perspectives) or objective performance indicators.

The study has various potential directions for further research. Firstly, studies should involve different geographical and cultural contexts should be used for verification of the suggested model. Secondly, various specific human-centred organisational practices may be considered, offering insight into the ef-

ficiency of each of them. Future studies could, for example, isolate and test the impact of individual human-centric practices – such as inclusive decision-making, safety-enhancing policies, or personalized training programs – on the development of EDC and innovation outcomes. Longitudinal research may allow for identifying the human-centric practices with the highest long-term impact, and the timing and sequence of such an impact on the innovation performance in the Industry 5.0 context. Moreover, the article presents only one of the important issues related to Industry 5.0, *i.e.*, human-centric orientation. We assumed its influence on the creation of sustainable innovations. In subsequent studies, scholars should consider other factors that could potentially influence sustainable innovations. It is also necessary to further explore the direction of further explanation of the mechanism of the influence of the human-centric approach on sustainable innovation, where the mediating elements will be, for example, attitudes towards work, *i.e.*, motivation or employee engagement. Finally, other variables may be considered as factors boosting the confirmed mechanism of influence on sustainable innovation, considering the scale of innovations implemented or the degree of novelty in the market.

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Appendix:

Items used for the measurement of each variable included in the study:

Human-centric organisation practices

Our organisation prioritizes skill development.

Our organisation provides training opportunities for employees to adapt to new technologies.

Our organisation actively seeks and values diversity in our workforce.

In our organisation diversity and inclusion are key components of our workforce strategy, reflected in our hiring and promotion practices.

Our organisation has systems in place to ensure that the work environment is safe, inclusive, and conducive to employee growth.

Our organisation actively considers the impact of digital transitions on employees during strategy development.

Sustainable innovation

Economic dimension

Our organisation has consistently increased expenditure for process innovation over the past five years, providing environmental and social benefits.

Our organisation has consistently developed and commercialized new products over the past five years, providing environmental and social benefits.

In our organisation, innovation contributes to the achievement of the Sustainable Development Goals (SDGs).

In our organisation, we introduced innovations that equally benefit economic performance and social and environmental responsibility.

Environmental dimension

In our organisation, we have improved the manufacturing processes over the past five years to reduce the use of raw materials and energy.

In our organisation, we have improved the manufacturing processes over the past five years to reduce the emission of hazardous substances or waste.

In our organisation, we have improved the manufacturing processes over the past five years to reuse and remanufacture components.

Over the past five years, in our organisation, we have redesigned and improved our product to meet environmental criteria or directives.

Societal dimension

In our organisation, we have improved the manufacturing processes over the past five years to reduce rates of injury, occupational diseases, and work-related fatalities.

In our organisation, our innovations address the needs of societal well-being.

In our organisation, we introduce innovations that contribute to the local community's prosperity (beyond our business interests).

In our organisation, our business strategies are developed with input from a diverse range of stakeholders, including cooperators, community, environmental groups, and customers.

In our organisation, we actively invest in and develop technologies and processes that enhance circular economy practices within our industry.

Employees dynamic capabilities

Employees in our organisation quickly notice and successfully recognize in the environment (both inside and outside of the organisation) opportunities and threats (including early warning signals) that can affect the work they do.

Employees in our organisation adapt effectively to the opportunities and threats appearing in the environment (both inside and outside the organisation). They undertake preventive actions that enable them to conduct the tasks entrusted to them despite changes in the environment.

Employees in our organisation quickly notice and successfully recognize problems appearing at the workplace.

Employees in our organisation quickly solve problems; they do it on their own or seek support (within the scope of knowledge and information) that allows them to perform assigned tasks.

Employees in our organisation generate innovative ideas and original solutions to problems.

Authors

The contribution share of authors is equal and amounted to 25% for each of them. AB, KT – conceptualisation and methodology, KT – calculations, AB, KT, OV, JZ – manuscript writing, discussion, and conclusion.

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Use of Artificial Intelligence

GAI (ChatGPT v.4.0) was used during the preparation of this manuscript. The scope of usage concerned only proofreading and language corrections.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The impact of digitalisation on employment and productivity in the financial sector:
A comparative analysis of information and communication technology usage of Central European and Baltic businesses

Arnold Tóth, Ramin Astanli, Erika Varga

A B S T R A C T
Objective: The article aims to examine the impact of digitisation on employment and productivity in the financial sector and provide a comparative analysis between the Central European and the Baltic countries as no study has yet compared these two regions in terms of digitalisation and information and communication technology (ICT) usage despite similar economic backgrounds.
Research Design & Methods: To address this, we applied a two-pronged approach that combines a literature review with an empirical analysis of secondary data. We used multivariate analysis of variance (MANOVA) to estimate the simultaneous total effect of ICT use on employment and productivity and ordinary least squares (OLS) regression to examine the specific relationships identified by MANOVA.
Findings: Central European countries generally exhibit higher levels of employment and productivity than their Baltic counterparts, highlighting regional differences in economic conditions and labour market dynamics. ICT has a major impact on productivity but is also associated with declining employment levels, which raises concerns about potential job displacement. Investments in the financial sector have a positive effect on employment, which highlights its crucial role in supporting employment growth.
Implications & Recommendations: By implementing best practices and encouraging a culture of ongoing learning and innovation, the digital transformation of Central Europe and the Baltic countries can become smooth and successful. Regional comparative analysis further provides valuable contextual insights, highlighting the need for tailored policy interventions.
Contribution & Value Added: The analysis shows that investments do not have a significant direct effect on productivity. Capital investment does not guarantee an increase in output, just emphasises the need for a strategic investment approach.
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INTRODUCTION

Nowadays, the role of the financial sector in fostering job growth, national economic development, and people's financial inclusion is becoming increasingly obvious. The speed of digitisation has changed employment in financial services (Niemand *et al.*, 2021). The rise of fintechs has altered the way how businesses operate, and labour organisation by the increased use of remote work and flexible sched-

uling (Garcia *et al.*, 2024). This long-term impact could result from the increased demand for digitalised financial services during the pandemic (Setiawan *et al.*, 2024).

Digitalisation encompasses skills and abilities while information and communication technology (ICT) concerns the use of ICT technology. Both have been profoundly reshaping employment patterns and productivity (Al-Surmi *et al.*, 2021). To guarantee sustainable growth, institutions must address the concerns about fair working conditions, skill development, and funding (Adeoye *et al.*, 2024).

Central European (CE) and Baltic countries have experienced significant economic transitions leading the groundwork for digitalisation efforts. In the Baltic countries (Estonia, Latvia, Lithuania), digitalisation has been integral to economic development, with Estonia particularly noted for its advanced e-government services (Himma-Kadakas & Kõuts-Klemm, 2023). According to Boikova *et al.* (2021), EU integration and investment, particularly in ICT infrastructure drives digitalisation in CE (including Poland, Hungary, and the Czech Republic). These regions continue to harness digital tools to enhance productivity and competitiveness in finance (Brodny & Tutak, 2022). That is why focusing on the digitalisation of the finance sector is essential.

How has digitalisation impacted employment and productivity in the financial sector of CE and Baltic countries? A comparative analysis of ICT usage between CE and the Baltic countries is essential to understand the distinct regional approaches to digitalisation in the financial sector as these two regions have not yet been compared to each other regarding the aspect of digitalisation and ICT usage despite their common economic background (*i.e.*, centrally planned economies).

LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

Digitalisation in the Financial Sector

Digitalisation in the financial sector has been reshaping how people deliver and consume financial services globally (Demidova *et al.*, 2024). Artificial intelligence (AI) and machine learning (ML) have become integral to the financial sector, driving efficiency and innovation (Chen *et al.*, 2023). Marengo (2024) argues that IoT technology enables connected devices to provide real-time data for various financial applications, leading to better decision-making.

Grishanova *et al.* (2022) state that one of the advances of digitalisation in finance is cloud computing, which has enabled financial institutions to reduce costs and improve flexibility. This shift also supports the development and deployment of new digital services more rapidly fostering innovation and competition such as apps, personalised financial advice platforms, and more integrated financial ecosystems (Breuer & Knetsch, 2023).

According to Anakpo *et al.* (2023), mobile payment solutions, digital wallets, and contactless payments bridge the gap for those without access to traditional banking services. Alqudah *et al.* (2023) state cryptocurrencies, such as Bitcoin and Ethereum, have also gained traction, offering an alternative to traditional currencies and payment systems worldwide. According to Adam *et al.* (2024), financial institutions that embrace these trends and invest in digital transformation are better positioned to thrive in an increasingly competitive and digital landscape.

The Impact of Digitalisation on Employment and Productivity

Digitalisation has profoundly reshaped employment patterns and created new opportunities while also presenting challenges such as job displacement. One of the most notable impacts of digitalisation is the automation of routine tasks (Kuncha & Sharma, 2024) and the rise of AI-powered chatbots and robo-advisors, freeing up human agents to tackle more complex issues (Huang *et al.*, 2024).

However, there is a demand for new skills such as proficiency in data analysis, strategic planning, cybersecurity, and digital literacy (Abrantes & Hang, 2023). According to Möller (2023), continuous learning and upskilling have become essential for career advancement in this digital era.

Digitalisation has also enabled remote work, offering greater flexibility to employees especially during and after the COVID-19 pandemic (Battisti *et al.*, 2022) as well as improved work-life balance

and increased job satisfaction (Al Mohamed *et al*., 2024). One of the most profound impacts of digital-isation on productivity, *i.e.*, automation of routine and repetitive tasks, reduces both the time and resources needed (Eziefule *et al*., 2024).

Online banking platforms, mobile apps, and AI-driven customer service solutions provide custom-ers with convenient and efficient access to financial services (Sheth *et al*., 2022), which also reduces the time and effort for communication and coordination, leading to more efficient operations.

ICT Usage in Central Europe and the Baltic Countries

Digitalisation has significantly impacted the CE financial sector, particularly through ICT. Various stud-ies (*e.g.*, Skare *et al*., 2023; Kádárová *et al*., 2023; Nicolás-Agustín *et al*., 2024) have highlighted its influence on employment, productivity, and operational efficiency. On the policy front, the European Union has implemented various initiatives to promote digitalisation, such as Act 2554 of the EU on the Digital Finance Package and the Digital Operational Resilience (DORA, 2022).

The rate and effectiveness of ICT adoption vary across CE countries (Bayar *et al*., 2024; Saba *et al*., 2024). According to Švarc *et al.* (2021), countries like Estonia and Poland have been at the forefront of digital transformation, with high levels of ICT adoption and significant investments in digital infrastruc-ture. In contrast, some countries in the region have lagged in ICT adoption, facing challenges such as limited digital skills and inadequate infrastructure (Stecenko & Stukalina, 2022). This disparity highlights the need for targeted policies tailored to regional differences and investments to ensure that all countries in the region can benefit from digitalisation, which has not been called for so far in the literature.

The adoption of ICT has also been a significant driver of transformation, impacting, among others, employment, productivity, and operational efficiency in the Baltic financial sector. Financial institu-tions and fintech companies have embraced digital banking (Mavlutova *et al*., 2023) and have made substantial investments in technological infrastructure, which has been pivotal in their digital transfor-mation (Kunicina *et al*., 2024). According to Szentmihályi (2023), Estonia, often referred to as the 'dig-ital nation,' has been a leader in this regard. The country has developed a robust digital infrastructure, including e-residency, digital ID cards, and blockchain technology for secure transactions (Espinosa, 2024). According to Raudla *et al.* (2024), Latvia and Lithuania have also made significant strides, with extensive broadband coverage and investments in fintech innovations.

Government policies have played a crucial role in promoting ICT adoption. Estonia's govern-ment has been particularly proactive, implementing policies that encourage digital innovation and entrepreneurship (Espinosa, 2024). For example, the Digital Agenda 2030 for Estonia (2021) aims to enhance the country's digital infrastructure and services. Similarly, Latvia and Lithuania (Bitė *et al*., 2023) have introduced policies to support digitalisation, such as tax incentives for tech startups and investments in digital education.

Our article focuses on Austria, the Czech Republic, Estonia, Latvia, Lithuania, Poland, Slovakia, and Slovenia and compares the impact of ICT on employment and productivity. Estonia and Poland lead in digital transformation, improving operational efficiency and innovation. Other CE countries face chal-lenges like limited digital skills and infrastructure, hindering their digital benefits. Our research inves-tigates these regional disparities in ICT adoption and infrastructure, offering targeted policy recom-mendations based on unique regional challenges and opportunities.

Consequently, we addressed the following research question:

What impact does ICT use have on employment and productivity in the financial sector of the CE and Baltic countries?

Building on the insights from Skare *et al.* (2023), Kádárová *et al.* (2023), Nicolás-Agustín *et al.* (2024), and Raudla *et al.* (2024), we tested three hypotheses:

H1: ICT use in finance leads to job changes, often reducing employment due to automation.

H2: Higher ICT use boosts productivity by enhancing operational efficiency.

H3: ICT's impact on employment and productivity varies between CE and Baltic countries due to regional differences.

RESEARCH METHODOLOGY

We conducted an empirical analysis using a quantitative research design based on data from authoritative sources such as OECD and Eurostat, covering the period from 2005 to the present. The dataset includes key financial sector indicators, particularly employment (number of jobs) and productivity (output per worker). We developed a composite index reflecting various aspects of ICT use, including employee computer and internet usage, business website functionality, use of enterprise software (*e.g.,* ERP, CRM), electronic order processing, and cloud computing adoption. In total, we used 18 variables to construct this index by averaging normalised and weighted values, validated against the DESI index. To control for investment effects, we included Eurostat's financial sector investment data, aligning with our research objectives, as investment significantly influences job creation, digital adoption, and innovation.

Our analysis used two statistical methods. First, we applied a multivariate analysis of variance (MANOVA) to assess the simultaneous effect of ICT use on employment and productivity. We then used ordinary least squares (OLS) regression to focus on how ICT affects employment and productivity individually to examine the specific relationships identified by MANOVA. We chose these methods because they fit our data well and align with our research objectives, allowing us to comprehensively analyse the complex relationships between ICT use, employment, and productivity.

The empirical model used in OLS regression takes the following form:

$$Yi = \beta0 + \beta1(ICT\ Composite\ Index) + \beta2(Financial\ Sector\ Investment) + \epsilon \qquad (1)$$

in which Yi represents employment or productivity as the dependent variable, the ICT composite index is the main independent variable, and financial sector investment serves as the control variable. This model allowed us to quantify the impact of ICT use on employment and productivity while controlling for other influencing factors.

RESULTS AND DISCUSSION

Digital Status of the Regions

The Baltic countries are making progress in digitalisation, Estonia is leading in overall digital performance, Latvia is excelling in connectivity, and Lithuania is strong in digital technology integration (Česnauskė, 2019). The European Commission's Digital Economy and Society Index (DESI) is the main tool for assessing digital progress across various components. Although digitalisation offers opportunities for economic growth and competitiveness, the Baltic countries have not yet fully exploited their potential (Česnauskė, 2019; Eteris, 2020). To address this, these countries are adopting sustainability and digital agenda plans (Eteris, 2020).

While digitisation can boost productivity and competitiveness, e-government services in Central and Eastern European countries remain relatively underdeveloped (Spaček *et al.,* 2020). Digital transformation has a significant impact on international competitiveness in the region (Grynia, 2022), yet enterprise digital maturity varies widely and still lags behind other EU countries (Brodny & Tutak, 2021). Despite differing national strategies and centralisation levels, countries like the Czech Republic, Hungary, and Romania are at similar stages of e-government development (Spaček *et al.,* 2020).

The Baltic countries have made significant progress in digital infrastructure and innovative digital policies. Estonia stands out for leading e-government initiatives and extensive digital literacy programmes. Although CE countries are trying to integrate digital skills into their education and training systems, there are still significant differences in digital infrastructure and resources. Despite efforts to increase digital literacy and promote a broader digital transformation, adoption rates and overall progress are generally slower than in the more developed Baltic countries (Anacka & Lechman, 2023).

DESI 2022 provides valuable insights into the digitisation progress of CE and Baltic countries. These countries show different levels of performance in key areas such as connectivity, digital skills and the application of digital technologies in business (Figure 1).
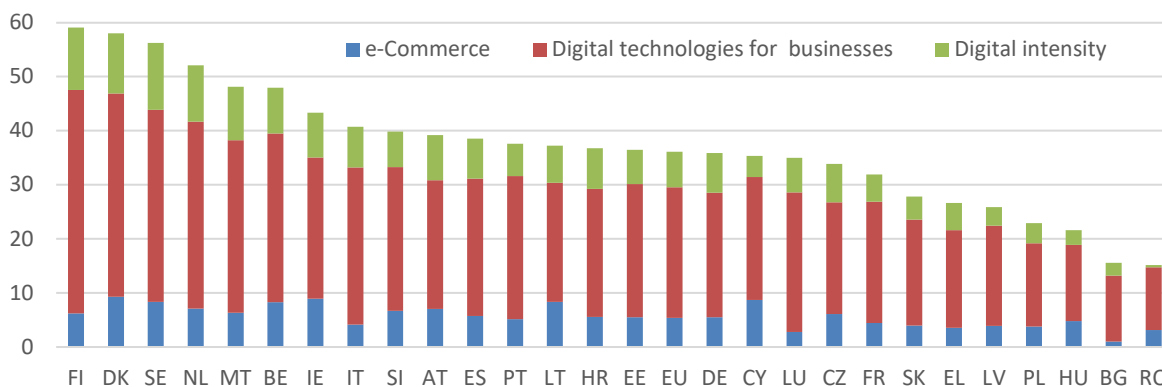
Figure 1. Integration of digital technologies
Source: DESI 2022, European Commission.

The digital landscape of CE and the Baltic countries shows a promising but uneven path towards digital transformation. Connectivity is strong, with Austria, the Czech Republic and Lithuania achieving over 95% broadband coverage, while Estonia excels with a 90% e-government take-up rate, highlighting its advanced digital infrastructure.

The digitalisation of business is changing in a big way. Poland and Slovakia lag, with only 15% of businesses using cloud services, compared to 40% in Estonia. Austria and Lithuania demonstrate strong digital skills, with around 75% of their population having basic digital skills.

Austria and Slovenia lead the way in terms of digital intensity, with many businesses reaching 'high' or 'very high' levels thanks to supportive policies and innovation. In contrast, Poland, Slovakia and Hungary face significant challenges, indicating a need for better infrastructure and digital skills. The Czech Republic has medium digital adoption with growth potential (Figures 1 and 2).
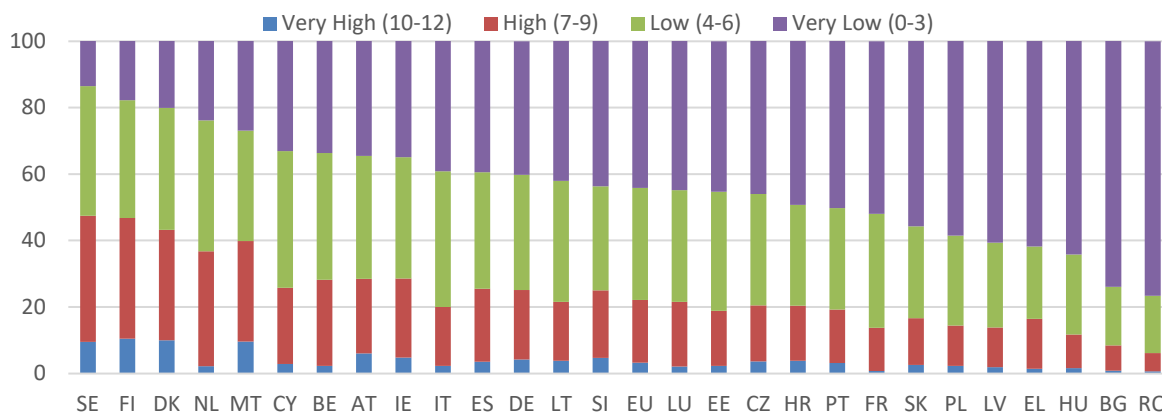
Figure 2. Digital Intensity Index by level (% of enterprises), 2022
Source: Eurostat, European Union survey on ICT usage and e-commerce in enterprises.

DESI 2022 data highlights the need for sustained investment and supportive policies to bridge the digital divide and increase digital competitiveness in the region. Countries like Estonia and Austria demonstrate high adoption of advanced digital technologies, while Lithuania and Slovenia perform well in e-commerce and digital government services. Figure 3 illustrates varied digital technology adoption among businesses in CE and the Baltic countries. The Figure shows Austria, Estonia, and Slovenia lead in digital integration, whereas Hungary, Poland and Latvia lag. The CE region has an average score of 20.03, below the EU average of 24.18, indicating the need for strengthened digital adoption efforts. The Baltic countries show a mixed performance, with Estonia leading the way, while Latvia and Lithuania have lower performances. This disparity reinforces the importance of aligned strategies to bridge the digital divide and promote comprehensive digital transformation in the region.
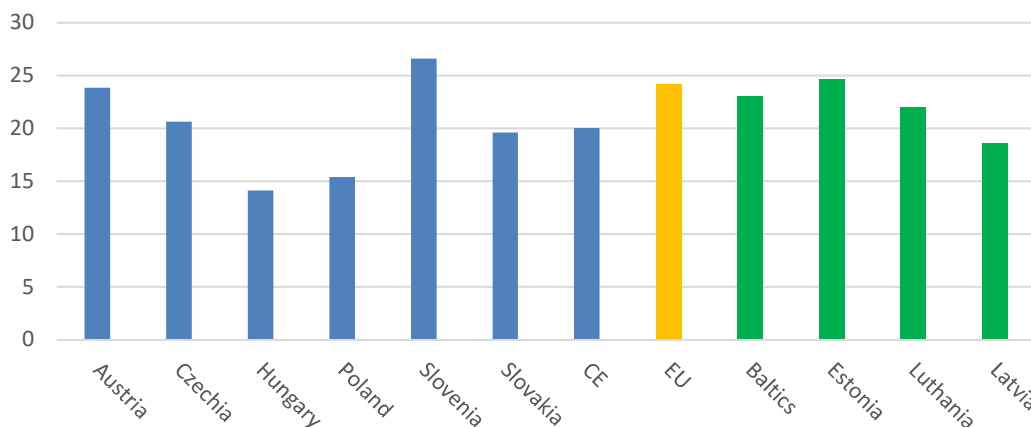
Figure 3. Usage of digital technologies by businesses
Source: own elaboration based on DESI data.

Impact of ICT usage on the regions

The results of MANOVA and OLS regression models provide valuable insights into the impact of ICT use and investment on employment and productivity in the financial sectors of CE and Baltic countries. The analysis shows that the mean and median levels of ICT adoption are generally higher in CE than in the Baltics, suggesting a more advanced use of technology in CE. In contrast, greater variability in ICT use across the Baltic countries may indicate uneven technology infrastructure or investment levels.

We assessed ICT use in the financial sector with various measures reflecting the adoption of digital technology, including the proportion of employees using computers and the Internet, the frequency of digital transactions, investments in ICT infrastructure, and the adoption of advanced digital tools and software. We combined these measures into a standardised composite index to provide a unified view of ICT use across the studied countries.

The data shows a clear upward trend in ICT adoption in all surveyed countries from 2005 to 2023, reflecting a growing commitment to digital transformation. Each country shows steady growth in the percentage of businesses integrating digital technologies, highlighting the benefits of digitalisation such as increased efficiency, competitiveness and innovation. For example, Estonia continues to lead in digital adoption, while Austria and the Czech Republic are also showing strong growth, highlighting their success in promoting a digital-friendly business environment (Figure 4).
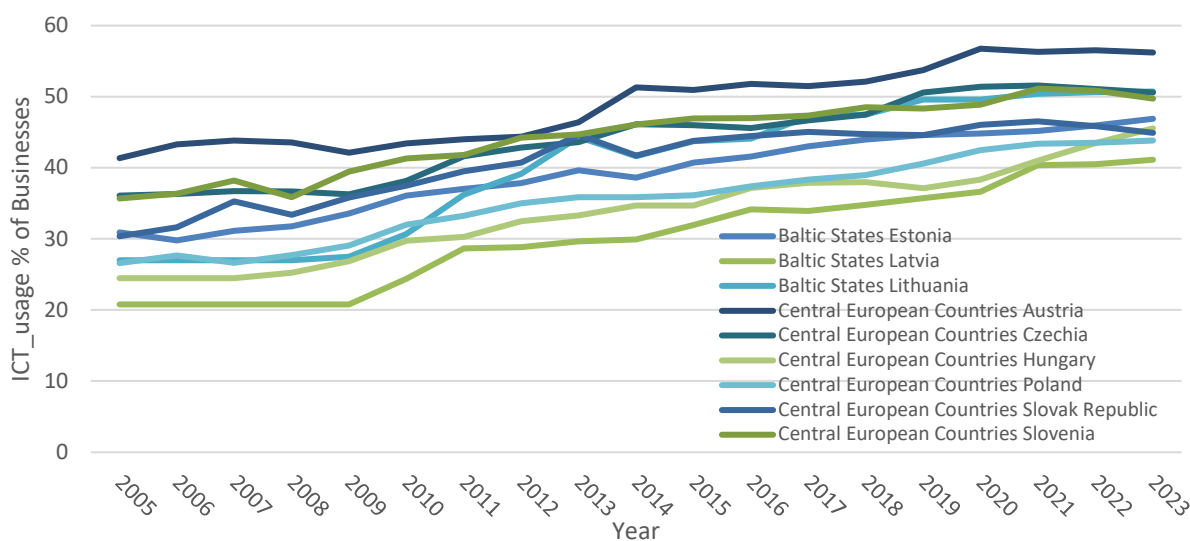
Figure 4. ICT usage in the financial sector
Source: own elaboration.

Along with trends in ICT use, investment patterns also revealed marked regional differences. CE countries exhibited higher average and median investment values than the Baltic countries, suggesting a more developed or wider scope of economic activities and investment opportunities in these regions. In contrast, the Baltic countries showed greater variability in investment levels, which may reflect differences in economic stability and investment practices (Figure 5).
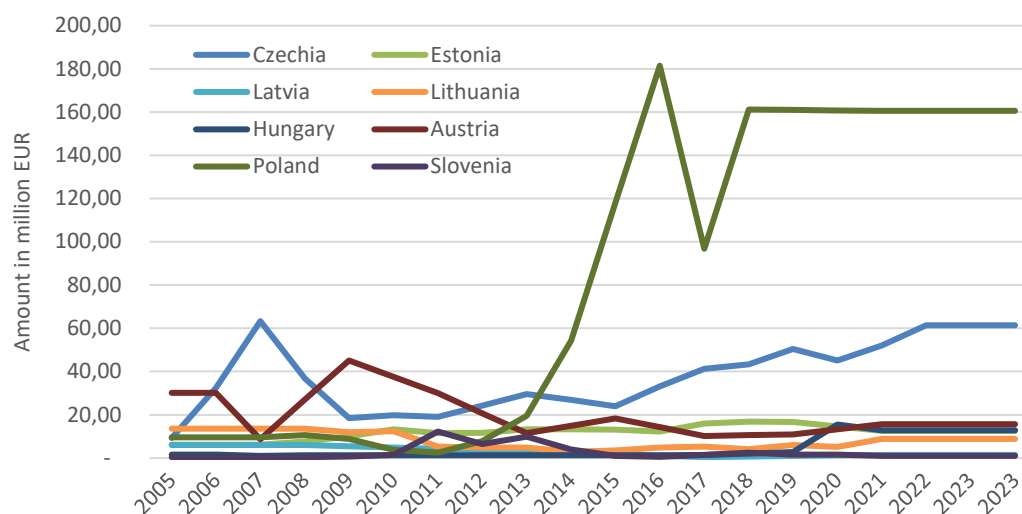
Figure 5. R&D spending by business enterprises
Source: own elaboration based on the Eurostat data.

A comprehensive analysis of the MANOVA results revealed significant findings regarding regional differences and the impact of ICT use and investment on employment and productivity. The overall model fit is robust, with a Wilks' Lambda of 0.7348, an F-value of 30.1391, and a p-value of 0.0000, confirming the model's significance. Additional statistics, *i.e.,* Pillai's Trace (0.2652), Hotelling-Lawley Trace (0.3609), and Roy's Greatest Root (0.3609), further support the presence of strong differences in the multivariate response.

Regarding ICT use, the Wilks' Lambda value of 0.9136 and F-value of 7.8956 indicate a significant effect on employment and productivity, supported by a p-value of 0.0005. Pillai's Trace (0.0864), Hotelling-Lawley Trace (0.0946), and Roy's Greatest Root (0.0946) further confirmed this underscoring the meaningful impact of ICT use.

For investment, the Wilks' Lambda value of 0.4721 and F-value of 93.3530 highlight a significant effect on employment and productivity, with a p-value of 0.0000 indicating a strong effect independent of ICT use. Pillai's Trace (0.5279), Hotelling-Lawley Trace (1.1180), and Roy's Greatest Root (1.1180) further corroborated it emphasizing the substantial role of investment in shaping these dependent variables (Table 1).

The test results indicated a significant overall effect of the model, demonstrating that both ICT use and investment significantly affected employment and productivity. Statistical tests confirm a strong collective effect of the independent variables on the dependent variables with high statistical significance ($p < 0.0001$). This robust significance underscores the relevance of ICT use and investment in explaining changes in employment and productivity.

Examining individual effects, ICT use had a significant impact on the combined dependent variables, as shown by a Wilks' lambda of 0.9136 and an F-value of 7.8956 ($p = 0.0005$). This result highlights ICT's crucial role in affecting employment and productivity, emphasising its importance in digitising the financial sector. Similarly, investment has a substantial effect, with a Wilks' lambda of 0.4721 and an F-value of 93.3530 ($p < 0.0001$), indicating a significant influence on employment and productivity outcomes.

OLS regression models further clarified these relationships. In the employment model, ICT use had a significant negative coefficient of -3.7166 ($p = 0.013$), suggesting that each unit increase in ICT use was associated with a decrease in employment of approximately 3.72 units. This negative relationship

likely reflects the role of digitisation in automating processes and enhancing efficiency, thereby reducing labour demand in the financial sector. Conversely, the investment coefficient had a significant positive effect on employment, with a value of 4.6265 (p < 0.0001), indicating that each unit increase in investment correlates with an increase in employment of about 4.63 units, supporting the idea that financial resources facilitate job creation and sector expansion.

Table 1. MANOVA model results

Group	Measure	Value	Num DF	Den DF	F Value	Pr > F
Intercept	Wilks' lambda	0.735	2.0000	167.0000	30.139	0.0000
	Pillai's trace	0.265	2.0000	167.0000	30.139	0.0000
	Hotelling-Lawley trace	0.361	2.0000	167.0000	30.139	0.0000
	Roy's greatest root	0.361	2.0000	167.0000	30.139	0.0000
ICT usage	Wilks' lambda	0.914	2.0000	167.0000	7.8956	0.0005
	Pillai's trace	0.086	2.0000	167.0000	7.8956	0.0005
	Hotelling-Lawley trace	0.095	2.0000	167.0000	7.8956	0.0005
	Roy's greatest root	0.095	2.0000	167.0000	7.8956	0.0005
Investment	Wilks' lambda	0.472	2.0000	167.0000	93.353	0.0000
	Pillai's trace	0.528	2.0000	167.0000	93.353	0.0000
	Hotelling-Lawley trace	1.1180	2.0000	167.0000	93.353	0.0000
	Roy's greatest root	1.1180	2.0000	167.0000	93.353	0.0000

Source: own study.

The OLS regression on productivity showed that ICT use is positively associated with productivity, with a coefficient of 0.8537 (p = 0.001), indicating that productivity rises by approximately 0.85 units for each unit increase in ICT use. This positive relationship highlights the role of digitisation in boosting efficiency and productivity in the financial sector. Similarly, the investment coefficient had a significant effect on productivity, with a value of 0.2183 (p = 0.001), suggesting that productivity increased by about 0.22 units for each unit increase in investment, highlighting the positive contribution of investment to productivity levels in the analysed context (Table 2.)

The analysis revealed the complex relationship between ICT use and investment in the financial sector. While ICT adoption is associated with increased productivity, it is also associated with reduced employment due to automation of tasks and optimization of processes. This dual effect emphasises ICT as a means of increasing efficiency but raises concerns about changing jobs. Conversely, investments play a positive role in job creation and sector expansion, although they do not significantly affect productivity, suggesting that increasing financial capital alone does not necessarily lead to higher output per worker.

Regionally, CE exhibited higher and more stable productivity levels, reflecting their developed economic infrastructure and stable economic environment. In contrast, the Baltics showed greater variability in productivity, which may indicate underlying economic challenges or a mismatch in investment and technology adoption.

We rejected the hypotheses that ICT use and investment have no significant effect on employment and productivity. Our findings show that **ICT use significantly reduces jobs** due to automation while **enhancing productivity**, and that **investment positively affects employment** while **significantly boosting productivity**.

Figures 6 and 7 depict regional differences in employment and productivity in the sector. Descriptive statistics show an upward trend in productivity in CE countries, while the Baltic countries exhibit variable productivity levels, remaining relatively stable over the period. This stability is primarily influenced by Latvia and Lithuania, which lag behind Estonia in digitisation and technological adoption. Estonia's success in digitisation suggests that Latvia and Lithuania should adopt similar strategies to increase their productivity. Noteworthy, investment levels vary across regions, with significantly higher average investment rates in CE (3 times on average over the period), where businesses tripled sector investment compared to the Baltic countries.

Table 2. OLS Regression results

Dep. Variable:	Productivity	R-squared:	0.137		Employment	R-squared:	0.498	
Model:	OLS	Adj. R-squared:	0.127		OLS	Adj. R-squared:	0.492	
Method:	Least Squares	F-statistic:	13.39		Least Squares	F-statistic:	83.35	
Date:	Fri, 02 Aug 2025	Prob (F-statistic):	4.03E-06		Fri, 02 Aug 2025	Prob (F-statistic):	7.17E-26	
Time:	16:16:12	Log-Likelihood:	-809.64		16:16:12	Log-Likelihood:	-1108.4	
No. Observations:	171	AIC:	1625		171	AIC:	2223	
Df Residuals:	168	BIC:	1635		168	BIC:	2232	
Df Model:	2				2			
Covariance Type:	nonrobust				nonrobust			
	coef	std err t	P>|t|	[0.025 0.975]	coef	std err t	P>|t|	[0.025 0.975]
const	64.8382	10.353 6.263	0.000	44.400 85.277	240.6554	59.417 4.05	0.000	123.355 357.956
ICT_usage	0.8537	0.258 3.308	0.001	0.344 1.363	-3.7166	1.481 -2.509	0.013	-6.641 -0.793
Investment	0.2183	0.063 3.49	0.001	0.095 0.342	4.6265	0.359 12.889	0.000	3.918 5.335
Omnibus:	75.044	Durbin-Watson:	1.927		92.169	Durbin-Watson:	1.831	
Prob (Omnibus):	0.000	Jarque-Bera (JB):	422.080		0.000	Jarque-Bera (JB):	345.778	
Skew:	1.519	Prob (JB):	2.22E-92		2.195	Prob (JB):	8.23E-76	
Kurtosis:	10.072	Cond. No.	237		8.409	Cond. No.	237	

Source: own study.
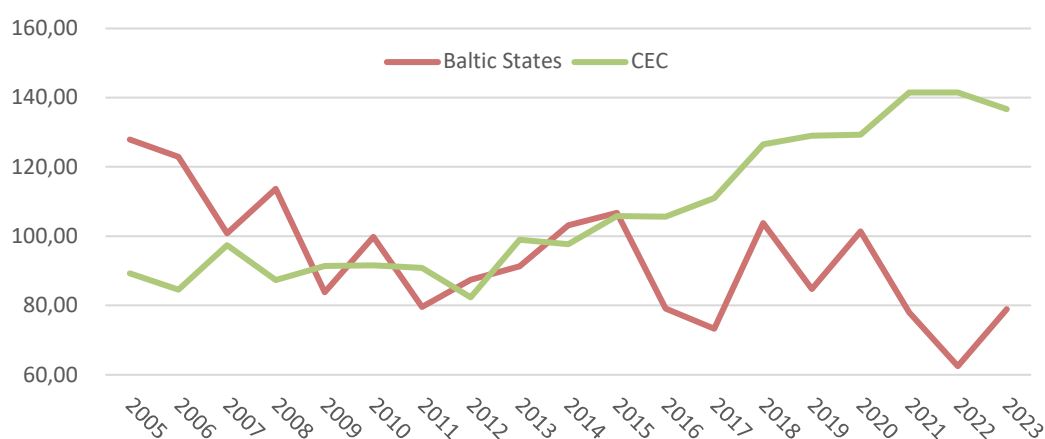
Figure 6. Average productivity in the regions
Source: own elaboration based on the OECD data.

This disparity in investment levels is likely to have different effects on productivity across these regions. The test results further confirm that employment trends differ between regions. CE shows a slight downward trend in employment, while the Baltics show more dynamic results with an ever increasing trend in recent years. These changes are likely influenced by different national strategies and other factors not controlled in the study, such as overall economic and political performance.
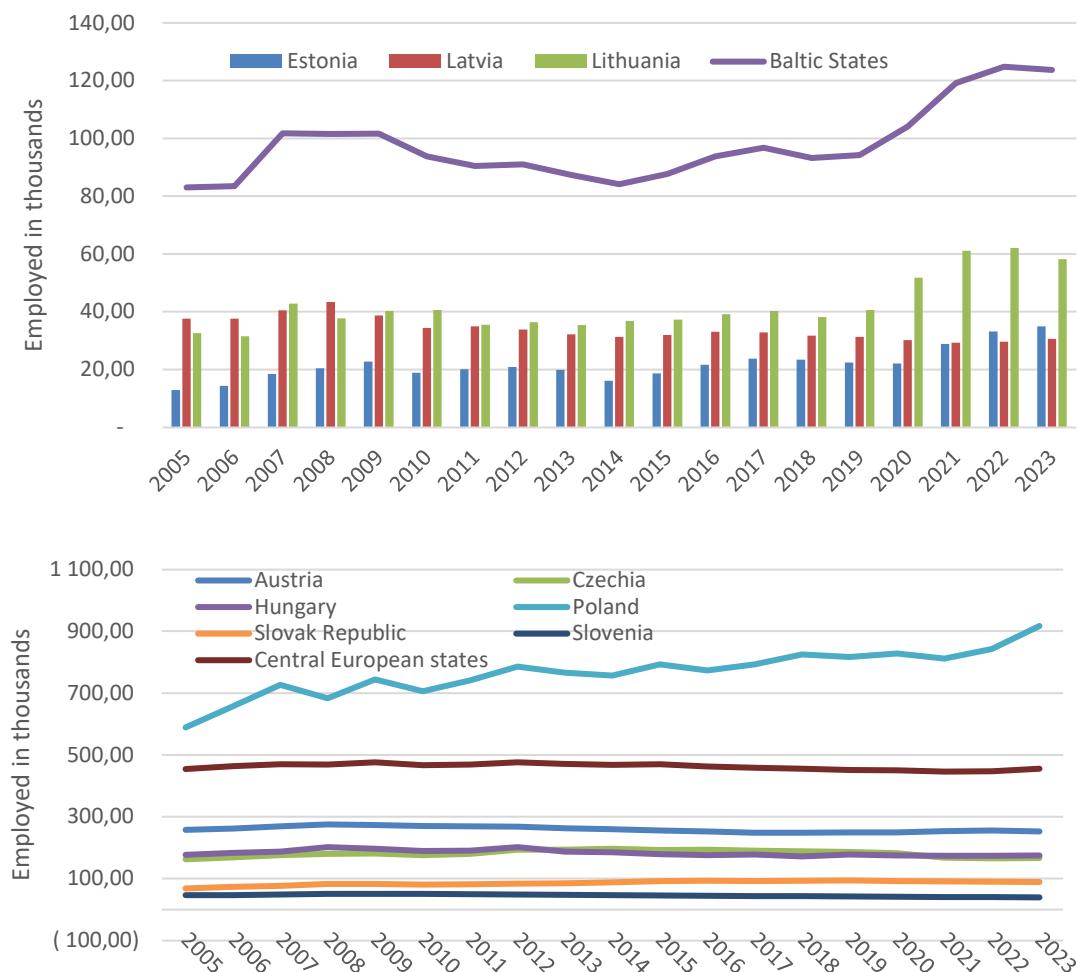
Figure 7. Employment by business enterprises in the regions
Source: own elaboration based on the OECD data.

Based on the results, we acknowledge several study limitations. Variations in data availability and quality across sources may affect result comparability and introduce inconsistencies. We addressed missing data for certain variables, particularly in the early years, for Latvia and Lithuania using interpolation. Our reliance on cross-sectional data limited the ability to establish causality or analyse trends. The indicators used to measure digital technology adoption may not fully capture the complexity and impact of digital transformation within enterprises. Regional differences in digitisation between CE and Baltic countries may influence the results and require further analysis to understand local contexts. We also did not fully account for the economic and political environments, which may affect digital adoption and effectiveness. Due to data limitations, we could not perform separate OLS and MANOVA analyses for the Baltic countries, restricting these to CE and potentially limiting generalizability.

Our article aims to understand the impact of digitalisation on employment and productivity. The consensus in the literature (Olaniyi *et al.*, 2024; Sheth *et al.*, 2022) is that digitalisation enhances productivity and operational efficiency but also creates challenges related to workforce displacement and skill gaps (Kaur *et al.*, 2023; Hellweg & Schneider, 2023).

The Baltic countries, particularly Estonia, have been pioneers in digital transformation. In contrast, CE has seen varied progress, with some countries advancing rapidly and others lagging due to bureaucratic hurdles. This variation illustrates the influence of cultural, economic, and political factors on technological diffusion, aligning with the diffusion of innovations theory (Acikgoz *et al.*, 2023).

Despite regional differences, both CE and the Baltic countries face common challenges like workforce displacement and the need for continuous upskilling, as well as opportunities for new job creation, enhanced productivity, and economic growth driven by digital innovation.

CONCLUSIONS

This article provides an in-depth examination of digitisation's impact, particularly using ICT, on employment and productivity in the financial sector across CE countries and the Baltic countries. The MANOVA results unambiguously show that both regional differences and the independent variables – ICT use and investment – significantly affect employment and productivity. CE countries generally exhibit higher levels of employment and productivity than their Baltic counterparts, highlighting regional differences in economic conditions and labour market dynamics.

The analysis shows that the use of ICT has a major impact on productivity, highlighting the transformative potential of digital technologies in enhancing sector performance. However, this advancement in ICT has also been associated with declining employment levels, raising concerns about potential job displacement.

Conversely, investments in the financial sector are shown to have a positive effect on employment, reinforcing the importance of capital flows in job creation and sector expansion. This finding highlights the crucial role of financial investment in supporting employment growth. Nevertheless, the analysis shows that investments do not have a significant direct effect on productivity. This observation suggests that while capital investment is vital to job creation, it alone does not guarantee an increase in output per worker. It emphasises the need for a strategic investment approach, where financial resources are aligned with other productivity-enhancing factors.

Digitalisation, particularly through ICT, enhances productivity and operational efficiency but reveals notable regional differences in adoption. This study builds on existing theories by comparing CE and Baltic countries, highlighting the need for context-specific digital strategies. Bridging these regional gaps requires tailored policy interventions. Central European policymakers could draw on successful Baltic strategies, such as Estonia's e-government initiatives and digital literacy programmes, to overcome bureaucratic barriers and accelerate digital transformation.

Recommendations

The findings suggest that supportive regulatory frameworks and proactive digital policies are essential. The focus must shift to investing in digital infrastructure such as high-speed internet access and secured digital platforms. Implementing educational programmes to enhance digital skills across all age groups can help bridge the skills gap.

This includes integrating digital literacy into school curriculums and offering adult education programmes. Providing social safety nets and retraining programmes for displaced workers can help mitigate the negative impacts of digitalisation. Policies should encourage continuous learning and adaptability. Encouraging a culture that embraces digital innovation and continuous learning (upskilling and reskilling) is crucial. Being open to new roles and responsibilities can help employees navigate the changing job landscape. Developing soft skills such as problem-solving and critical thinking is also beneficial.

Avenues for Further Research

Despite the valuable insights, there are gaps in the research that require further exploration. One notable gap is the long-term impact of digitalisation on employment patterns and job quality. While short-term effects are well-documented, longitudinal studies could provide a deeper understanding of how digitalisation reshapes the labour market over time. Moreover, more research is needed on the effectiveness of various policy interventions in bridging the digital skills gap and supporting workforce transitions. Comparative studies across different regions and sectors could also shed light on best practices and successful strategies for managing digital transformation. The impact of ICT usage in the regions in more detail can also be a topic for further research.

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Use of Artificial Intelligence

The manuscript is free from AI usage.

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Understanding artificial intelligence chatbot quality and experience: A higher education student perspective

Ines Dužević, Tomislav Baković, Vivien Surman

A B S T R A C T
Objective: The article aims to identify the key aspects that define service quality for artificial intelligence chatbots (AICB) in higher education, based on insights from students. The second objective is to put AICB quality into the broader context of other key variables associated with student experience of AICB, such as AICB adoption, AICB usability, AICB engagement, and AICB mistrust.
Research Design & Methods: Based on extant service quality research and established scale development techniques, the study constructs, refines, and validates a multidimensional AICB service quality scale through a series of pilot and validation studies. The article includes both qualitative and quantitative technics, as we developed a questionnaire based on a literature review and 48 mini focus group interviews. In total, 308 participants filled out the questionnaire. For the analyses, we applied both exploratory and confirmatory factor analysis together with scale validation and correlation analysis.
Findings: We began the AICB service quality scale with 27 items across five dimensions: AICB quality, AICB mistrust, AICB usability, AICB adoption, and AICB engagement. The final scale consisted of 15 items across four dimensions with only AI engagement left out. Data analysis emphasised the critical role of AI quality in AI usability and AI adoption. The research also confirmed AI mistrust is an important aspect with a negative connection to AI quality.
Implications & Recommendations: The study results have several theoretical and practical implications. From the theoretical standpoint, we confirmed that the quality of artificial intelligence (AI) plays a central role in forming student experience. Quality of AICB received the highest score in this analysis (5.03) while AICB mistrust scored lowest (3.58). On the other hand, when it comes to individual correlations between student experience elements and AICB quality, mistrust in AICB shows a negative correlation with the highest score (-0.48). Use and adoption are both connected to AICB quality in a positive way. Results show us there is room for improvement in both AICB quality and student experience since average scores were in the range of 4.5-5.0. The results also emphasised the importance of reducing AICB mistrust for improving AICB quality and overall experience.
Contribution & Value Added: The AICB quality scale facilitates theory development by providing a reliable scale to improve the current understanding of student perceptions regarding different aspects of AICB quality. Higher education institutions (HEI) can use the study results to understand the impact of new technologies such as AICB on student experiences.

Article type:	research article
Keywords:	artificial intelligence (AI); chatbots; artificial intelligence chatbots (AICB); AICB experience; AICB quality; higher education
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INTRODUCTION

Higher education institutions (HEIs) function as service providers, they are under extensive pressure to satisfy the needs and expectations of various stakeholders, mainly customers. In the higher education system, students are the primary customers, as they directly engage with educational services, invest in their learning, and ultimately benefit from the acquired knowledge and skills (Eagle & Brennan, 2007). Therefore, this article examines students as customers. Higher education institutions look for opportunities that allow for an increase in institutional performance and related satisfaction. The growing competition at both the national and international levels, the increase in the number of HEIs, the growing demand for domestic institutions to appear on the international scene, as well as the need to increase their competitiveness, require institutional management to pay more attention to the education services quality and the students' expectations. The application of AI into education processes has a significant influence on both institutional performance and student satisfaction. However, there is limited literature on measuring AICB service quality and experience in HEIs.

With the widespread adoption of AI services in every aspect of business and life, it is important to explore its quality aspects and monitor its performance by developing valid measurement scales. According to the quality management literature, understanding the voice of the customers is the basis for quality enhancement. Therefore, the state-of-the-art has already started to pay attention to the implementation of different methods to explore customer experiences with AI services (Marimon *et al.*, 2024; Noor *et al.*, 2022; Prentice, 2023; Qian *et al.*, 2022). However, there is a need for further research and development of comprehensive instruments focusing on this field (Cox, 2021).

The implementation of AI in higher education (HE) is spreading immensely, highlighting many new challenges (biases in datasets and algorithms, plagiarism, and privacy concerns) and opportunities (increasing stakeholder satisfaction). According to Hannan and Liu (2023), AI has the potential to reshape HEIs in various ways. It changes the roles of students and teachers in the education system (Blau & Shamir-Inbal, 2018; Niemi, 2020; Ali *et al.*, 2021). Perception of students' role in HE evolved from passive consumers to the users whose needs must be identified and satisfied, and finally to the active participants in the teaching and learning process who equally participate in all processes (Duzević *et al.*, 2018). The new role of students is even more important considering the technology development and evolution of new teaching and learning models, based on AI. Students are offered different AI-based services for learning and research purposes, and with good preparation and guidelines this could increase the effectiveness and productivity of the educational processes (Liu *et al.*, 2022). Therefore, understanding the student experience is crucial for enhancing HE service quality.

One of the areas in which AI services are used is certainly AI chat tools or chatbots. The use of AI in HE is becoming increasingly popular (Dempere *et al.*, 2023; Rudolph *et al.*, 2023; Neuman *et al.*, 2023), but it is not yet possible to speak of mass application. Chat tools for individual courses and some universities as a whole are still a long way from being an industry standard (Heryandi, 2020). Many studies look at the implementation process and related experiences with AI chat tools in HE and show that students adopt them very quickly (Crawford *et al.*, 2023). For this reason, we focused on the broader question of how students perceive the quality of services offered by AICB (AI-based chatbots, especially Chat GPT) and their current experiences.

This article aims to examine services, including AICBs, as conventional services and assess their quality comprehensively. As students increasingly demand higher standards and play a more active role in shaping HE services, it becomes essential for HEIs to align their processes with student expectations. Noteworthy, AICB services are now integral to the teaching and learning experience, necessitating rigorous evaluation and quality measurement. To this end, we employed mixed-method approaches to develop and validate a reliable scale for assessing AICB service quality. This scale offers valuable insights for HE professionals in evaluating AICB performance and assists developers in identifying and addressing specific user needs and expectations.

Our research questions were the following:

RQ1:   What are the key dimensions for assessing the quality of AICB for students in HE?

RQ2:   What is the connection between AICB quality and other key aspects of AICB experience?

The article is structured as follows. The subsequent section presents a review of the relevant literature, emphasizing key aspects of service quality in higher education from the customer perspective, the integration of artificial intelligence in HE services, and the associated dimensions of AI-enabled service quality. The following section outlines the research methodology, detailing the development of the survey instrument and the procedures employed for data collection. Thereafter, we present the principal findings, followed by a critical discussion that contextualizes the results within the existing body of literature. Finally, the article concludes by summarizing the key outcomes of the research and outlining implications for future studies.

LITERATURE REVIEW

This part of the article discusses the key concepts namely: customer experience, AI services and the problem of measuring their quality.

Customer Experience and Service Quality in HE

With the development of HE, the focus is on the needs and expectations of students and other direct stakeholders. The increasingly intense competition for potential students makes it necessary to measure, evaluate, and provide feedback on the appropriate aspects of student experiences, perceptions, and satisfaction with adequate methods (Elsharnouby, 2015; Tóth & Surman, 2019). Scholars study students' experience within different fields and determine it as a very complex area connected to service quality. From the student life cycle perspective, it can be explored based on the freshman experiences (Kahu & Nelson, 2018), career development (Stiwne & Jungert, 2010), student engagement (Close, 2018; Kuh, 1995), student development (Surman *et al.*, 2022) and participation in extracurricular activities (Dean & Gibbs, 2015; Bakoban & Aljarallah, 2015).

In the last 25 years, the research focus in the quality management field moved towards customer experiences (Tan *et al.*, 2016). The primary focus is to identify the areas and processes in HE that affect students' development and growth and to define the institutional practices that can improve study experiences (Hong *et al.*, 2020). Considering the topic's complexity and different perspectives, research can explore the student experiences through three dimensions: the social dimension which includes the relationship between students and different subjects they meet during student life, the educational dimension containing all the factors related to the teaching and learning, and personal dimension which focuses on different aspects of student life. To summarise, we may define student experience as the physical and emotional perceptions that students feel during the interactions with products, systems or services provided by the HEIs and interactions with persons that are related to the academic environment (Matus *et al.*, 2021).

The modern HE system is based on innovative teaching and learning techniques and the use of technology to enhance student experiences and provide student support. AI-based support systems have the potential to significantly improve the productivity and effectiveness of all educational processes. Therefore, it is of utmost importance to explore student perceptions and experiences. Our study contributes to a nuanced understanding of student perspectives, serving as a foundational resource for further explorations and strategic integrations of AI within HE systems.

The Use of AI Services in HE

Artificial intelligence is a technology that enables systems or machines to imitate the behaviour of intelligent beings (Poole & Mackworth, 2010). It is a multidisciplinary field that aims to understand the functioning of human minds and apply the same principles in technology design. We may expect many changes in HE based on AI implementation, as today, the use of AI in the classroom is becoming an integral part of the learning process (Goralski & Tan, 2020). Scholars explore the application of

modern technology in HE mainly through the new role of the students, as they increasingly become active and independent participants in educational processes (Bedzsula & Tóth, 2019). They became partners in these processes with their participation in designing content, teaching-learning experiences and outcomes, and assessing the learning outcomes (Blau & Shamir-Inbal, 2018). Accordingly, the teacher's role is also changing in such a way that in digital pedagogy the emphasis is on facilitating and guiding students (Niemi, 2021). These changes bring new opportunities for enhancing educational processes. The use of AI tools has the potential to increase teaching effectiveness, optimise the curriculum, and encourage students to deep learning (Liu *et al.*, 2022). Moreover, AI can imitate the role of both the teacher and the student (Dodigovic, 2007) and possibly replace the teacher (Goralski & Tan, 2020). Chen *et al.* (2020) highlight that the implementation of AI in HE has started as computer technologies, and transferred into web-based online education services, and the newest transformation is into humanoid robots and chatbots that serve as educators independently of the instructors. The use of AI could make it easier to perform different administrative tasks, such as assessment and grading of student work, curriculum customization and review of other teaching materials (Chen *et al.*, 2020) and improve assessments to better prepare students for careers (Slimi & Carballido, 2023). Therefore, it is necessary to reshape the HE system because otherwise, people will no longer see it as a means of employment or career development (Siau, 2017). Moreover, AI can improve the studying experience through the customization of international student support. By 2025 the number of international students will increase to 8 million, and this trend brings challenges such as language barriers, cultural differences, or specificities of the local education system. AI can play an important role in solving these issues (Wang *et al.*, 2023; Marcus *et al.*, 2023). Academic counselling is another possibility, but it is still in the testing phase (Khare *et al.*, 2018).

The implementation of AICBs in HE presents many challenges and concerns (Westman *et al.*, 2024). These include concerns about data privacy, over-reliance on AI and erosion of critical thinking skills (Duran, 2024), reduced human interactions (Duran, 2024), potential algorithmic bias and plagiarism risk (Williams, 2024), transparency, reliability, and access equity (Al-Zahrani, 2024). Maeda and Quan-Haase (2024) emphasise the negative consequences of anthropomorphised chatbots that play social roles and often just want to earn the trust of their human users, while this trust can potentially be misused and opens a series of ethical questions like sensitive information leaks etc. These negative aspects of AICB implementation in HE resulted in mistrust and prejudice that represent a critical barrier to the full realization of the technology's potential (Hutson & Plate, 2024). Therefore, there is a need for balanced regulation of AICBs application in HE to ensure thoughtful and responsible integration of AICBs within HEIs (Dempere *et al.*, 2023).

To summarise, the influence of AI on the HE system is complex and multifaceted. The number of research papers that use concrete indicators is very limited since AI is developing rapidly. There is a need for additional research on AI effects on HE systems using a comprehensive approach that integrates different research areas (Cox, 2021). The future development of HE will certainly include different AI-based tools. Therefore, it is important to explore students' expectations and perceptions of widely available AI tools, and based on that, monitor the service quality performance.

The primary focus of this article is the direct students' attitude and experience with publicly available AI-based tools, highlighting the AICB. We centred the research on AICB because they are adopted by users at a rapid pace including many university students, who found them very useful for everyday study purposes (Dempere *et al.*, 2023; Rudolph *et al.*, 2023; Crawford *et al.,* 2023; Neumann *et al.*, 2023). Furthermore, HEIs will eventually need to offer their versions of AICB at different levels resulting from the changing customer needs (Hien *et al.*, 2018; Heryandi, 2020). However, it seems that the rapid adoption of commercialised AICB like ChatGPT has shifted the focus from developing customised AICB to investigating what is the best way of using the ones that are already available to students in the context of HE (Rudolph *et al.*, 2023).

Measuring AI Service Quality Dimensions

The measurement process and dimensions of service quality differs between sectors. According to the literature, when focusing on technology, service quality should include perceived quality dimensions

and dimensions related to technology dissemination. As Dou *et al.* (2024) presented, the incorporation of AI into various processes could strategically influence the performance and the value created, therefore, its service quality evaluation is very important. Yan *et al.* (2023) highlighted that user service and information security are some of the main factors related to AI service quality measurement. There are various scales for measuring AICB service quality, based on different dimensions (Alwagdani, 2024; Grassini, 2023; Jabborow *et al.*, 2023; Lazar *et al.*, 2020; Lupo & Buscarino, 2021; Kim-Soon *et al.*, 2014; Noor *et al.*, 2022; Prentice, 2023; Qian *et al.,* 2022; Scharowski *et al.*, 2024; Westman *et al.*, 2021). Most of the scales are derived from the E-S-QUAL scale for assessing electronic service quality with the following variables: efficiency, system availability, fulfilment, and privacy (Parasuraman *et al.*, 2005). Prentice (2023) developed a scale specific to AI application as a service with the following dimensions: reliability, assurance, tangibility, empathy, and responsiveness. A study by Noor *et al.* (2022) focused on AICB service quality and used a scale with seven second-order and eighteen first-order constructs. The authors found a positive influence on customer satisfaction, perceived value, and intention of continuous use of AICBs. Moreover, Qian *et al.* (2022) proposed a multidimensional scale to evaluate service quality across AI service agents with dimensions such as efficiency, security, availability, enjoyment, contact, and anthropomorphism. Although each article focused on different special areas, part of their conclusions were the same: more and deeper research is needed to discover and validly measure the service quality of AI in general.

Scholars usually conduct studies with AI in HE focus concerning web-based online education service quality. These studies are based on the technology acceptance model (TAM) developed by Davis (1989). The model suggests that perceived ease of use is an antecedent of perceived usefulness which directly influences IT system usage. Lupo and Buscarino (2021) developed an effective measurement tool considering the students' perspectives and revealed the three-factor structure, including usability, security, and fundamental content. Kim-Soon *et al.* (2014) extracted the following dimensions: availability, convenience, organised interface, ease of use, meeting needs, and schedule flexibility. Meanwhile, Al-Mughairi and Bhaskar (2024) did not exactly deal with the service quality aspect of AI in HE, however, their findings give input to the determination of these dimensions. They presented that the main motivating factors of using AI in teaching (by the teachers) are the exploration of innovative education technologies, the personalization of teaching and learning, time-saving and the support in professional development. The inhibiting factors included the reliability and accuracy concerns, the reduced human interaction, the privacy and data security problems, the lack of institutional support and the possible overreliance on them. Pereira *et al.* (2023), Hamam (2021) and Huddar *et al.* (2020) studied the HE AICBs demonstrating that they play a significant role in the digital transformation of education, offering support for university education and providing individualised experiences for students. They pinpointed that they improve teaching and learning, increase student engagement, and provide 24/7 availability for answering queries. Since AI-based services are largely incorporated into HE processes, there is a need to develop a comprehensive and reliable instrument for measuring its quality from the perspective of students.

Another stream of literature (Chadha, 2024; Maeda & Quan-Haase, 2024; Lazar *et al.*, 2020) focuses more on variables closer to customer experience with AI. Chadha (2024) analysed AI-driven personalised learning systems through case studies, showing how they improve student engagement and tailor educational experiences, while also addressing concerns about fairness and accessibility.

As we may see from previous research they are mostly oriented on developing scales for measuring AI quality or they analyse customer experiences. In this article, we focus on connecting these two areas of research. One may assess AICB service quality as any other service, more precisely, user perceptions and experiences can serve to define key dimensions of AICB service quality, considering both the quality of the technology and its dissemination.

RESEARCH METHODOLOGY

Our study aimed to determine core elements that could represent the variables of AI quality related to chatbots and put these variables into the broader context of customer experience. The research

contained the following steps (Figure 1). Based on the literature review, we determined the main service quality elements related to the HE student perspectives of AI. Then, we conducted 48 mini-focus groups to understand these elements more deeply and complete the list of AI service quality factors. As a result of the literature review and focus group interviews, we developed an online questionnaire and shared it with the students of the Faculty of Economics and Business. Based on the collected data exploratory factor analysis (EFA), and confirmatory factor analysis (CFA), we performed scale reliability analysis and correlation analysis.
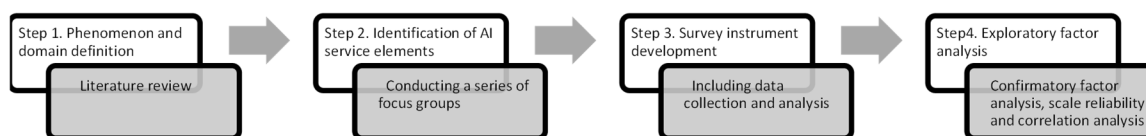
Figure 1. Outline of research methodology
Source: own elaboration.

Identification of AI Service Elements

We conducted the focus group interviews in September and delved into the perceptions and perspectives of 222 HE students regarding the incorporation of AI within the realm of academia. Employing a structured approach through 48 mini-focus groups, consisting of 4-6 participants each, we sought to elucidate three critical dimensions of AI's role in HE.

Defining Quality in AI Operations

We prompted students to articulate their understanding of quality in AI operations, resulting in the identification and delineation of a comprehensive array of 192 distinct quality dimensions. Participants highlighted speed and accuracy as top priorities regarding the quality of AI. Many students pinpointed the reliability and validity of the information provided by the AI. Therefore, the incorporation of AI in the operation of various frameworks should handle these two dimensions on a high level, since their absence would fundamentally deteriorate the effectiveness of the implementation, the users' experience and commitment as well.

Artificial Intelligence's Role in Institutional Operations

The study sought to extract insights into the perceived utility and applicability of AI within the operational framework of HEIs. Participants delineated 116 potential use cases, outlining a diverse spectrum of applications spanning administrative, pedagogical, and operational facets (most of which the literature pinpointed as well). Students saw the support provided by AI in many institutional areas. According to the responses, it could help in optimal timetable planning (from both students' and lecturers' points of view), task design, case study and exams, as well as, in the correction of them. Students pointed to the help of administrative activities and frequently asked questions operation. They also saw its relevance in the improvement of presentation slideshows and the support of research work.

Artificial Intelligence's Support in HE Studies

We encouraged participants to envision scenarios where AI could serve as a facilitative tool in augmenting their HE pursuits. This elicited 125 scenarios, highlighting the students' perspectives on the potential integration of AI as a supportive mechanism in academic endeavours, including personalised learning aids and advanced research assistance. Mainly, students would use AI to improve their thesis works, and their essays and to help their preparation for the exams. Moreover, they would implement it in an AICB to aid the student life on the university campus.

As highlighted, the students participating in these focus groups worked mainly alone on the received three topics, the primary work of the moderators was to start or continue the discussion along the results of the literature analysis, whether it stops or gets stuck, and to gain a deeper understanding of the highlighted aspects and dimensions to prepare the questionnaire.

Survey Instrument Development

We created the survey in view of the performed focus groups and literature review. The question-naire included five phases with 37 questions each measured on a Likert scale from 1 to 7 (for the questions see Appendix).

The first phase focused on the student experience of quality dimensions pinpointed by previous re-search: accuracy, reliability, efficiency, scalability/objectivity, interoperability, adaptability, design and context, min. error or biases (eight questions). For deriving these questions, we used the work of Jab-borow *et al.* (2023) which delves into quality assessment metrics for AI-based systems. Noor *et al.* (2022) also performed a study on the service quality scale for AI service agents and we used those results to define our questions. The second phase included AICB mistrust (six questions). To develop these ques-tions, we used the work of Scharowski *et al.* (2024) whose study highlights the need to differentiate between the measures of AI trust and AI mistrust. We primarily derived the usability of AICB (nine ques-tions) from Westman *et al.* (2021) although their primary focus was developing AI for career guidance. The fourth phase concentrated on AICB engagement (ten questions). For deriving the questions about engagement, we used the work of several authors (Maeda & Quan-Haase, 2024; Grassini, 2023; West-man *et al.*, 2021). The last phase focused on AICB adoption (four questions). The standpoint from which scholars addressed AI adoption differed from author to author: attitude towards AI (Grassini, 2023), using the technology acceptance model (TAM) as a starting point (Lazar *et al.*, 2020), and using AI as a career guiding tool (Westman *et al.*, 2021). When defining questions, a distinction between usability and en-gagement needs to be made. Under usability, we primarily focused on the reasons why the students are using AICB while under engagement more focus is on how they use them. Usability resolves around how well AICB does certain tasks (Weichbroth, 2020) while engagement covers more fundamental changes based on preferences and behaviours (Prentice *et al.*, 2020).

Data Collection

We researched a sample of students from the Faculty of Economics and Business, University of Zagreb. We created the questionnaire using an online platform and distributed it to students who actively attended classes during the winter semester of the academic year 2023/2024. The sample included students from undergraduate and graduate programs. We distributed the questionnaire to 1000 stu-dents, and after sending two reminders, we received 308 properly completed questionnaires. One of the questions eliminated those students who did not have proper experience with AI tools, and for that reason, we performed further analyses with 235 answers. The survey responses allowed us to conduct EFA with the statistical package for social sciences (SPSS 25) software.

RESULTS AND DISCUSSION

Primarily, this article aimed to identify the key aspects that define service quality for AI chatbots in higher education. Additionally, it is possible to put AI quality into the broader context of other key variables associated with student experience of AICB, such as AICB adoption, AICB usability, AICB en-gagement, and AICB mistrust. Table 1 presents descriptive statistics for the analysed variables.

Exploratory Factor Analysis

Exploratory factor analysis (EFA) allows researchers to explore the underlying structure of service quality by identifying patterns in data. It can reveal latent factors that represent key components (Bartholomew *et al.*, 2011; Yong & Pearce, 2013) of service quality for AI. The results of the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity are key indicators used to evaluate the suitability of data for factor analysis. In this case, the data was very suitable for factor analysis, as evi-denced by the high KMO value (0.852) and the significant Bartlett's test of sphericity ($p < 0.001$).

Table 6 (in Appendix 1) lists the eigenvalues associated with each factor before extraction, after extraction, and after rotation. SPSS extracts all factors with eigenvalues greater than one which leaves us with nine factors.

Table 1. Descriptive statistics for statements used

Aspect	Mean	Std. deviation	Aspect	Mean	Std. deviation
QUALD1	5.02	1.21	ENG6	5.14	1.68
QUALD2	4.74	1.25	ENG7	4.50	1.49
QUALD3	5.50	1.14	ENG8	3.83	1.84
QUALD4	4.97	1.24	ENG9	4.24	1.78
QUALD5	5.15	1.23	ENG10	3.38	1.42
QUALD6	5.17	1.32	USE1	5.44	1.44
QUALD7	5.35	1.31	USE2	4.95	1.57
QUALD8	4.68	1.39	USE3	4.78	1.61
MIST1	3.09	1.28	USE4	4.72	1.57
MIST2	3.21	1.34	USE5	4.20	1.64
MIST3	3.85	1.58	USE6	3.88	1.70
MIST4	4.07	1.61	USE7	5.15	1.34
MIST5	3.83	1.65	USE8	5.37	1.54
MIST6	4.14	1.67	USE9	5.00	1.65
ENG1	3.56	1.84	ADOP1	3.37	1.98
ENG2	5.35	1.41	ADOP2	4.07	1.92
ENG3	4.77	1.53	ADOP3	4.86	1.63
ENG4	4.68	1.59	ADOP4	4.73	1.68
ENG5	3.28	1.94	–	–	–

Source: own study in SPSS.

Another important aspect to consider is the rotated component matrix. The factors that we defined in the first part of the research process were: AICB quality, AICB mistrust, AICB engagement, AICB usability, and AICB adoption. After the rotation, there were four factors and suppressing of loadings less than 0.4 made interpretation considerably easier. The four factors retained for further analysis were: AICB quality, AICB mistrust, AICB usability and AICB adoption.

Table 2. Rotated component matrix (principal component analysis, varimax rotation with Kaiser normalization)

Variable	1	2	3	4	5	6	7	8	9
QUAL5	0.748								
QUAL4	0.738								
QUAL1	0.698								
QUAL3	0.692								
QUAL2	0.669								
QUAL6	0.607								
QUAL7	0.598								
QUAL8	0.566								
USE5		0.826							
USE6		0.746							
USE3		0.736							
USE9		0.639							
USE2		0.638							
USE4		0.634							
USE7		0.570					0.405		
USE8		0.461							
MIST4			0.778						
MIST3			0.775						
MIST1			0.690						
MIST2			0.606						

Variable	1	2	3	4	5	6	7	8	9
MIST6			0.569						
MIST5			0.529						
ADOP2				0.694					
ADOP3				0.676	0.478				
ADOP4				0.659	0.541				
ENG5				0.594			0.442		
ENG7				0.591					
ADOP1(R)					-0.680				
USE1					0.661				
ENG3						0.679			
ENG2					0.436	0.631			
ENG1						0.562			
ENG4						0.557			
ENG6							0.640		
ENG10								0.812	
ENG9									0.807
ENG8									0.503

Source: own study in SPSS.

We conducted a principal component analysis (PCA) on the 37 items with orthogonal rotation (varimax). The KMO measure verified the sampling adequacy for the analysis, KMO= 0.852, and all KMO values for individual items were above 0.6 which was above the cut-off level. Bartlett's test of sphericity = 3673.971, p ≤ 0.001, indicated that correlations between items were sufficiently large for PCA. We ran an initial analysis to obtain eigenvalues for each component in the data. Nine components had eigenvalues over Kaisers criterion of 1 and in combination explained 63.91% of the variance. We chose four factors instead of nine to balance statistical rigour with interpretability and practical significance. While the Kaiser criterion suggests retaining nine factors, the first four explained a sufficient cumulative variance of 46.467%, and the scree plot showed a clear break after the fourth factor, indicating diminishing contributions from additional factors. This approach ensures a more parsimonious and meaningful model aligned with the article's theoretical framework. Table 2 shows the factor loadings after rotation. The items that cluster on the same component suggest that component 1 represents AICB quality, component 2 AICB usability, component 3 AICB mistrust, and component 4 AICB adoption.

Confirmatory Factor Analysis

Ideally, researchers should perform confirmatory factor analysis (CFA) on an independent sample to validate the model further (Byrne, 2016). However, due to practical constraints, we conducted the analysis on the same dataset used for initial development. We will acknowledge this limitation, and future research will aim to replicate the findings on a separate sample to enhance the model's generalizability and robustness. We decided to follow through with this step because it significantly adds to our conclusions about AICB quality and its context. We conducted the confirmatory factor analysis of 15 items and four variables to verify the model. We used a sample of 235 student users of AICB to conduct this analysis. Before presenting the analysis results, we needed to remove several items (Qual5, Qual6, Use9 and Adop2) because of low factor loadings or high residual variances as suggested by the first CFA output. After removing these items, the quality of our model increased above key threshold levels. Using indices recommended by Bagozzi and Yi (1988), initial CFA results indicated a significant chi-square value ($\chi 2 = 234.147$, $p < 0.001$).

Moreover, CFA results indicated that the proposed model demonstrated an acceptable fit to the data, supporting its use in subsequent analyses. Incremental fit indices, such as the comparative fit index (CFI = 0.906) and incremental fit index (IFI = 0.908), exceed the commonly recommended threshold of 0.90, indicating a good level of fit (Hu & Bentler, 1999). Absolute fit measures, including the root mean square error of approximation (RMSEA = 0.090, 90% CI [0.076, 0.103]), fell within the acceptable range (< 0.10), though slightly above the ideal threshold of 0.06 (Browne & Cudeck,

1993). Furthermore, the standardized root mean square residual (SRMR = 0.067) was below the recommended cutoff of 0.08 (Hu & Bentler, 1999). All factor loadings are statistically significant (p < 0.001) and substantively meaningful, providing further evidence for the construct validity of the factors. We will address minor areas for improvement, such as reducing residual variances for certain items, in future research. We will also elaborate on the theoretical justification for the model in the discussion, linking the constructs and their interrelations to the broader literature.

Scale Reliability Analysis

When using factor analysis to validate a questionnaire, one should examine the scale's reliability. Cronbach's alpha is the most common measure of scale reliability. The usual cut-off point for scale reliability is 0.8 or 0.7 (Heyes, 2009). Regarding the reliability analysis for the scale measuring AI quality, we used the previously determined four factors as subscales: AI Service quality, AI use for studying, AI mistrust and AI interactions. As Table 4 demonstrates, in all subscales, the reliability result is acceptable.

Table 3. Scale reliability analysis for AICB

Subscale	Cronbach alpha	Mean	No of items
AI quality	0.851	5.037	4
AI usability	0.865	4.518	5
AI mistrust	0.781	3.589	4
AI adoption	0.882	4.805	2

Source: own study in SPSS.

Factor Correlation Analysis

As we may see from correlation analysis AI was positively correlated to AI usability and AI mistrust, but negatively correlated to AI mistrust. This means that raising the quality of AICB positively impacts its usability and adoption. On the other hand, the lower quality of AICB increases mistrust in AI. All correlations were significant except for the one describing the connection between AI usability and AI mistrust.

Table 4. Correlation analysis

Correlations		AI quality	AI usability	AI mistrust	AI adoption
AI quality	Pearson Correlation	1	0.378**	-0.486**	0.257**
	Sig. (2-tailed)		0.000	0.000	0.000
	N	235	230	234	225
AI usability	Pearson Correlation	0.378**	1	-0.182**	0.377**
	Sig. (2-tailed)	0.000		0.006	0.000
	N	230	231	230	223
AI mistrust	Pearson Correlation	-0.486**	-0.182**	1	−0.108
	Sig. (2-tailed)	000	0.006		0.108
	N	234	230	234	225
AI adoption	Pearson Correlation	0.257**	0.377**	−0.108	1
	Sig. (2-tailed)	0.000	0.000	0.108	
	N	225	223	225	226

Note. **Correlation is significant at the 0.01 level (2-tailed).
Source: own study in SPSS.

Discussion

Both EFA and CFA confirmed four primary variables contributing to AICB implementation among the student population in higher education: 1) AICB quality, 2) AICB usability, 3) AICB mistrust, and 3) AICB adoption. The AICB quality dimension is the factor that includes accuracy, reliability, efficiency, and scalability/objectivity. The list of quality items excluded from research includes interoperability, adaptability, design and context, and min. error and biases. These resemble previous findings from Noor *et al*. (2022) who found six dimensions of quality in AI service agents (overlap in efficiency). Jabborov *et*

al. (2023) also investigated the quality of AI systems through a list of quality attributes and our results overlap in the attributes of reliability, scalability, and efficiency.

The second factor was AICB usability which addresses different ways AI helps in the learning process. The items that were significant in the research cover topics as: language learning, social conversations, team assembly, and career help. Westman *et al*. (2022) focused on career guidance and found a positive contribution from AI. In a similar vein, Lupo and Buscarino (2021) recognised usability as a dimension of online education service quality. The work of Weichbroth (2020) focuses on the usability of mobile applications but it reveals the lack of definitions that make different aspects of new technology use hard to investigate.

The factor of AICB mistrust is related to results that are incorrect and confusing, or that require previous knowledge and clarifications. The literature mentions that AI algorithms work on the principle of 'customer satisfaction' which means their primary goal is delivering answers and the correctness of those answers is secondary (Mollick, 2024). Previous studies also emphasise the lack of accuracy and confidence in the AI results (Al-Mughairi & Bhaskar, 2024; Cox, 2021). Other studies also highlight the importance of trust in AI as a central element for improving performance and engagement and the need for treating trust and mistrust as two separate concepts (Scharowski *et al*., 2024, Marimon *et al*., 2024). Moreover, Alwagdani (2024) emphasised the role of mistrust in his research on the use of AI tools by the teacher population and proposed an approach based on targeted, collaborative, and ethical implementation.

The fourth factor, namely AI adoption, basically describes the preferences of students when it comes to including AI as a topic in courses and curriculum. The analysis left out two. The first one that related to teacher's bias and was reverse coded and the second one connected to including AI in student jobs and career opportunities.

We included the variable AI engagement in our theoretical framework as previous research emphasised the need to investigate how people engage chatbots in every aspect of human life including studying. Maeda and Quan-Haase (2024) emphasise the capability of AI tools to play human roles sometimes with bad and unethical considerations. The attitude that chatbots can roleplay as humans and therefore easily engage students is present in literature (Georgescu, 2018; Yang & Evans, 2019). Our scale emphasised the questions on how students engage with AICB but we excluded them from the final analysis due to the poor fit with the model. As suggested by Prentice *et al*. (2020), engagement covers more fundamental changes based on the preferences and behaviours of customers and we can conclude that although the adoption of AI technologies has been rapid, changing human behaviour will probably take some more time.

The scale also allows for recommending some of AICBs to students for faculty and work purposes. This will also become increasingly important since more HEIs will need to include AI services in various activities at the level of institution, program, and individual courses and all of these services require monitoring according to objective criteria. The article provides chatbot developers with feedback because they can track both the quality and experience certain groups like HE students get from using their services. Moreover, the study suggests there is still a high level of mistrust in AI services that both service providers and users need to address.

However, we noted several limitations. The study did not account for students' expectations regarding AICB quality, and the research sample was limited to students from a single faculty. Future research should validate this scale across different AI services and investigate causal relationships between AICB quality and influencing factors, as well as the impact of AICB quality on other implementation issues. Moreover, conducting a CFA on another sample would further validate the results. When it comes to the questions used our general impression is that we used questions that were too broad and not easy to understand by the student population.

We recommend several directions for future research, such as validating the AICB quality scale for other AI services and exploring the causal factors influencing AI service quality. Moreover, investigating variables such as student experience, which may be affected by AI service quality, will provide further insights into the broader implications of AI in HE. We also think research should address the link between AICB implementation and student performance in terms of their grades and overall satisfaction. Moreover, scholars may also investigate moderating factors related to services, the student and the

student performance to uncover the boundary conditions under which the AICB service quality scale is likely to influence service outcomes. Researchers may also conduct longitudinal studies to assess how ongoing use of AICB can change HE outcomes. It would also be interesting to perform a similar survey on the population of teachers to check whether there are some big discrepancies in the treatment of AI from student and teacher perspectives.

CONCLUSIONS

The widespread adoption of AI tools and services is anticipated to permeate all key stakeholders in HE. As lead users, students have already recognised the advantages of these tools (Chen *et al.*, 2020). Conversely, HEIs, as formal entities, must address the implementation of AI services in a structured manner, raising questions related to regulation, ethics, and service quality (Cox, 2021; Marcus *et al.*, 2023; Yan *et al.*, 2023). To facilitate the mass adoption of AI services, it is crucial to evaluate their quality systematically (Dou *et al.*, 2024). This study proposes using an AICB scale for assessing the quality of commercially available AICBs and recommends their application for educational purposes. Moreover, the study highlights other key aspects of AICB experience in HE and their connection to AICB quality.

This study aimed to develop a robust scale for measuring the quality of AICBs, such as ChatGPT. Noteworthy, students already widely use AICBs in HE (Dempere *et al.*, 2023; Rudolph *et al.*, 2023; Crawford *et al.*, 2023; Neuman *et al.*, 2023). The research commenced with an extensive literature review to identify key variables associated with customer experience in AI services, particularly from the students' perspective. We conducted qualitative research, including focus groups with the student population, to refine these variables. The resulting core elements for assessing AICB quality in HE included: 1) AICB quality, 2) AICB usability, 3) AICB mistrust, 4) AICB adoption, and 5) AICB engagement. Compared to previous research (Hamam, 2021; Huddar *et al.*, 2020; Noor *et al.*, 2022; Prentice, 2023; Qian *et al.*, 2022), we further advanced the concept of AICB quality by investigating the relationship between AICB quality and other variables associated with AICB experience. The combination of EFA and CFA confirmed four primary variables contributing to AICB student experience: 1) AICB quality, 2) AICB usability, 3) AICB mistrust, and 4) AICB adoption.

The developed AICB quality factor provides a theoretical framework for linking AICB service quality with various aspects of the AICB experience. As a practical implementation direction, HEIs can utilise this scale to assess and enhance the implementation of accessible AICB services. Moreover, this study contributes to the service quality literature by presenting a scale with sound psychometric properties for measuring AICB quality.

Four key dimensions shape the implementation of AICB in higher education: quality, usability, mistrust, and adoption. The AICB scale quality is defined by attributes such as accuracy, reliability, efficiency, and scalability, which aligns with previous studies (e.g., Noor *et al*., 2022; Jabborov *et al*., 2023). However, the scale excludes aspects like adaptability and design. Moreover, AICB usability highlights the practical benefits of AI in areas like language learning and career guidance, supported by findings from Westman *et al*. (2022) and Lupo and Buscarino (2021). Noteworthy, AICB mistrust emerges as a critical factor, rooted in inaccuracies and ethical concerns, consistent with literature emphasising trust as pivotal for engagement and performance (Mollick, 2024; Scharowski *et al*., 2024). Finally, AICB adoption underscores the importance of integrating AI into curricula, reflecting student preferences, although broader engagement dynamics remain underexplored. These findings reinforce the need for targeted, ethical, and collaborative approaches to AI integration in academic contexts.

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Appendix:

Table 5. Questions used in the survey

S.No.	Abbreviation of the element	Question	Adapted according to
1	**QUALD1**	How would you rate your experience with AI tools in terms of accuracy?	Jaborov *et al*., 2023; Noor *et al*., 2022; Parasuraman *et al*., 2005
2	**QUALD2**	How would you rate your experience with AI tools in terms of reliability?	Jaborov *et al*. 2023; Noor *et al*., 2022; Parasuraman *et al*., 2005
3	**QUALD3**	How would you rate your experience with AI tools in terms of efficiency?	Jaborov *et al*., 2023; Noor *et al*., 2022; Parasuraman *et al*., 2005
4	**QUALD4**	How would you rate your experience with AI tools in terms of scalability/objectivity?	Jaborov *et al*., 2023; Noor *et al*., 2022; Parasuraman *et al*., 2005
5	**QUALD5**	How would you rate your experience with AI tools in terms of interoperability?	Jaborov *et al*., 2023; Noor *et al*., 2022; Parasuraman *et al*., 2005
6	**QUALD6**	How would you rate your experience with AI tools in terms of adaptability?	Jaborov *et al*., 2023; Noor *et al*., 2022; Parasuraman *et al*., 2005
7	QUALD7	How would you rate your experience with AI tools in terms of design and context?	Jaborov *et al*., 2023; Noor *et al*., 2022; Parasuraman *et al*., 2005
8	QUALD8	How would you rate your experience with AI tools in terms of min. error or biases?	Jaborov *et al*., 2023; Noor *et al*., 2022; Parasuraman *et al*., 2005
9	**MIST1**	The results provided by AI tools are incorrect.	Scharowski *et al*., 2024; Marimon *et al*., 2024
10	**MIST2**	The results provided by AI tools are confusing.	Scharowski *et al*., 2024; Marimon *et al*., 2024
11	**MIST3**	The results provided by AI tools typically require some basic knowledge of the field.	Scharowski, *et al*., 2024; Marimon *et al*., 2024
12	**MIST4**	The results provided by AI tools typically require further clarification.	Scharowski *et al*., 2024; Marimon *et al*., 2024
13	MIST5	The typical use of AI tools offers too many bullets/enumerations.	Scharowski *et al*., 2024; Marimon *et al*., 2024
14	MIST6	I have noted examples of incorrect statements in AI output.	Scharowski *et al*., 2024; Marimon *et al*., 2024
15	ENG1	I use AI tools for studying needs on a regular basis.	Maeda and Quan-Haase, 2024; Grassini, 2023; Westman *et al*., 2021
16	ENG2	The AI tools interface is user-friendly.	Maeda and Quan-Haase, 2024; Grassini, 2023; Westman *et al*., 2021
17	ENG3	The typical use of AI tools for me would be/is in the process of gathering new ideas.	Maeda and Quan-Haase, 2024; Grassini, 2023; Westman *et al*., 2021
18	ENG4	The typical use of AI tools for me would be/is in search of clear definitions.	Maeda and Quan-Haase, 2024; Grassini, 2023; Westman *et al*., 2021
19	ENG5	I would be/am ready to pay for some additional AI features.	Maeda and Quan-Haase, 2024; Grassini, 2023; Westman *et al*., 2021
20	ENG6	I usually/would double-check the results provided by AI tools.	Maeda and Quan-Haase, 2024; Grassini, 2023; Westman *et al*., 2021
21	ENG7	When I see the result from AI I typically (would) want to know more.	Maeda and Quan-Haase, 2024; Grassini, 2023; Westman *et al*., 2021
22	ENG8	When using AI tools, I (would) often get the feeling that I am communicating with a person.	Maeda and Quan-Haase, 2024; Grassini, 2023; Westman *et al*., 2021
23	ENG9	I have some concerns about the ethical implications of AI tools, such as biases in algorithms and job displacements.	Maeda and Quan-Haase 2024; Grassini, 2023; Westman *et al*., 2021
24	ENG10	A lot of teachers use some form of AI in their teachings.	Maeda and Quan-Haase, 2024; Grassini, 2023; Westman *et al*., 2021

S.No.	Abbreviation of the element	Question	Adapted according to
25	**USE1**	AI can help with F.A.Q.	Westman *et al*., 2021; Davis, 1989
26	**USE2**	AI can help with language learning.	Westman *et al*., 2021; Davis, 1989
27	**USE3**	AI can help with having a social conversation.	Westman *et al*., 2021; Davis, 1989
28	**USE4**	AI is useful in everything.	Westman *et al*., 2021; Davis, 1989
29	**USE5**	AI can help in team assembly.	Westman *et al*., 2021; Davis, 1989
30	**USE6**	AI can help choose the right career path.	Westman *et al*., 2021; Davis 1989
31	USE7	AI can provide additional and supplementary materials.	Westman *et al*., 2021; Davis, 1989
32	USE8	AI can provide immediate answers.	Westman *et al*., 2021; Davis, 1989
33	USE9	AI can help the exam preparation with examples and tasks.	Westman *et al*., 2021; Davis, 1989
34	ADOP1 (R)	I noticed teachers have a negative bias toward using AI for studying.	Lazar *et al*., 2020; Grassini, 2023; Westman *et al*., 2021
35	ADOP2	I am interested in working in AI-related fields or incorporating AI into my future career.	Lazar *et al*., 2020; Grassini 2023; Westman *et al*., 2021
36	**ADOP3**	I believe universities should incorporate more AI-related courses or education into their curriculum.	Lazar *et al*., 2020; Grassini, 2023; Westman *et al*., 2021
37	**ADOP4**	I believe universities should incorporate more AI-related tasks and examples into their courses.	Lazar *et al*., 2020; Grassini, 2023; Westman *et al*., 2021

Note. Each of the proposed statements was rated on a Likert scale from 1-7; Bolded items are questions with a load of 0.6 or higher; R stands for reverse coded.

Source: own study.

Table 6. Total variance explained (Principal Component analysis)

Compone nt	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of Variance	Cumulativ e %	Total	% of Variance	Cumulativ e %	Total	% of Variance	Cumulativ e %
1	9.151	24.733	24.733	9.151	24.733	24.733	4.400	11.893	11.893
2	3.805	10.283	35.016	3.805	10.283	35.016	4.336	11.720	23.613
3	2.426	6.557	41.573	2.426	6.557	41.573	3.413	9.224	32.836
4	1.811	4.895	46.467	1.811	4.895	46.467	2.765	7.474	40.310
5	1.709	4.619	51.086	1.709	4.619	51.086	2.249	6.077	46.387
6	1.361	3.677	54.764	1.361	3.677	54.764	2.211	5.976	52.363
7	1.268	3.426	58.190	1.268	3.426	58.190	1.602	4.331	56.694
8	1.102	2.980	61.170	1.102	2.980	61.170	1.403	3.792	60.487
9	1.015	2.744	63.914	1.015	2.744	63.914	1.268	3.427	63.914
10	0.917	2.479	66.393						
11	0.883	2.387	68.780						
12	0.866	2.341	71.121						
13	0.795	2.149	73.270						
14	0.753	2.035	75.304						
15	0.730	1.974	77.278						
16	0.707	1.910	79.189						
17	0.627	1.695	80.884						
18	0.603	1.629	82.513						
19	0.559	1.511	84.023						
20	0.540	1.460	85.483						
21	0.510	1.379	86.862						
22	0.465	1.257	88.118						
23	0.458	1.237	89.356						
24	0.426	1.150	90.506						
25	0.416	1.124	91.629						
26	0.390	1.053	92.683						
27	0.355	0.960	93.643						
28	0.327	0.884	94.526						
29	0.310	0.838	95.364						
30	0.271	0.731	96.095						
31	0.252	0.681	96.777						
32	0.247	0.668	97.444						
33	0.235	0.635	98.079						
34	0.217	0.587	98.666						
35	0.199	0.538	99.204						
36	0.157	0.424	99.628						
37	0.138	0.372	100.000						

Source: own elaboration in SPSS.

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Use of Artificial Intelligence

GAI tools (ChatGPT) were used soley for language editing and proofreading. The authors take full responsibility for the content and conclusions of this work.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Determinants of the perception of FinTech companies as environmentally friendly: European consumers' perspective

Dariusz Piotrowski, Anna Iwona Piotrowska

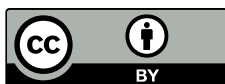| A B S T R A C T |
|---|
| **Objective:** The aim is to identify the determinants of the perception of FinTech companies as environmentally friendly institutions. |
| **Research Design & Methods:** The empirical base used in the work comprises data obtained in a survey conducted using computer-assisted web interviews of 2 000 respondents from the United Kingdom, Germany, Poland, and Ukraine. We used the ordinary logit models in the data analysis. |
| **Findings:** We identified the perceived benefits of using artificial intelligence (AI) technology in the financial sector and personal values and beliefs regarding sustainable development as the key factors determining whether FinTech companies are perceived as environmentally friendly institutions. Moreover, we found that education and financial knowledge are significant determinants. |
| **Implications & Recommendations:** For FinTech companies to be perceived as environmentally friendly, decision-makers must take actions supporting environmental sustainability and implement an appropriate communication policy. Building a green institutional image is supported by educating consumers about finance, promoting ecological responsibility, and encouraging more frequent use of financial applications. It is also important to highlight environmental initiatives while avoiding greenwashing, as individuals engaged in environmental protection are particularly sensitive to manipulation in this area. The findings of the study can also serve to increase the effectiveness of communication between FinTech companies and market participants in the area of environmental protection. Considering the importance of the variable related to the AI use in finance, the messaging should emphasise the positive environmental impact of digital technologies employed by FinTech companies. |
| **Contribution & Value Added:** The study significantly contributes to the development of green FinTech research, as it is the first to address how FinTech companies come to be regarded as environmentally friendly. Identifying the determinants of the relevant perceptions is particularly important since the literature shows that most consumers are not convinced of the beneficial impact of banks and FinTech companies on the environment. The study's particular contribution is the identification of universal determinants independent of the respondents' country of origin, which FinTech company managers should consider when designing services and communicating with consumers. Empirical evidence also indicates that the value-belief-norm theory contributes to explaining the perception of FinTech companies as green. We should associate the uniqueness of the work with the use of data obtained in a survey of respondents from several European countries with different levels of financial market development and different degrees of implementation of the UN Sustainable Development Goals. |
| **Article type:** research article |
| **Keywords:** green FinTech; digital financial services; sustainable development goals (SDGs); artificial intelligence in finance; value-belief-norm (VBN) theory |
| **JEL codes:** G23, O44, Q55 |
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INTRODUCTION

In recent decades, the development of the global economy has been largely uneven, unfair, and to the detriment of the environment and future generations. The international community has responded by adopting a plan of action for people, planet, and prosperity. The 2030 Agenda for Sustainable Development (United Nations, 2015) contains 17 Sustainable Development Goals (SDGs) that are directly or indirectly related to environmental sustainability (Mishra *et al.*, 2024; Scharlemann *et al.*, 2020). Financial institutions are seen as vital to achieving the SDGs, and their involvement in environmental protection is reflected in the development of green finance (Ronaldo & Suryanto, 2022; Alieksieiev *et al.*, 2021; Tsai, 2024; Chaudhry & Hussain, 2023; Feridun & Talay, 2023). The services offered include support in financing pro-ecological investments, selecting projects based on the degree of harmfulness of their impact on the environment, and shaping environmentally friendly consumer behaviours and attitudes (Oanh, 2024; Bakry *et al.*, 2023; Saeed Meo & Karim, 2022).

The increase in the use of digital technologies in the financial sector has led to efficiency improvements among banks and other intermediaries, contributing to progress in achieving the SDGs (Kashif *et al.*, 2024; Bhuiyan *et al.*, 2024; Mertzanis, 2023; Carè *et al.*, 2023; Arner *et al.*, 2020). The literature refers to the use of advanced digital technologies, such as big data, artificial intelligence (AI), and cloud computing, to improve the efficiency of financial services provided as FinTech (Jiang, 2023; Knewtson & Rosenbaum, 2020; Chen *et al.*, 2019). The term also serves to refer to the new financial industry and innovative companies and start-ups that provide financial services using advanced digital technologies (Haddad & Hornuf, 2019; Schueffel, 2016). Krupa and Buszko (2023) indicate that in this latter approach, we should define FinTech concerning non-banking financial institutions.

We may apply an analogous classification to the phenomenon of green FinTech analysed in this study. The term may refer to the use of modern digital technologies to achieve beneficial results in the field of environmental sustainability (Liu *et al.*, 2024; Macchiavello & Siri, 2022; Deng *et al.*, 2019; Green Digital Finance Alliance and Swiss Green FinTech Network, 2022). It may also refer to FinTech companies and start-ups focusing their offer on green financial services (Ashta, 2023; Puschmann *et al.*, 2020).

One may achieve the beneficial environmental effect of FinTech through two channels: by changing the way financial institutions operate (Qin *et al.*, 2024; Awais *et al.*, 2023; Yang *et al.*, 2021) and by expanding and increasing the attractiveness of the financial services provided. In this case, the reduction in gas and dust emissions and the increase in energy efficiency occur among the clients of these institutions (Siddik *et al.*, 2023; Liu & Li, 2022; Liu *et al.*, 2023; Dorfleitner & Braun, 2019; Xue *et al.*, 2022).

Statista data (2024) indicates the growing importance of FinTech companies and start-ups in the international financial market. These companies have also exhibited a growing interest in the green aspects of financial services. Moreover, FinTech has a broad impact on businesses, the environment, and consumer behaviour. Thus, the activity of FinTech companies in the area of environmental sustainability is important from a scientific point of view and requires in-depth analysis.

Creating an image of FinTech companies as environmentally friendly requires taking action to protect the environment alongside effective communication of these efforts. Consumers' perceptions of FinTech companies as green may have beneficial implications for the business of these entities and, in a broader sense, for achieving the SDGs. With this in mind, we aimed to identify the determinants of the perception of FinTech companies as environmentally friendly institutions.

The scarce literature on green FinTech currently focuses on FinTech's impact on gas and dust emissions. Moreover, FinTech is commonly understood as the use of advanced digital technologies in finance, and existing analyses tend to focus on the Chinese market. There is almost no research addressing consumer assessments of the activities of FinTech companies in relation to the natural environment. Against this background, the advantage of this study is that it employs survey data from several European countries that vary in their level of financial market development and the degree to which they have met the SDGs.

Digital technologies have been successfully used by the financial sector for many decades. In fact, FinTech companies have built their operations entirely around them. Recently, the attention of busi-

nesses, academia, and consumers has increasingly focused on AI development. It is therefore worth investigating whether consumers perceive the potential of such technologies being used by financial institutions to support environmental protection. In turn, based on the value-belief-norm (VBN) theory (Canlas & Karpudewan, 2023; Chen, 2015), we can expect that consumer engagement with environmental issues will foster a positive assessment of FinTech companies' sustainability efforts. With this in mind, we asked the following research questions:

RQ1: Does emphasising the business application of AI help create the image of FinTech as an institution supporting environmental protection?

RQ3: Are consumers' values and beliefs about sustainable development important factors influencing the perception of FinTech companies as institutions supporting environmental protection?

The remainder of the study is structured as follows. Section 2 sets out a literature review addressing the impacts of FinTech on the natural environment. Section 3 presents the material and research methods used in the analysis. Section 4 contains the results of the logit model estimation and a discussion on the determinants of the perception of FinTech as environmentally friendly financial institutions. The final section contains the research conclusions and recommendations.

LITERATURE REVIEW

The literature review in this work focuses on the impact of FinTech on environmental sustainability. There are several approaches to presenting the phenomenon, and they differ in terms of the type of data obtained and the possibility of determining the impact of FinTech on the environment.

Presentation of Green FinTech Companies and Services

Puschmann *et al*. (2020) analyse the offer of green FinTech services in Switzerland by companies such as Carbon Delta, Energy Web, Greenmatch, and Raizers. However, their study data do not indicate the degree of use of these services, focusing only on the potential impact of FinTech on the environment. Ashta (2023) compares the impact on the natural environment of two groups of FinTech entities operating on a global scale (PayPal, Mastercard, Ant Group, Fiserv) and those operating on a smaller scale (Treecard, Raise Green, Trine, MioTech, Aspiration) based on data that are mainly drawn from official company reports. The results indicate the advantage of large FinTech companies in terms of the quality of data, showing the impact on the environment and social impact. However, various company initiatives have reduced this impact. Carè *et al*.'s (2023) case study of FinTech companies CNote, Doconomy, Ando Money, and Tred consider their impact with respect to achieving the SDGs. The study uses data from news articles, websites, and project reports; information important for understanding the essence of FinTech functioning was also obtained through interviews with employees of these institutions. The results show the types of activities undertaken by these FinTech companies in the area of environmental protection and offer a method of measuring the environmental impact of each financial transaction.

The Impact of FinTech on the Environment as Assessed by Respondents

In their study of 30 Alipay users, Zhao and Abeysekera (2024) found a positive impact of the Alipay Ant Forest platform on consumer behaviour in the area of environmental protection. The analysis of Aboalsamh *et al*. (2023) also focuses on the impact of green FinTech technology on consumer behaviour and business activity. Their study, in which eight individual respondents from the Middle East with green FinTech experience participated, shows the positive impact of FinTech. This study also identifies the need to increase consumer awareness of green FinTech technologies and their impact on consumer behaviour. In the final study analysed here, 302 employees of the banking sector in Bangladesh indicated the positive effects of digital technologies in banks in the area of green financing and green innovation and the measurable environmental benefits (Guang-Wen & Siddik, 2023).

Determining the Impact of FinTech on the Environment Based on Statistical Data

The literature review shows that most studies using econometric analyses identify a positive impact of FinTech on environmental quality (Liu *et al*., 2024; Macchiavello & Siri, 2022; Deng *et al*., 2019). Specifically, FinTech's impact on the environment manifests in reduced pollution and greenhouse gas emissions, more efficient use of resources (Muhammad *et al*., 2022; Tao *et al*., 2022; Vergara & Agudo, 2021) and the increased energy efficiency of economies (Liu *et al*., 2022). Studies showing the impact of FinTech on the environment mostly employ data presenting changes in the levels of gas and dust emissions (Ma *et al*., 2023; Xu *et al*., 2023; Delina, 2023; Tao *et al*., 2022; Coffie *et al*., 2022). A limitation of the studies in the literature is that they usually consider digital technologies used in finance rather than FinTech in the sense of innovative companies in the financial services sector. Moreover, the data for levels of CO2, SO2, PM2.5 and dust emissions, as well as the use of digital technologies in finance, are most often for a single country, usually China (Udeagha & Muchapondwa, 2023; Liu *et al*., 2023; Zhou *et al*., 2022; Muganyi *et al*., 2021).

**Consumers' Awareness and Perception of Financial Institutions
in the Field of Environmental Protection**

Consumer awareness of green finance practices most often refers to the banking sector. Numerous studies indicate a lack of consumer knowledge regarding green financial services provided by banks. This is manifested by the dominance of negative responses or answers indicating a lack of awareness of the phenomenon, compared to affirmative responses. The findings presented in the literature concern the banking sector in India (Yasmin & Ahamed, 2024), Pakistan (Ellahi *et al*., 2023), Nepal (Rai *et al*., 2019), and Brazil (Rocha *et al*., 2025). Only one article refers to the environmental impact of FinTech companies (Piotrowska & Piotrowski, 2025). The results of this study indicate that, regardless of the country included in the analysis and whether FinTech applications are used, respondents show a very low level of knowledge about the environmental initiatives undertaken by FinTech companies. Several studies also identified determinants and examined the relationships between variables analysed in the area of green finance. The study by Sharma *et al*. (2025) demonstrated a positive relationship between the level of awareness of banks' green practices and the adoption of advanced digital technologies supporting green finance. The research by Rocha *et al*. (2025) identified a positive correlation between consumers' awareness of pro-environmental activities of banks and variables such as green loyalty, green trust, and green attitude. In turn, the studies by Alshebami (2021) and Gazi *et al*. (2024) highlight a positive link between green banking practices and the green image of banks.

In summary, the literature review confirms the conclusions of Liu *et al*. (2024), Galeone *et al*. (2024), Kwong *et al*. (2023), Xu *et al*. (2023), and Liu *et al*. (2023) that green FinTech is a new and poorly covered research area. Moreover, thus far, studies have focused on FinTech as the application of advanced digital technologies in finance, not innovative financial institutions. Most studies use statistical data on pollution, and few include analyses based on survey data. We identified only one article that determined the respondents' level of knowledge regarding the environmental impact of FinTech companies' services. Most importantly, however, the studies show a gap in research on the determinants of consumers' perception of FinTech institutions as environmentally friendly. Previous work on perception and image focused on the banking sector. Therefore, the article is the first to examine the drivers of perception of FinTech companies as institutions involved in the area of environmental protection.

RESEARCH METHODOLOGY

We obtained the data used in this study in a survey involving 2 000 respondents aged 21-60. The research sample included 500 respondents from four countries, *i.e.*, Ukraine, Poland, Germany and the United Kingdom (UK). We chose these countries because of several considerations. Firstly, previous studies involving respondents tended to overlook the European market. This article helps to address that gap. Secondly, the similarities and differences between the analysed countries allow for meaningful comparisons and the potential to generalise the conclusions. The United Kingdom and Germany are

geographically and culturally regarded as Western European countries, while Poland and Ukraine as Central and Eastern European countries. In terms of financial sector development, the United Kingdom and Germany lead. Ukraine, by contrast, lags significantly behind the other countries, both in this respect and in terms of implementing the Sustainable Development Goals in its economy.

We obtained empirical data using computer-assisted web interviews. This method was appropriate due to the study's target group, *i.e.*, active users of the Internet or mobile banking. We developed the questionnaire in separate language versions for each group of respondents, and at least two native speakers verified it. This action and the use of plain language ensured that the content of the questionnaire was understood in the same way in each country. Moreover, the survey questionnaire included an introduction that explained the essence of FinTech companies and listed examples of their services. We conducted pilot studies before the actual survey.

The authors obtained the consent of the Research Ethics Committee of the Faculty of Economic Sciences and Management (decision number: 10/2023/FT). The Committee expressed their positive opinion on the concept of the study and the survey questionnaire. We retained a professional research agency, Interactive Research Center, to ensure the quality of the empirical data; the agency has extensive experience in the field of international survey research. Based on the questionnaire developed by the authors, the agency prepared an electronic survey and was responsible for obtaining an appropriate research sample. The agency conducted its activities reliably and following ethical principles, observing the provisions of the ICC/ESOMAR International Code on Market, Opinion and Social Research and Data Analytics.

The study participants were people who were part of the research panels in the individual countries. Efforts were made to ensure that the samples were representative in terms of gender, age and place of residence. This was achieved by first assessing the basic socio-demographic characteristics of the participants who responded to the survey invitation. In the case of positive verification, the respondent proceeded to the next part of the survey concerning the use of digital technologies in finance. Each respondent had the opportunity to interrupt the study at any time, with the possibility of returning to complete it by a specified date. Participation in the study was voluntary, and we obtained the data anonymously. Table 1 presents basic characteristics of the respondents.

Table 1. Frequency distributions of the socio-demographic variables in the samples

Variable	Poland	Ukraine	Germany	United Kingdom
	%	%	%	%
Gender				
Female	49.0	51.0	49.4	50.0
Male	51.0	49.0	50.6	50.0
Age				
21-25	10.0	9.4	8.2	11.2
26-35	27.2	27.0	24.0	26.4
36-45	29.4	27.6	23.4	24.6
46-55	23.8	23.8	28.2	25.4
56-60	9.6	12.2	16.2	12.4
Place of residence				
Rural area	20.6	17.4	19.2	20.4
City up to 20 000 residents	12.6	15.6	17.4	15.4
City between 20 001 and 50 000 residents	13.0	10.2	15.4	11.0
City between 50 001 and 100 000 residents	15.2	8.4	10.8	11.6
City between 100 001 and 200 000 residents	10.8	3.0	8.2	10.0
City between 200 001 and 500 000 residents	9.8	19.0	8.8	9.8
City above 500 000 residents	18.0	26.4	20.2	21.8
Number of observations	500	500	500	500

Source: own study.

Table 2 presents the variables used in the study. The dependent variable was Green FinTech perception (GFT). We divided the explanatory variables into the following categories: socio-demographic characteristics, technological advancement, and personal beliefs and values.

Due to the lack of research on the perceptions of FinTech companies as environmentally friendly, we completed the selection of explanatory variables with reference to the results of research in the areas of green finance, pro-environmental behaviour, and the adoption of financial innovations. Ellahi *et al.* (2023) found that socio-demographic characteristics, such as age and gender, determine green banking awareness, and Song *et al.* (2023) indicate that mobile payments are more likely to be accepted and used by younger, better-educated consumers. The results of Nguyen (2022) suggest that perceived financial knowledge increases the use of FinTech services. According to Serdarusic *et al.* (2024), the adoption of FinTech has a significant impact on banking sustainability, and users' familiarity with specific technologies and previous experience in using them are important factors in their adoption (Hino, 2015; Bauer *et al.*, 2005). The above-mentioned results justify the use of variables relating to socio-demographic and technological characteristics in our study.

Moreover, the literature demonstrates that there is a relationship between environmental concern and individual behaviour (Stern, 2001). According to the VBN theory, people who hold pro-ecological values and believe that their actions can help restore threatened values feel a personal obligation to take pro-ecological action (Stern *et al.*, 1999). This approach has proven effective in explaining, among other things, the choice to use sustainable travel modes (Lind *et al.*, 2015) and green consumption behaviours (Hong *et al.*, 2024). Previous studies indicated that pressure from consumers (Bukhari *et al.*, 2022), especially those with high levels of environmental awareness (Choudhury *et al.*, 2013), was an important factor in the implementation of green banking practices. Pro-environmental attitudes were also a significant factor in the adoption of green financial products (Iqbal *et al.*, 2024; Ellahi *et al.*, 2023). This suggests that respondents' pro-ecological beliefs and personal norms may influence their assessment of pro-ecological actions taken by FinTech entities. For this reason, we included variables related to personal beliefs and values.

Table 2. Characteristics of the study variables

Variable group	Variable description
Dependent variable	
Green FinTech perception (*GFT*)	FinTech companies operating in the UK/Poland/Germany/Ukraine* provide services taking into account the needs of the natural environment: 1—Strongly disagree, 2—Disagree, 3—Somewhat disagree, 4—It's hard to say, 5—Somewhat agree, 6—Agree, 7—Strongly agree
Explanatory variables	
Socio-demographic characteristics	
Gender (*GEN*)	Gender: 1—female, 2—male
Age (*AGE*)	Age of respondent in years in the range of 21 to 60
Residence (*RES*)	Size of the respondent's place of residence: 1—Rural area 2—City up to 20 000 residents 3—City between 20 001 and 50 000 residents 4—City between 50 001 and 100 000 residents 5—City between 100 001 and 200 000 residents 6—City between 200 001 and 500 000 residents 7—City above 500 000 residents
Education (*EDU*)	Level of education of the respondent: 1—Incomplete primary, primary, secondary education 2—Vocational education 3—Further education 4—Higher education—bachelor's degree 5—Higher education—master's degree and higher
Financial knowledge—	Respondent's assessment of their financial knowledge: 1—Very poor, 2—Poor, 3—

Variable group	Variable description
subjective assessment (*KNW*)	Rather poor, 4—It's hard to say, 5—Rather good, 6—Good, 7—Very good
Technological advancement	
FinTech application use (*APP*)	Respondent uses financial applications from technology companies: 1—No, 2—Hard to say, 3—Yes
AI improve the quality of customer service (*AIQ*)	Artificial intelligence allows financial institutions to improve the quality of customer service (elimination of human errors and mistakes, greater accuracy and speed of transactions/operations): 1—Strongly disagree, 2—Disagree, 3—Somewhat disagree, 4—It's hard to say, 5—Somewhat agree, 6—Agree, 7—Strongly agree
Personal beliefs and values	
Supporting the financially weaker (*SFW*)	I believe financially weaker people should be supported: 1—Strongly disagree, 2—Disagree, 3—Somewhat disagree, 4—It's hard to say, 5—Somewhat agree, 6—Agree, 7—Strongly agree
Decision's impact on the environment (*ENV*)	The impact of my decisions on the natural environment is important to me: 1—Strongly disagree, 2—Disagree, 3—Somewhat disagree, 4—It's hard to say, 5—Somewhat agree, 6—Agree, 7—Strongly agree
Save more and consume less (*SAV*)	I believe that we should save more and consume less: 1—Strongly disagree, 2—Disagree, 3—Somewhat disagree, 4—It's hard to say, 5—Somewhat agree, 6—Agree, 7—Strongly agree

Note: *appropriate country name displayed in each language version.
Source: own study.

We employed the ordinary logit model to identify the determinants of the perception that FinTech companies support environmental protection. Logit models are versatile research tools widely used in various contexts for analysing preferences (Cramer, 2003). The application of the ordered logit model was required since the dependent variable took the form of seven ordered values. Opinion surveys such as ours frequently employ Likert-type scales that provide a clear rating between categories, ranging from 'strongly disagree' to 'strongly agree.' Because this logit model specification allows for the use of all information available in a variable, it is often used in the social sciences (Liao, 1994).

The following represents the ordered logit model for the ordinal variable Y and K independent variables:

$$\log\left(\frac{P(Y \le j | x)}{1 - P(Y \le j | x)}\right) = \mu_j - \sum_{k=1}^{K} \beta_k x_k, j = 1, 2, \dots, J - 1 \tag{1}$$

in which (Liao, 1994):

$\mu_1, \mu_2, \dots, \mu_{J-1}$ - are threshold parameters;

$\beta_1, \beta_2, \dots, \beta_K$ - are the coefficients;

J - is the number of ordered categories.

RESULTS AND DISCUSSION

The ordered logit model allowed us to identify variables that significantly affected the perception of FinTech companies as environmentally friendly. Table 3 presents the estimation results.

The two key variables from the perspective of answering the research questions – AIQ and ENV – significantly affected the perception of FinTech companies as environmentally friendly (GFT) for respondents in all analysed countries. The results of estimations also showed that EDU and KNW were statistically significant for Germany, Poland and the UK, while SFW in the case of Ukraine, Poland and the UK. The relationship between GFT and GEN, AGE, RES, and APP was significant only in the case of Ukraine. The likelihood of FinTech companies being perceived as environmentally friendly increased with respondents' sense of their own financial literacy, their belief that the use of AI has a positive impact on the quality of financial services, their experience using FinTech applications, and the need to help the vulnerable and be aware of the environmental impact of their decisions. In contrast, the likelihood of

perceiving FinTech companies as environmentally friendly decreases with a respondent's age, the size of their place of residence, level of education and whether they are a man.

Most studies on green FinTech show that the use of digital technologies in finance positively impacts the environment. These conclusions are usually based on econometric analyses using statistical data on the levels of FinTech development, gas and dust emissions, and energy efficiency. We take a different approach, focusing on consumers and their opinions. We assume that the business of FinTech companies and SDGs implementation would benefit from consumers noticing and positively evaluating their efforts in the area of environmental sustainability.

Unlike existing studies, our previous analysis (Piotrowska & Piotrowski, 2025) indicates that the beneficial impact of FinTech on the environment is not clear. A lack of awareness or knowledge about the impact of FinTech companies on the environment was reported. In this situation, FinTech companies that care whether consumers perceive them as environmentally friendly institutions should increase their environmental sustainability activities and ensure proper information is communicated about these. The message should be easy for consumers to notice and understand. In this respect, the results of the ordered logit model estimation may prove helpful. However, we cannot directly relate these results to the literature as there are no existing studies on the determinants of FinTech companies being perceived as supporting environmental protection.

The estimation results (Table 3) indicate that with an increase in a respondent's level of education, the probability of perceiving FinTech companies as institutions supporting environmental protection decreases. We may explain this phenomenon by the fact that more educated people are more critical of the claims made regarding sustainable development in the financial sector. They see a discrepancy between the slogans proclaimed by financial institutions and the practical efforts made to support environmental protection. The literature presents this phenomenon as an opposition to greenwashing practices (Marko & Kusá, 2023; Meet *et al*., 2024).

Another important factor is the subjective assessment of financial knowledge. The positive relationship between a respondent's proclaimed level of knowledge of financial issues and their perception of FinTech companies as environmentally friendly may be because their financial knowledge also includes awareness of green finance. Consumers with extensive financial literacy may be more aware of the environmental activities of financial institutions. Scientific research conducted over the last several decades in the UK, Germany, Poland (Ringel & Mjekic, 2023; Akomea-Frimpong *et al*., 2021; Dziawgo, 2014), and relatively recently also in Ukraine (Zapotichna, 2024) shows that environmental protection is strongly emphasised by financial sector institutions. These sources also help explain the difference in the importance of green finance factors between Ukraine and the other countries analysed. The higher level of financial market development and social awareness of green issues justify the importance of the EDU and KNW variables for the UK, Germany, and Poland. Due to a less developed offer of financial services and less emphasis on environmental protection issues, the Ukrainian society acquires the belief in the environmental friendliness of the services offered by FinTech companies through direct use of them (APP).

Apart from financial issues, FinTech also emphasises the importance of digital technologies. The modelling results indicate a positive relationship between the perceived benefits of using AI technology in the financial sector and the perception of FinTech companies as environmentally friendly. Those convinced that AI can positively impact the quality of financial services may also see the benefit of greater use of advanced digital technologies for environmental sustainability. Many previous studies of FinTech emphasise that AI, big data, and cloud computing increase access to green finance by expanding the range of services and reducing information asymmetry and financing costs (Tao *et al*., 2022; Zhou *et al*., 2022; Lv & Xiong, 2022; Dynan *et al*., 2006). In turn, Si Mohammed *et al*. (2024) identified a positive relationship between the use of AI and FinTech and promoting eco-friendly investments and non-greenwashing practices. On the other hand, Altarawneh (2025) showed that integrating Big Data analytics into environmental activities increases FinTech brand visibility. This approach is consistent with the broader concept of data-driven sustainability, which postulates the integration of artificial intelligence and advanced data analysis in environmentally conscious decision-making (Addy *et al*., 2024). Therefore, we may assume that the results of our study allow for a positive answer to the

Table 3. The results of the estimated ordered logit models

Variables / Statistics	Dependent variable: Green FinTech perception (GFT)											
	(1)				(2)				(3)			
	UA	PL	DE	UK	UA	PL	DE	UK	UA	PL	DE	UK
GEN	−0.310*	−0.160	−0.113	−0.090	−0.379**	−0.160	−0.222	−0.223	−0.411**	−0.122	−0.209	−0.217
	(0.172)	(0.175)	(0.167)	(0.173)	(0.173)	(0.176)	(0.169)	(0.175)	(0.177)	(0.178)	(0.169)	(0.178)
AGE	−0.021**	0.001	−0.024***	−0.025***	−0.016*	0.007	−0.013	−0.013*	−0.019**	−0.003	−0.015*	−0.011
	(0.008)	(0.008)	(0.008)	(0.007)	(0.009)	(0.008)	(0.008)	(0.008)	(0.009)	(0.008)	(0.008)	(0.008)
RES	−0.104***	−0.055	0.039	0.089**	−0.101***	−0.062	0.005	0.071*	−0.095**	−0.062	0.005	0.046
	(0.039)	(0.040)	(0.038)	(0.040)	(0.039)	(0.040)	(0.039)	(0.040)	(0.039)	(0.041)	(0.040)	(0.041)
EDU	−0.091	−0.270***	−0.098	−0.138*	−0.092	−0.256***	−0.148**	−0.188**	−0.049	−0.253***	−0.162**	−0.209***
	(0.077)	(0.086)	(0.068)	(0.075)	(0.077)	(0.087)	(0.069)	(0.076)	(0.078)	(0.088)	(0.070)	(0.077)
KNW	0.178**	0.480***	0.246***	0.266***	0.133	0.413***	0.166**	0.192***	0.079	0.315***	0.147**	0.166**
	(0.087)	(0.080)	(0.068)	(0.072)	(0.089)	(0.082)	(0.070)	(0.074)	(0.091)	(0.084)	(0.070)	(0.075)
APP	–	–	–	–	0.240**	0.178*	0.093	0.044	0.273***	0.125	0.081	0.059
					(0.096)	(0.095)	(0.094)	(0.096)	(0.097)	(0.097)	(0.094)	(0.097)
AIQ	–	–	–	–	0.281***	0.277***	0.434***	0.464***	0.227***	0.212***	0.409***	0.397***
					(0.077)	(0.070)	(0.069)	(0.063)	(0.078)	(0.071)	(0.070)	(0.063)
SFW	–	–	–	–	–	–	–	–	0.276***	0.156**	−0.044	0.229***
									(0.088)	(0.071)	(0.066)	(0.073)
ENV	–	–	–	–	–	–	–	–	0.162**	0.407***	0.193***	0.312***
									(0.080)	(0.076)	(0.067)	(0.063)
SAV	–	–	–	–	–	–	–	–	0.075	0.012	−0.039	−0.001
									(0.073)	(0.070)	(0.070)	(0.076)
Observations	500	500	500	500	500	500	500	500	500	500	500	500
Number and percentage of cases 'correctly predicted'	265 (53.0%)	239 (47.8%)	217 (43.4%)	235 (47.0%)	265 (53.0%)	249 (49.8%)	220 (44.0%)	238 (47.6%)	268 (53.6%)	258 (51.6%)	226 (45.2%)	246 (49.2%)

Note: coefficients and standard errors in parentheses; *p<0.1; **p<0.05; ***p<0.01; UA: Ukraine, PL: Poland, DE: Germany, UK: United Kingdom.
Source: own study.

first research question. Putting emphasis on the business application of AI by FinTech companies appears to be a useful tool in shaping their image as institutions supporting environmental protection. This finding is in line with previous studies indicating the beneficial impact of using AI in green finance (Omri *et al.*, 2025; Hassanein & Tharwat, 2024; Yang *et al.*, 2025).

The last two variables considered – respondents' beliefs and values regarding social and environmental issues – support the VBN theory. Our study indicates that those most interested in the environmental aspects of FinTech are people who value sustainable development, manifested in their care for others (seeing a need to support those in difficult financial circumstances) and for the environment (awareness of the impact of individual decisions). These individuals more easily perceive the ecological dimension of FinTech companies' activities, which may translate into the adoption of green FinTech services. Our findings are consistent with the results of previous research. Hong *et al.* (2024) reported the positive relationship between the variables of the VBN theory and the adoption of green consumption behaviours, highlighting the importance of personal norms and environmental awareness. Numerous other studies also indicate that people supporting sustainable development values are more sensitive to phenomena occurring in their environment, have a higher propensity for pro-environmental behaviour (Chen, 2015; Hiratsuka *et al.*, 2018), and adopt pro-environmental solutions (Hilale & Chakor, 2024; Vorobeva *et al.*, 2022; Bockarjova & Steg, 2014) and consumer engagement (Mehta & Handriana, 2024). Furthermore, several studies show that the perceived benefits for the environment of having and using a sustainable innovation and the ability to signal their positive features motivate people to adopt these innovations (Korcaj *et al.*, 2015; Noppers *et al.*, 2014; Noppers *et al.*, 2015). Therefore, the results of our study allow for answering the second research question. It has been demonstrated that personal values and beliefs regarding sustainable development are important determinants of the perception of FinTech companies as institutions supporting environmental protection.

CONCLUSIONS

The few studies to date indicate that many respondents are unaware of the environmental protection efforts of banks and FinTech companies. This observation is extremely valuable for the managers of these institutions and should motivate intensified efforts toward environmental sustainability and increase the effectiveness of their communications concerning the environment. From a business point of view and due to the expected benefits for humanity and the planet, it is important that environmental activities are accompanied by a proper message. The logit estimations may be useful for companies presenting their financial services offerings and achievements in the area of green FinTech to establish an image of FinTech as environmentally friendly.

The results of our study indicate that consumers' values and beliefs regarding sustainable development are important factors determining the perception of FinTech companies as institutions supporting environmental protection. This finding provides empirical support for the value-belief-norm theory. It also indicates that promoting environmental awareness by offering green financial services, and in particular, encouraging their use, can positively influence the perception of FinTech companies as environmentally friendly. However, presenting actual activities and their effects on the environment should consider ethical issues. This is particularly the case for educated people who are more sceptical about green FinTech and sensitive to greenwashing practices. The above recommendations provide valuable guidelines for decision-makers in promoting green FinTech in Europe, but also more broadly, worldwide.

Empirical evidence also shows the potential of building the image of a green institution based on the message about the AI use in financial services. FinTech companies should emphasise the benefits for the environment resulting from the implementation of advanced digital technologies in their communications with consumers. This conclusion is a step forward in relation to previous studies, which were usually limited to identifying the beneficial impact of using digital technologies in finance on the environment. Noteworthy, incorporating this recommendation significantly broadens the target audience of the message and may contribute to increasing its effectiveness.

While the research conducted for this article provides insight into consumer perceptions of FinTech players, it is somewhat general in nature. A future case study could consider several FinTech companies that are assessed as environmentally friendly. In particular, these should consider environmental sustainability success factors relating to green FinTech activities and communications. It is also advisable to conduct in-depth research to identify differences between countries in the factors that significantly influence consumers' perception of FinTech companies as green. Research in this area should also cover countries outside Europe.

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Use of Artificial Intelligence

The manuscript is free of AI/GAI usage.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Technological investments and green energy production in Central and Eastern Europe

Marcin Salamaga

A B S T R A C T
Objective: The article aims to examine the impact of technological investments on the development of wind energy and photovoltaics in Central and Eastern European countries (CEE) belonging to the EU.
Research Design & Methods: In the analysis of the impact of expenditure on technical investments, I used panel threshold analysis and bootstrap simulation tests. I built the models based on the basis of annual data on the renewable energy market from 2013-2023 from the 'Our World in Data' databases and Eurostat.
Findings: Research and development (R&D) expenditure stimulates the production of electricity from wind turbines to a greater extent than from PV panels. The strongest stimulation of electricity production simultaneously by a wind turbine and PV panels will occur when R&D expenditure ranges from 0.96% to 1.39% of GDP. If these expenses are in the range of 0.78% to 0.96% of GDP, solar energy will be stimulated the most, while if R&D expenditures are in the range of 1.39% to 1.61%, wind energy will be stimulated the most by these expenses. A simultaneous weakening of the development of wind and solar energy will occur when R&D expenditure is below 0.78% of GDP. Exceeding subsequent R&D expenditure thresholds weakens the effects of increasing energy production from renewable energy sources, which is caused by the intensification of the impact of various barriers inhibiting the development of renewable energy sources.
Implications & Recommendations: The obtained results may be helpful for decision-makers responsible for shaping energy policy in individual countries of Central and Eastern Europe. Stimulation of the renewable energy sector through R&D expenditure is limited due to the existing barriers to the development of renewable energy sources specific to various countries. Fully exploiting the potential of renewable energy requires a gradual overcoming of these limitations. Energy policy aimed at eliminating barriers to the development of renewable energy should consider the local conditions of individual countries in terms of their natural conditions, available resources, energy infrastructure, diversification of energy sources, etc.
Contribution & Value Added: The article presents an original analysis of the impact of expenditure on technological investments using panel threshold analysis and bootstrap simulation tests. The presented results bring added value to economic and policy research in the renewable energy sector.
Article type:	research article
Keywords:	renewable energy sources; wind energy; photovoltaics; panel threshold analysis; Central and Eastern Europe (CEE)
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INTRODUCTION

Climate change caused by excessive greenhouse gas emissions has far-reaching effects at the national and global levels. The costs that the economy incurs as a result of them are enormous and many sectors, industries, and entire societies experience them. Among others, they include material losses in the economy's infrastructure caused by devastating weather phenomena (floods, droughts, hurricanes), losses in agricultural crops and the growing threat to food security, costs resulting from

disruptions in foreign trade and supply chains, and many others. Moreover, the limited supply of fossil fuels, their growing and unstable prices, and the desire to diversify energy sources force the governments of individual countries to conduct an energy transformation, the key element of which is replacing conventional energy sources with renewable energy sources (Xie *et al.*, 2020; Zhou *et al.*, 2019; Sun *et al.*, 2021). Photovoltaics and wind energy are very important in this respect, as they support sustainable development, combining economic benefits with environmental protection, and in the long term, improve the quality of life and help preserve natural resources for future generations. However, the development of this type of renewable energy requires continuous investments in new technologies. Thanks to them, it is possible to increase the efficiency of energy production through efficient solar panels and wind turbines and, in the longer term, reduce the costs of energy production (Matsuo, 2019; Zhou & Gu, 2019). Countries can achieve it through both innovative solutions and the modernization and expansion of the existing energy infrastructure, which in many countries of Central and Eastern Europe is very outdated (Mazurek-Czarnecka *et al.*, 2022; Szép *et al.*, 2023; Leal Filho *et al.*, 2021). In addition to improving photovoltaic panels and wind turbines to increase their efficiency, the key directions of technological investments in the area of renewable energy include the construction of energy storage facilities and smart energy networks integrated with traditional energy networks (Mengxuan *et al.*, 2024; Leal Filho *et al.*, 2021).

Of course, the effectiveness of the energy transformation is also conditioned by a number of other factors that will not be the subject of detailed considerations in this study, such as appropriate regulatory and political support (*e.g.*, a feed-in tariff system) or raising environmental awareness and appropriate education (Mengxuan *et al.*, 2024; Mazurek-Czarnecka *et al.*, 2022). Previous scientific research shows that the relationship between technological innovation and energy production from renewable energy sources is not necessarily linear and various factors such as technological infrastructure, the level of investment in modern technologies, or the state's energy policy may differentiate it. Thus, the efficiency of clean energy production and the rate of cost reduction of renewable energy technologies may depend on the level of countries' technological advancement, the level of expenditure on technological investments, and the number of patents related to renewable energy sources (Leal Filho *et al.*, 2021; Li *et al.*, 2023). Here, technological investments are financial outlays aimed at implementing new or improving existing technologies to increase productivity, efficiency or innovation.

In countries with a low level of innovation, these effects may be weaker, and among technological leaders – significant (Li *et al.*, 2023; Mengxuan *et al.*, 2024). Hence, it seems justified to look for appropriate threshold values of investments in technologies (measured by R&D expenditure or the number of patents), above which the effects of changes in the renewable energy sector are significant (and below which they are, for example, poorly visible). Indicating such thresholds is possible using econometric modelling conducted based on historical data including selected indicators of renewable energy development, R&D expenditure and other macroeconomic variables. A dedicated tool for estimating this type of threshold is panel threshold regression models and I will use these models in this article (Hansen, 1999). They allow us to capture the nature of relationships between variables that are not possible to observe in ordinary linear regression models.

In this research, such models will serve to isolate the range of values of the share of R&D expenditures in GDP, at which the strength and dynamics of stimulating wind energy and photovoltaics through investments in green technologies are the most intense, and the range of values of R&D expenditures, where they are weak. I aimed to comprehensively examine the impact of technological investments on the production of green energy in Central and Eastern European countries. The technological investments considered in this article concern projects involving the implementation of technologies related to renewable energy sources (construction of wind farms, photovoltaic farms, energy storage facilities or energy infrastructure), while the term green energy refers to electricity generated by wind turbines or photovoltaic panels. The choice of these countries resulted from the fact that researchers rarely analyze in a comprehensive way the impact of innovation and technological investments on the diffusion of renewable energy technologies and energy production from renewable energy sources in all these countries (Mengxuan *et al.*, 2024). Meanwhile, the energy transformation that

these countries are going through requires overcoming numerous difficulties related to the strong dependence of their economies on fossil fuels, outdated energy infrastructure, lack of their own renewable energy technologies and the need to import them, insufficient funds for the modernization of energy systems requiring the withdrawal of conventional electricity sources and replacing them with renewable energy sources (Pakulska, 2021; Mazurek-Czarnecka *et al.*, 2022).

The problems that the economies of CEE countries face are often more serious than in Western European countries, which generally have their own base of advanced renewable energy technologies (Leal Filho *et al.*, 2021). Therefore, monitoring the progress in the energy transformation and identifying ways to overcome the barriers that slow down this transformation seems to be a necessity. By filling the research gap, this article will at least partially answer what actions to take to improve the effectiveness of renewable energy implementation in CEE countries and thus support the energy transformation process. The research conclusions can support decision-makers responsible for shaping energy policy at national and EU levels. This is even more important because EU countries, under various agreements, directives and general EU strategies, are obliged to replace conventional energy sources with renewable energy sources. Therefore, energy transformation is a necessity, and the countries of Central and Eastern Europe, due to their technological backwardness and the strong dependence of their economies on fossil fuels, require particularly intensive actions in this area. The main novelty of this article is the presentation of the impact of technological investments on the development of wind energy and photovoltaics in the countries of Central and Eastern Europe using the panel threshold regression model. This is the first application of this research method in the analysis of the production of these two types of green energy in the economies of Central and Eastern European countries. The main advantage of using panel threshold regression over the tools used by other researchers is the possibility of isolating nonlinear relationships between variables. Thanks to the applied approach, the research results allow for the formulation of specific recommendations for decision-makers responsible for economic policy. For example, the article answers the question of the level at which R&D expenditures should be set, and to which sectors they should be directed, to optimize the structure and level of green energy production.

LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

Research on technological investments' impact on the development of renewable energy sources has been conducted for years. However, recently, the intensity of publications on this subject has significantly increased, which probably results from the intensification of activities aimed at energy transformation undertaken at the levels of individual countries and the entire EU. Based on the literature studies, we can conclude that researchers focus on various aspects of this issue, which allows us to distinguish certain directions of research on stimulating the development of renewable energy sources through technological investments, such as analysis of the efficiency and effectiveness of renewable energy sources, cost analysis, development of system innovations or research on the scalability of production of renewable energy infrastructure components. As part of the first of the above-mentioned research trends, I tried to check to what extent spending on research and development, together with other stimulants, increases the overall share of renewable energy sources in the energy mix of individual countries or regions, or examine how the efficiency and productivity of these energy sources change.

Using the autoregressive distributed lags model (ARDL), Chmielewski *et al.* (2023) showed that in EU countries there is a strong positive relationship between research and development expenditure and the increase in energy consumption from renewable sources, while their impact on reducing fossil fuel consumption and energy prices is less significant. Using a similar research methodology, Li *et al.* (2020) proved the positive impact of eco-innovation, as well as energy productivity, human capital, and energy prices on the development of renewable energy. In turn, Sun *et al.* (2021) examined the impact of R&D expenditure, and in particular, the impact of the international dissemination of knowledge related to the reduction of energy intensity on energy efficiency in EU countries. Using data from the OECD Triadic Patent Families database for 24 innovative countries from 1994-2013, they proved the existence of a positive relationship between these values, and among the most energy-efficient countries, they indi-

cated Germany, France, Great Britain, the Netherlands and Switzerland. Churchill *et al.* (2021) analysed the impact of R&D expenditure on energy consumption per capita and using the local linear dummy variable estimation (LLDVE) method on the example of OECD countries, they showed positive effects in the area of renewable energy, although their occurrence depended on the period under study.

Geng and Ji (2016) demonstrated the existence of a long-term balance between technological innovation and other external drivers and renewable energy consumption. Moreover, they proved the existence of bidirectional causality between these categories. There are relatively many articles in which scholars examine the relationships in question for Asian markets. An example would be the article by He *et al.* (2018), in which the authors confirmed a positive relationship between the studied variables for the Chinese market. They obtained these results by examining 29 provinces in China using a dynamic panel approach. Kocsis and Kiss (2014) studied the relationships between the share of renewable energy consumption in gross energy consumption, GDP per capita and research and development expenditure in European Union countries. They confirmed a positive relationship between research and development expenditure and renewable energy consumption at various GDP levels.

Li *et al.* (2023) obtained interesting results from the study of the impact of technological investments on the diffusion of renewable energy technologies using panel threshold regression. Using the example of G10 countries, they showed that technological innovations have little impact on renewable energy when technological innovations are below a certain threshold of the share of R&D spending in GDP. Exceeding this threshold means that technological innovation has a strong positive impact on renewable energy. Xie *et al.* (2020) showed that the development of new technologies can stimulate the positive impact of renewable energy consumption on green economic development while reducing the dependence of gross domestic product (GDP) on fossil fuels improves the coordination of the relationship between these quantities. The second of the mentioned trends focuses on diagnosing factors that reduce the costs of renewable energy. Scholars who undertook cost analysis were, among others, Matsuo (2019), Zhou and Gu (2019), and Elia *et al.* (2021). They showed that research and development expenditure directed towards renewable energy sources contributes significantly to reducing unit production costs. These authors propose various forms of support for the renewable energy sector to increase its efficiency and reduce energy production costs.

For example, Esmaieli *et al.* (2018) suggest an approach based on supporting research and development activities to reduce the investment costs of wind units. It involves paying a fixed amount of money to wind units in proportion to their installed capacity, which then allocate the received funds for research and development activities. Appropriate simulations conducted by the authors confirmed the effectiveness of this type of support compared to other known incentives. Numerous works highlight the importance of both learning by doing and learning by searching (R&D spending) in driving technological progress that is expected to significantly accelerate cost reduction and market penetration of renewable energy (Hayamizu *et al.*, 2014; Zhou & Gu, 2019; Cory *et al.*, 1999). Moreover, researchers emphasize the need for institutional support and policy instruments to promote renewable energy adoption and cost reduction (Zhou & Gu, 2019).

Despite relatively numerous publications devoted to the impact of technological investments on the development of renewable energy in various countries, there is no in-depth analysis of such a relationship for the EU countries of Central and Eastern Europe. Meanwhile, most of these countries face greater challenges in implementing the energy transformation compared to Western European countries due to their strong dependence on their own fossil fuels (*e.g.*, Poland) or their import from abroad (Hungary), an outdated energy network requiring high expenditure, modernization, limited budget funds for costly transformation, the low energy efficiency of old buildings that dominate the housing structure, social and political resistance to the reduction of employment in the energy sector and mining. The few works that undertake a broader study of the impact of technological investments on energy efficiency in CEE countries include an article by Mengxuan *et al.* (2024). Using Grenger's panel causality analysis, the authors demonstrated the impact of various factors on energy efficiency and showed the existence of a feedback relationship. They showed, among others, that through various economic and political factors, technological investments significantly affect energy efficiency in the

Czech Republic, Latvia, Lithuania, Slovakia and Slovenia. They used panel threshold regression aggregate energy efficiency (calculated ratio of total energy generated to GDP), which makes it difficult to assess the contribution of renewable energy sources to the energy transformation of individual countries. For this reason, it seems necessary to fill the research gap and analyse the impact of technological investments separately on wind and solar energy in CEE countries, which will allow for assessing the effectiveness of tools stimulating the diffusion of energy based on renewable energy sources. To examine the relationship between technological investments and the development of wind and solar energy, I used a threshold panel regression model, which allowed me to capture the non-linear relationships that occurred between these variables (Mengxuan *et al.*, 2024; Li *et al.*, 2023). To achieve the main research objective, I decided to verify the following hypotheses:

H1: In CEE countries, there is at least one threshold point of R&D expenditure, exceeding which significantly changes the impact of technological investments on the amount of energy generated by wind turbines or photovoltaic panels.

H2: In CEE countries, the impact of technological investments on the production of energy from wind turbines is different than from photovoltaics.

Hypothesis H1 was inspired by literature studies, including empirical studies on various economies in the world, in which it was possible to identify threshold values for investment in innovations that differentiate the effects resulting from the production of green energy (Li *et al.*, 2023; Mengxuan *et al.*, 2024). Moreover, literature studies indicate that in CEE countries, the investment priorities of the governments of individual countries in the development of photovoltaics and wind energy are not the same, which is the result of, among others, specific natural conditions in these countries (*e.g.*, wind potential, solar radiation), social conditions (lower acceptance of wind energy) and economic conditions (differences in investment costs) (Mazurek-Czarnecka *et al.*, 2022; Leal Filho *et al.*, 2021). In turn, this shows the validity of hypothesis H2. The econometric model I used enabled the verification of both these hypotheses.

RESEARCH METHODOLOGY

Considering the differences in the levels of technological innovation measured by R&D expenditure in various EU countries, I expected that I would encounter thresholds affecting the production of electricity by wind farms and energy from photovoltaics. Determining threshold values for the level of technological innovation would allow for identifying the directions and strength of the impact of R&D on wind and solar energy in the surveyed countries. For this purpose, I used threshold panel regression (Hansen, 1999), which would eliminate the random effect of artificial grouping. I used this type of regression to study the relationship between energy efficiency and technological investments in Central and Eastern European countries, among others, Mengxuan *et al.* (2024).

However, they modelled the overall efficiency of electricity production, which does not allow for determining how R&D expenditure translates into an increase in energy production coming entirely from renewable energy sources or from individual types of renewable energy sources. This study overcame this limitation and built models separately for wind and solar energy (the amount of energy generated by these types of renewable energy sources was modelled), which facilitates the assessment of the ability of investment expenditure to stimulate energy transformation. This is also the unique contribution of this work: separating solar energy from wind energy in threshold panel regression models provides much greater possibilities for controlling the state's innovation policy in the field of RES. The study covered 11 Central and Eastern European countries that are EU members, namely, the Czech Republic, Croatia, Bulgaria, Estonia, Hungary, Lithuania, Latvia, Poland, Romania, Slovakia, and Slovenia. I built the models based on annual data on the renewable energy market from 2013-2023 from the 'Our World in Data' (2024) databases and Eurostat (2024).

The research included models with one threshold point for R&D spending and a model with two threshold points. The modelled endogenous variable is green energy production defined as energy generated by wind turbines or photovoltaic panels, which seems to be the right category to reflect the

development of renewable energy sources (Mengxuan *et al.*, 2024). The proposed explanatory variables are substantively related to the development of renewable energy sources and the amount of energy produced by them. Obviously, GDP, R&D and the number of patents in renewable energy technologies influence the level of green energy production, because renewable energy sources require investment and innovation (Li *et al.*, 2023). Research and development expenditure includes expenses incurred on creating new technologies as well as improving existing solutions that support the efficiency, availability, and profitability of renewable energy. Electricity consumption also determines the demand for energy also from renewable energy sources (Geng & Ji, 2016). Thus, I also considered it. The model also includes the price of electricity as a determinant of green energy production, as it is expected that the rising prices of electricity from fossil fuels will encourage the search for cheaper energy sources (Elia *et al.*, 2021). Many studies also indicate a possible relationship (negative or positive) between CO2 emissions and renewable energy production (Mazurek-Czarnecka *et al.*, 2022). Thus, I also included this variable in the model. The equations of these models were as follows:

Single threshold model:

$$Y_{it} = \theta + \alpha_1 CO2_{it} + \alpha_2 TNP_{it} + \alpha_3 EP_{it} + \alpha_4 GDP_{it} + \alpha_5 EC_{it} + \alpha_6 RDE_{it} + \beta_1 RDE_{it} I(R\&D \leq \delta)$$
$$+ \beta_2 RDE_{it} I(R\&D > \delta) + \mu_i + \varepsilon_{it} \tag{1}$$

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$$+ \beta_2 RDE_{it} I(R\&D > \delta) + \mu_i + \varepsilon_{it} \tag{2}$$

in which:

Y - energy generated by wind turbines or by photovoltaic panels (TWh);
CO2 - emissions per person (t);
TNP - total number of patents in renewable energy technologies;
EP - energy price (euro/MWh);
GDP - *GDP per capita* (USD);
EC - electricity consumption per capita (MWh);
RDE - research and development expenditure (% of GDP);
I - an indicator function, taking the value 1 when the condition is met and 0 otherwise;
R&D - threshold variable;
δ_1 - the single threshold value, δ_2 – the double threshold value;
μ - the individual fixed;
ε **-** random interference term.

I took the values of the following variables *Y*, *CO2*, *TNP* from the 'Our World in Data' database, and the remaining ones from the Eurostat database.

I estimated the parameters of equations (1) and (2) using the fixed effects (FE) estimator (Hansen, 1999). Prior to the estimation of the models, I tested the threshold effect, the aim of which is to demonstrate the existence of statistically significant non-linearity in the relationships between variables resulting from the presence of the threshold effect. This allowed me to confirm whether it is actually justified to distinguish separate subgroups depending on the value of the threshold variable. Moreover, it was also necessary to determine the appropriate number of thresholds for the considered relationship between the variables. As part of the examination of the existence of the threshold effect, I tested a set of statistical hypotheses: H_0 – the threshold effect does not occur in the linear model with the slope coefficient β ($\beta_1 = \beta_2$); H_1 – there is a threshold effect ($\beta_1 \neq \beta_2$). The test statistic then took the following formula:

$$F_1 = \frac{n(T-1)(S_0 - S_1(\hat{\delta}))}{S_1(\hat{\delta})} \tag{3}$$

in which:

S_0 - the sum of squared residuals in the model without threshold effect;
$S_1(\hat{\delta})$ - sum of squared residuals in model without threshold effect $(\hat{\delta})$;
n - number of observations;
T - number of time periods.

The F1 (3) test statistic when H_0 was true had a non-standard distribution without critical values, it was necessary to use bootstrap tools to generate quantiles of this distribution. Therefore, according to Hansen's (1999) procedure, I calculated the following test statistic:

$$LR_1(\delta) = \frac{n(T-1)(S_0(\delta)-S_1(\hat{\delta}))}{S_1(\hat{\delta})} \qquad (4)$$

Statistics (4) serves to test the hypothesis H_0: $\delta = \delta_0$ and it has a non-standard distribution.

Moreover, it is proved that, assuming $n \to \infty$, $LR_1(\delta) \to \vartheta_d$, the random variable ϑ has the following distribution function:

$$P(\vartheta < x) = (1 - \exp(-0.5x))^2 \qquad (5)$$

By transforming function (5), you can obtain a formula that serves to calculate critical values:

$$c(\alpha) = -2\ln(1 - \sqrt{1-\alpha}) \qquad (6)$$

If $LR_1 > c(\tau)$, I rejected H_0: $\delta = \delta_0$ and confirmed the existence of a threshold point.

RESULTS AND DISCUSSION

This section will present the results of the panel threshold regression for wind energy and solar energy. Tables 1 and 2 present the results of bootstrap tests of the number of threshold points, which enabled the selection of the appropriate number of points used in the estimation of parameters of panel regression models built for energy production from wind turbines and photovoltaic panels.

Table 1. Results of testing the number of threshold points of panel regression for wind energy

Type of threshold	Threshold estimates	F	p
Single threshold	1.613	47.253	0.001
Second threshold	0.964 1.613	36.284	0.025
Triple threshold	0.536 0.964 1.613	5.72	0.642

Source: own study.

Based on the results of the F bootstrap and p-value bootstrap tests, I could conclude that the number of threshold points in the model describing wind energy production was two, and these were R&D shares of 0.964% and 1.613% of GDP, respectively (for triple threshold p-value>0.05).

Similarly to wind energy, I performed a test for the number of threshold points for photovoltaics (Table 2).

Table 2. Results of testing the number of threshold points of panel regression for photovoltaics

Type of threshold	Threshold estimates	F	p
Single threshold	1.392	41.796	0.002
Second threshold	0.779 1.392	28.389	0.031
Triple threshold	0.451 0.779 1.392	9.524	0.438

Source: own study.

The results of the F1, F2, and F3 statistics for single threshold, second threshold and triple threshold and bootstrap p-value proved that the number of threshold points in the model describing the production of electricity from PV was also two and these shares of R&D in GDP were equal to 0.779% and 1.392%, respectively. Tables 3 and 4 present the estimation results of the appropriate threshold panel regression models for wind energy and photovoltaics.

Table 3. Results of parameter estimation of panel threshold regression for wind energy

Parameter	Coefficient	Standard error	t	p
const	-4.3923	1.6576	-2.6498	0.0093
CO2	-0.3678	0.1309	-2.8101	0.0059
TNP	0.0056	0.0014	3.8978	0.0002
EP	0.0051	0.0019	2.7249	0.0075
GDP	0.8633	0.2429	3.5547	0.0006
EC	0.5528	0.2219	2.4915	0.0144
R&D ≤ 0.96 %	1.2915	0.5600	2.3064	0.0231
0.96% < R&D ≤ 1.61%	1.6812	0.7586	2.2161	0.0290
R&D >1.61%	1.5658	0.6159	2.5425	0.0125

Source: own study.

In both panel threshold regression models, there were two thresholds for research and development expenditure that differentiate the pace of development of wind and solar energy. Both models fit the empirical data quite well, as evidenced by the determination coefficient values of 0.7376 and 0.8699, respectively. Based on the results in Table 3, I could conclude that the strongest impact of technological investments on the volume of electricity production from wind farms occurred between the first and second thresholds of R&D expenditure, which amounted to 0.96% and 1.61% of GDP, respectively. If the share of R&D expenditure fell within this range, an increase in technological investments by 1‰ generated an increase in the production of electricity generated by wind turbines by an average of approximately 168 GWh, *ceteris paribus*. When R&D expenditure constituted less than 0.96% of GDP, their impact on wind energy was much weaker: an increase in technological investments by 1‰ results in an increase in electricity production by on average approx. 129 GWh, *ceteris paribus.* It seems obvious that with insufficient financing of scientific research and too little support for innovative activities, the development of renewable energy sources will obviously be slower and the amount of electricity they generate will be lower.

However, another effect may be surprising: with the level of R&D expenditure above 1.61% of GDP, the pace of wind energy development also slowed down: an increase in technological investments by 1‰ resulted in an increase in electricity production by an average of approx. 157 GWh *ceteris paribus*, *i.e.*, by approx. 11 GWh less than with the share of R&D expenditure ranging from 0.96% to 1.61% of GDP. This may result from various factors, such as redirecting part of R&D expenditure to support renewable energy sources other than wind energy, limited capacity of transmission networks in Central and Eastern European countries, lack of appropriate wind conditions for the effective use of wind technology, limited opportunities for the development of offshore farms due to lack of access to the sea (in the case of some countries), opposition of local communities to plans to build further wind farms (due to concerns about their undesirable impact on human health, landscape, etc.) Control variables such as GDP, electricity consumption, and the number of patents in the field of renewable energy have a stimulating effect on the development of wind energy, with GDP having the strongest impact on the development of this form of energy: its increase by 1 thousand USD per person implies an increase in energy production from wind turbines by an average of approximately 0.863 TWh. *ceteris paribus*. Other authors have confirmed the direction of the influence of control variables on renewable energy production (Zwarteveen *et al.*, 2021; Şener et al., 2018; Strantzali & Aravossis, 2016). The only control variable that destimulated wind energy turned out to be CO_2 emissions, which reduced the production of electricity from wind turbines. This may be surprising because the increase in CO_2 emissions is one of the reasons for moving away from traditional fossil fuels and replacing them with renewable energy sources. However, the ambiguous impact of CO_2 emissions on the production of energy from renewable energy sources is also confirmed by other scientific analyses (Saidi & Omri, 2020). The impact of energy prices on the development of wind energy was not statistically significant in the discussed model, while many research results confirm a significant relationship between these categories (Li *et al.*, 2020).

Table 4. Results of parameter estimation of panel threshold regression for photovoltaics

Parameter	Coefficient	Standard error	t	p
const	-0.4162	1.1389	-0.3654	0.7155
CO2	-0.1855	0.1809	-1.0259	0.3073
TNP	0.0096	0.0011	8.6390	0.0000
EP	0.0020	0.0027	0.7332	0.4651
GDP	0.9741	0.0321	3.0310	0.0031
EC	0.4912	0.1530	3.2108	0.0018
R&D ≤ 0.78%	0.3237	0.0817	3.9616	0.0001
0.78% < R&D ≤ 1.39%	0.9456	0.2418	3.9107	0.0002
R&D >1.39%	0.8552	0.2486	3.4398	0.0009

Source: own study.

The calculation results presented in Table 4 indicate that technological investments are a less effective tool for energy transformation related to photovoltaics than for wind energy. The increase in the production of electricity from PV due to the change in technological investments was lower than the increase in the production of electricity from wind turbines resulting from a similar increase in these investments. The strongest stimulation of electricity production from PV by R&D expenditure was visible when the share of these expenditures in GDP was in the range from 0.78% to 1.39%. Then, a 1-per-mille increase in technological investments results in an increase in electricity production from photovoltaics by an average of approximately 95 GWh, *ceteris paribus*. The same increase in technological investments implied an increase in electricity production from PV on average by approximately 32 GWh, if R&D expenditure constituted less than 0.78% of GDP, and caused an increase in energy production by approximately 86 GWh, *ceteris paribus*, if R&D expenditure constituted above 1.39% of GDP.

Therefore, too low a level of R&D expenditure (below the value of the first threshold of 0.78% of GDP) weakens the energy transformation in the field of photovoltaics, and this is not surprising: electricity production is then lower on average by approximately 63 GWh (compared to the situation when R&D expenditure is in the range from 0.78% to 1.39% of GDP). Similarly to the case of wind energy, exceeding the second threshold value of R&D expenditure also resulted in a reduction in the scale of electricity production from PV by approximately 9 GWh (compared to the scenario when R&D expenditure fell between the two thresholds). This situation may result from various barriers to the development of solar energy, such as the lack of attractive and guaranteed tariffs for settling the costs of selling and purchasing electricity by prosumers, limited capacity of transmission networks, lack of sufficient energy storage infrastructure, and insufficient level of sunlight, especially among the Baltic countries. In some countries of Central and Eastern Europe, the applicable settlement tariffs force prosumers to sell energy generated by PV at low prices when they have to pay a price for the purchased electricity that is many times higher. Moreover, frequent changes in tariffs and changes in regulations regarding renewable energy are not a factor conducive to the development of this sector (Mazurek-Czarnecka *et al.*, 2022). In turn, deficiencies in the energy infrastructure, and outdated solutions also constitute a serious technical barrier to the inclusion of further prosumers in the energy system, which is unable to absorb the overproduction of electricity.

The direction of influence of control variables on the development of photovoltaics turned out to be similar to that in the case of wind energy. The increase in energy production from PV is stimulated by GDP, per capita electricity consumption and the number of patents in the field of renewable energy. Among these variables, GDP has the strongest impact on the production of energy from PV: its increase by 1 thousand USD per person implies an increase in the production of energy generated by photovoltaics by an average of approximately 0.974 TWh, *ceteris paribus*. The obtained result stating a positive relationship between the number of patents filed in RES and green energy production is consistent with the results obtained by other researchers (Leal Filho *et al.*, 2021; Li *et al.*, 2023). CO_2 emissions did not have a significant impact on the development of photovoltaics in the analyzed model, which is

confirmed, for example, by the results obtained by Saidi and Omri, 2020. Similarly to the study conducted for wind energy, here too electricity prices did not significantly stimulate energy production from PV, which is contrary to the results of other researchers (Li *et al.*, 2020). The above analysis regarding both types of renewable energy sources shows that the strongest stimulation of electricity production generated jointly by wind turbines and PV panels will occur when R&D expenditure ranges from 0.96% to 1.39%. If these expenses are in the range of 0.78% to 0.96% of GDP, solar energy will be most strongly stimulated by technological investments, while if R&D expenditures are in the range of 1.39% to 1.61%, only wind energy will be most strongly stimulated by these investments. A simultaneous weakening of the development of wind and solar energy will occur when R&D expenditure is below 0.78% of GDP. The results obtained in this work regarding the thresholds of R&D expenditures can be treated as specific guidelines for decision-makers in the countries of Central and Eastern Europe responsible for the investment and energy policy of the states. If the priority is the development of wind energy, then the state's expenditures on R&D should be correspondingly higher than in the case when the priority is the development of photovoltaics. If the country wants to develop both energy sources on a similar scale, then R&D expenditures at the level of about 1% of GDP are sufficient. Of course, the choice between investing in solar and wind energy should be decided individually for each country based on an assessment of natural conditions (sun exposure, wind potential), energy infrastructure, and social conditions (level of social acceptance for RES). In addition, decisions on setting priorities for the development of photovoltaics or wind energy must take into account the different impacts of technological investments on the development of wind and solar energy due to differences in the technological maturity of both types of green energy, its production costs and operating conditions. Wind energy is considered to be technologically more mature and more developed than photovoltaics, but requires larger initial investments (high costs of wind turbines). In turn, photovoltaics has a greater potential for breakthrough innovations, so marginal benefits from R&D expenditures may be greater compared to wind energy. The R&D expenditure thresholds given in this article are not excessive, and achieving/exceeding them will effectively stimulate the development of RES. However, it should be remembered that the given R&D expenditure thresholds are determined as averages for all the CEE countries considered, which results from the specificity of the econometric panel data models used. The natural conditions of these countries, their exposure to the sun, wind availability, and energy infrastructure may show some differences. This means that the implementation of a specific RES development policy in a specific country may require an appropriate correction of the estimated threshold values, so as to adapt them to the specificity of the natural and economic conditions occurring in that country. It is also necessary to note the potential limitations associated with the applied econometric model of threshold panel regression. They may concern, among others, possible problems with threshold identification, endogeneity of variables or specificity of panel data. In this study, appropriate control tests confirmed the correct specification of the model. The correctness of the number of threshold points and the correctness of their values was confirmed by the Hansen procedure (1999) based on strong results of bootstrap F and bootstrap p-value tests, while the lack of significant correlation between explanatory variables and the random component was confirmed by the Durbin-Wu-Hausman (DWH) test. Demonstrating the lack of endogeneity of explanatory variables indicates that the model did not contain significant measurement errors and that no significant variables were omitted. The added value of the presented results compared to the results in other works lies primarily in the fact that it was possible to create independent models for two types of green energy for the CEE countries, while other authors using similar research tools generally do not make such a separation of energy from RES (Mengxuan et al., 2024). Separating solar energy from wind energy provided much greater opportunities to assess the impact of technological innovations on the development of RES and made it possible to formulate much more detailed recommendations for decision-makers responsible for innovation policy than is the case in other scientific works. Moreover, by including two thresholds of R&D expenditure in the estimated models, the flexibility of the results increased significantly, which broadened the available decision-making options for those responsible for national renewable energy policies. Other works in the same area using similar research tools provide much less specific guidance

for decision-makers and politicians in Central and Eastern European countries (Mengxuan *et al.*, 2024; Mazurek-Czarnecka *et al.*, 2022) or they are too general (Pakulska, 2021).

CONCLUSIONS

The countries of Central and Eastern Europe shape their energy transformation policy based on various factors resulting from their current structure of energy sources, the geographical location determining the optimal use of the renewable energy potential, the state of energy infrastructure, the possibility of diversification of energy sources, *etc*. However, all EU member states are obliged to achieve climate neutrality, which requires them to significantly increase the share of low-emission sources in their energy mix. This is not possible without appropriate technological investments that can be used to control the development of renewable energy sources. The mechanism of stimulating photovoltaics and wind energy can be modelled and I presented such an approach in this article.

The threshold regression tool I used provides valuable conclusions regarding the mechanism of the impact of variables on the development of wind and solar energy. This allowed me to formulate important recommendations regarding the thresholds of R&D expenditures depending on the priority set by the government in the energy mix. If this priority is the parallel development of wind energy and photovoltaics, the share of R&D expenditure should be between 0.96% and 1.39%. If the priority is the development of solar energy alone, these expenditures should not exceed the threshold of 0.96% of GDP, and if the governments of the countries focus on wind energy, the share of R&D expenditure in GDP should exceed 1.39%. Countries that currently fall short of their R&D spending targets should consider changing their budget plans to increase public funding for R&D. It may be necessary to implement budget programs that will allow for planning long-term investments in science and innovation, as well as increasing the intensity of applying for appropriate funds from EU programs. It should also be remembered that R&D expenditure includes not only funds from the state budget but also from the private sector. In the second area, decision-makers also have a lot to do: it is necessary to create a package of incentives for the private sector to participate in these expenditures to a greater extent. This can be achieved by, among others: a system of tax reliefs for private investors, credit guarantees, grants and financial subsidies, creating new research and development centres that connect companies, universities and research institutes to jointly solve technological problems and greater state involvement in public-private projects. To achieve the assumed thresholds of R&D expenditures, decision-makers must take actions that will lead to an increase in public expenditures on the one hand, and on the other hand, will mobilise the private sector.

The article positively verified two research hypotheses. I showed that in CEE countries, there was at least a threshold point of expenditure on R&D, (H1) and the strength of the impact of technological investments on the production of energy from renewable sources in the area of wind energy was significantly greater than in the area of photovoltaics (H2).

Noteworthy, the results allowed me to conclude that a continuous increase in the level of expenditure on research and development does not guarantee the achievement of maximum development effects of these energy sources and therefore does not guarantee the optimal pace of energy transformation. The results of this research have shown that no worse effects in this respect can be achieved when R&D expenditures are at a moderate level, because their further increase (after exceeding subsequent thresholds) weakens the effects of increasing energy production from renewable energy sources, which is caused by the intensification of the impact of various barriers. These include: insufficient pace of development of transmission and storage infrastructure in CEE countries (too slow modernization of technical infrastructure does not keep pace with investments in new technologies), priority treatment of sectors other than the RES sector (*e.g.*, digital technologies sector) when distributing funds allocated for R&D R, as well as the too slow pace of implementation of innovations in the area of renewable energy, which means that the increase in energy production from renewable energy sources is weaker than potentially possible (Pakulska, 2021; Mazurek-Czarnecka et al., 2022; Leal Filho et al., 2021).

Certainly, important barriers to fully benefiting from the increase in R&D in the area of renewable energy also include: low social awareness of renewable energy and residents' resistance to some renewable energy installations, lack of favourable and stable settlement tariffs with electricity prosumers, di-

recting part of the investment into technologies 'temporary' related to non-renewable energy sources (*e.g.*, investments in LNG terminals), administrative and bureaucratic resistance creating problems for investors at the stage of obtaining permits for the construction of installations RES (especially wind farms), the insufficient share of private capital involved in often very expensive renewable energy infrastructure investments (Mengxuan *et al.,* 2024; Mazurek-Czarnecka *et al.*, 2022; Szép *et al.*, 2023; Leal Filho *et al.*, 2021). Undoubtedly, both photovoltaics and wind energy play a key role in the energy transformation of Central European countries belonging to the EU, but full use of their potential requires a gradual overcoming of the above-mentioned limitations. Otherwise, the constant increase in R&D spending will not translate into the development of the renewable energy sector as expected.

Based on the evaluation of the obtained threshold panel regression models, these models relatively well reflected the studied relationships, but we must remember that they have their limitations. In general, a methodological problem may be the determination of the number of thresholds, as well as the endogeneity of variables caused by, for example, the lack of taking into account important explanatory variables or measurement errors. If they occur, it may be necessary to change the specification of the entire model. The cognitive value of the model could certainly be expanded by considering further macroeconomic variables, thanks to which it would be possible to monitor the development of RES using other economic policy instruments. Noteworthy, the panel data model provides average results for the entire Central and Eastern Europe region, which may not be appropriate for the specific economy of a single country. Therefore, in the future, further detailed studies are necessary, conducted for each country. Thanks to this, recommendations regarding renewable energy policy will be more accurate, because they will be dedicated to individual economies.

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Use of Artificial Intelligence

I declare that I did not use AI/GAI tools when preparing this article.

Conflict of Interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Towards a cleaner environment: Determinants of willingness to pay for clean air and renewable energy in Poland

Michał Król, Kamil Makieła, Łukasz Mamica

A B S T R A C T
Objective: The article aims to compare the willingness to pay for energy from renewable sources with the willingness to pay for clean air in Poland and to establish factors that influence these phenomena. These topics are usually addressed in separate studies, making a credible comparison difficult.
Research Design & Methods: We survey a representative group of single-family residents and apply advanced machine learning techniques based on Bayesian model selection (averaging) to construct a credible list of factors that determine willingness to pay for clean energy.
Findings: We find that people are willing to pay more for clean air than for energy from renewable sources. Both aspects of willingness to pay are affected by the size of the electricity bills, the importance of the environment and the knowledge about renewable energy supplies. Willingness to pay for energy from renewable sources is also influenced by educational level and awareness of the need to increase the share of renewable energy in the domestic energy mix. Furthermore, we find that young people are more willing to pay for energy from renewable sources, whereas older people are more likely to pay for clean air.
Implications & Recommendations: Arguably, a higher willingness to pay requires, first and foremost, greater environmental awareness and the promotion of its benefits among the population at large. Since willingness to pay studies are based on respondents' declarations, their actual willingness to bear the costs of energy transition may be lower. A variety of initiatives should be taken to foster closer bonds between people and their environment to make them feel more responsible for the shared objective.
Contribution & Value Added: The study bridges a significant gap by examining the willingness to pay for renewable energy and clean air in the same sample of respondents. We focus on single-family home residents. Using quantitative methods, we identify factors that are common to willingness to pay for clean air and renewable energy sources, as well as those that are specific to each type.
Article type: research article
Keywords: willingness to pay; clean air; air pollution; renewable energy sources; Bayesian model selection
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INTRODUCTION

Air quality in Poland is among the worst in Europe, particularly in the southern part of the country, where even lax quality standards are routinely exceeded during the winter season (Blazy *et al.*, 2021; EEA, 2024). Although the share of renewable energy sources (RES) in the country's gross energy consumption improved over the last two decades, it remains relatively low compared to the rest of the EU (Eurostat, 2025). As a result, attempts have been made to assess the willingness of Polish citizens to bear at least some of the costs of the necessary energy transition by assessing their willingness to pay (WTP).

Studies dealing with WTP for clean air come mainly from China (see, *e.g.*, Freeman *et al.*, 2019; Ito & Zhang 2020), while scholars have studied WTP for clean, renewable energy sources (RES) for some time in Europe (see, *e.g.*, Borchers *et al.*, 2007; Sundt & Rehdanz, 2015; Hojnik *et al.*, 2021). In Poland, Kowalska-Pyzalska (2019) and Mamica (2021) have conducted similar studies on RES. To our knowledge, this study is the first attempt to compare WTP for clean air with WTP for RES based on the opinions of the same representative group and to focus on residents of single-family homes. We argue that having the two WTPs measured based on the same method and the same sample provides a better, more credible insight into their differences. Clean air and green energy are somewhat similar topics. Hence, if WTPs for them are compared separately, the differences found may be attributed, at least partially, to, *e.g.*, differences in research methodology or sample characteristics.

The questionnaire survey was conducted from July to August 2021 among a representative sample of 1007 people who live in single-family homes in Poland using the computer-assisted telephone interviewing (CATI) method. We chose this group because a large portion of such dwellings still rely on coal-derived energy. Therefore, the decisions taken by their owners may have a significant impact on the overall air quality and energy transition of the country.[1]

The article is structured as follows. Section 2 explains the rationale behind the energy transition in Poland and describes selected studies that evaluate the WTP of people for renewable energy and clean air. Section 3 describes the data acquisition and Bayesian modelling techniques used in the study. Section 4 presents the results and a discussion. Section 5 concludes.

LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

The European Union aims to achieve climate neutrality by 2050 (European Commission, 2019a) through a series of policy recommendations for national strategies (Kud *et al.*, 2021). To make environmentally friendly energy sources (RES hereafter) an effective tool to achieve the stated goals, an appropriate strategy must be adopted, considering locally specific factors, social contexts, and barriers to renewable energy development (Jeleński *et al.*, 2021).

In a 2017 analysis of all EU countries, Poland recorded the smallest decrease (about 1%) in CO_2 emissions (Brodny & Tutak, 2021), which results directly from its coal-dominated energy mix (Karpinska & Śmiech, 2021). In general, Poland accounted for 7.7% of EU emissions (greenhouse gases and air pollutants) in 2017 (Brodny & Tutak, 2021). In 2021, coal-fired power generation accounted for 72.4% of total power produced in Poland (Forum Energii, 2022). The proportion of coal in the energy mix is steadily decreasing (Tokarski *et al.*, 2024).

The resistance to the switch from coal is mainly due to the strong position of the coal mining industry and the government that supports it. Close ties between coal companies and the government serve to safeguard the interests of the coal lobby. The state owns a large stake in most coal companies and unions play a considerable role in political decision-making (Brauers & Oei, 2020). Noteworthy, coal is used not only for energy production but also for heating. Air in Poland is among the most polluted in Europe, particularly in the South (Blazy *et al.*, 2021). In 2018, the daily limit allowed for PM10 was exceeded in 39 of 46 zones (Adamkiewicz *et al.*, 2021). Usually, the average annual concentration of PM2.5 should not exceed 5 μg/m3 (EEA, 2023). In 2023, the average concentration of PM2.5 in Poland was 2.8 times higher than the WHO annual air quality guideline (IQAir, 2024).

Recently, there has been an increasing trend towards more reliance on environmentally friendly or renewable energy sources, especially in the residential sector (Cardella *et al.*, 2022). To address low emissions and increase the share of renewable energy sources in its total energy supply, Poland launched its Clean Air programme in 2018, which aims to replace 3 million old solid fuel boilers with a 22.4 billion EUR state budget subsidy available over ten years (Blazy *et al.*, 2021). Since the cost of renewable energy is often higher than that generated from burning fossil fuels, a system of subsidies

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[1] W define an owner of a single-family home as someone who owns the building, lives there (alone or with family members) and is responsible, or co-responsible, for paying household bills. Next, we define a single-family home as a free-standing residential building occupied by only one family. The interviewers questioned either the homeowners, or their relatives if they were also responsible for paying bills.

for the former is required (Shen *et al.*, 2020). Therefore, WTP for renewable energy and clean air should be seen as a composite indicator of public support for energy transition. This approach assesses the price that people are willing to pay for a given commodity using survey methods (Bigerna & Polinori, 2014). The issue of WTP for clean energy has been studied for some time (Borchers *et al.*, 2007; Hojnik *et al.*, 2021; Sundt & Rehdanz, 2015). Respondents are usually asked how much they would be willing to spend 'extra' each month if the energy used to power their homes came from renewable sources rather than non-renewable sources (Navrud & Bråten, 2007; Soon & Ahmad, 2015). The WTP plays an important role in the implementation of ambitious renewable energy development policies (Dogan & Muhammad, 2019). The few studies that deal with WTP for clean air come mostly from China (Freeman *et al.*, 2019; Ito & Zhang, 2020), although some work in this field was done decades ago (Harrison & Rubinfeld, 1978). The WTP for clean air applies to both pollutants produced by motor vehicles and by coal-fired boilers (Katz & Sterner, 1990; Nishitateno & Burke, 2021).

For quite some time now, there has been a widespread consensus that we should see virtually every positive change in entitlement as advantageous. The most accurate way to assess the monetary contribution to the well-being that results from such adjustments is to evaluate the largest amounts that individuals are prepared to pay, known as WTP (Nguyen *et al.*, 2021). The WTP is a unique metric capable of accounting for external factors, and quantifying outcomes in monetary terms. Consequently, it facilitates straightforward comparisons of costs and benefits, enabling a clear assessment of net benefits (Gafni, 2001). The contingent valuation method (CVM) and the discrete choice experiments (DCE) can both serve to quantify how each component affects WTP (Alberini *et al.*, 2018). Direct and indirect surveys are two popular strategies to collect relevant data to estimate WTP. Unlike revealed preferences, which reflect actual behaviour, data obtained from surveys are often known as stated preferences. In direct surveys, respondents are asked how much they would be willing to pay for a particular product. Conversely, in indirect surveys, products are evaluated using a rating or ranking system, which makes it easier to estimate a preference framework and thus determine WTP (Breidert *et al.*, 2006). The stated preference approach has some limitations for estimating WTP, namely: 1. respondents may deliberately mark certain answers to influence policy; 2. they may not be motivated to give considered or meaningful answers; 3. the answers given may not necessarily reflect the actual future contributions, and 4. the way the questions are phrased may affect the answers (Hudson & Ritchie, 2001). However, despite its flaws, WTP makes it possible to identify the factors that affect the declared amounts of extra payments. Therefore, we have compiled the following three hypotheses for this research:

H1: Most people in Poland are willing to pay extra for clean air and renewable energy.

H2: Most people in Poland declare a greater willingness to pay extra for actions aimed at improving air quality compared to having electricity generated from RES.

H3: H3. Similar determinants affect the willingness to pay for clean air and the willingness to pay for renewable energy.

Based on a review of existing studies, Kowalska-Pyzalska (2019) argues that the following factors have a positive impact on WTP for RES: familiarity with RES, attitudes toward the environment and RES, household income, social norms, home ownership, education level, knowledge of technical aspects of energy systems and risk-taking. On the other hand, age (older individuals tend to declare smaller extra payments), the focus on comfort and happiness, resistance to risk and loss, and the perception that switching energy suppliers is difficult, may all have a negative effect on WTP. Finally, household size, gender, energy price, total energy bills paid (sometimes the higher the price, the lower the declared WTP), and the source of green energy yield ambiguous results. A survey of Dutch residents showed that WTP for sustainable energy is associated with 'understanding and worry' (Pleeging *et al.*, 2021).

The authors have decided to investigate the WTP for air quality improvement and RES to obtain a broader and more coherent perspective on energy transformation, allowing insights that would be unattainable if these analyses were independent.

RESEARCH METHODOLOGY

In July-August 2021, the Office of Social Research 'Observer' surveyed 1007 adults living in single-family homes in Poland using the CATI method. Before the actual survey, they conducted a pre-test on a group of 20 respondents. The interviewers were trained to clarify any misunderstandings and ensure that the respondents provided accurate responses. The survey comprised 44 questions, but for this study, we chose 22 of them as potential explanatory factors. We removed several corrupted and incomplete responses from the data set. Moreover, according to studies conducted so far, households are reluctant to respond to income-related questions (Sokołowski *et al.*, 2023), which the pre-test confirmed.

The survey included the following questions about the WTP for clean air and RES:

1. How much would you be willing to pay extra each month to improve air quality in your neighbourhood?
2. How much would you be willing to pay extra each month for energy if it came from renewable sources?

For the sake of clarity, we label the willingness to pay for clean air as WTP1, while the willingness to pay for renewable energy sources (RES) as WTP2. We do not expect the respondents to decide whether they are ready to pay for one or the other. The questions are open-ended. The number of verified responses for question 1 is 803, and 818 for question 2. This is due to missing or incorrect responses. Furthermore, the study aims to identify the factors that influence people's willingness to pay more (or less) rather than the factors that influence the willingness to pay at all. That is, while previous studies focused on the latter (cf., *e.g.*, Kowalska-Pyzalska, 2019), we wish to study the factors that affect the dynamics of WTP. That is why only nonzero responses are considered to identify the factors using Bayesian model selection methods.

In total, for the regression analysis, we have identified 621 complete responses for willingness to pay more for better air quality (WTP1>0) and 673 for energy from RES (WTP2>0). These values are lower than for questions 1 and 2 alone because some of these responses were incomplete with respect to the potential determinants. The proportion of people who were unwilling to pay for clean air (WTP1=0) and clean energy (WTP2=0) was not that substantial. It equalled 182 (22.7%) and 145 (17.7%), respectively, with 123 respondents giving negative answers to both questions. Based on the literature, we have compiled the list of potential variables for WTP1 and WTP2. Table 1 presents the variables, which were largely developed based on the literature (Dogan & Muhammad, 2019; Hojnik *et al.*, 2021; Kowalska-Pyzalska, 2019; Liobikienė & Dagiliūtė, 2021; Zorić & Hrovatin, 2012).

It is more than likely that only a subset of these variables is relevant to determining the variation of WTP1 and WTP2. Therefore, we treat them as potential determinants of WTP variation. To establish the actual determinants of WTP1 and WTP2, we apply Bayesian model selection, BMS hereafter (Zeugner & Feldkircher, 2015). BMS is a probability-based model selection technique known from statistics and machine learning, which has made its way into numerous fields including survey data analysis (see, *e.g.*, Aliverti & Russo, 2022; Little, 2022). Noteworthy, the way the research question in this study is phrased affects the selection of the inference method. If we were to examine the factors that affect the decision only whether to pay (or not) we would then use logistic or tobit regression, and then we would include the zero-value observations for WTPs (cf., *e.g.*, Kowalska-Pyzalska, 2019). However, since (i) we focus on the factors that affect WTP dynamics and (ii) the number of zero-value observations is relatively modest, we opt for BMS.

The BMS procedure involves sampling from a model space of all possible 2^k regression models (where k is the maximum number of regressors) and detecting configurations with the highest explanatory power. In practice, the algorithm almost never runs over all 2^k models as it is designed to terminate once a sufficient number of the most probable models is found. The explanatory power of each model in this procedure is evaluated using posterior model probability, which is a standard Bayesian practice. The most prevalent application of BMS is for covariate selection (Steel, 2020) and our application is no different. We investigate the model space to estimate the Posterior Inclusion Probability (PIP), which determines how likely it is for a given determinant (*i.e.*, the potential factor) to be included

in the optimal model and thus how relevant it is. The lower the PIP, the less likely a given predictor is to be included in the optimal model, and thus the less relevant it is in explaining WTP. In general, there is no rule as to what the cut-off value for PIP should be, and this is usually determined empirically. We return to this aspect in the results section. Another important piece of information is the direction of influence of a given determinant. In BMS, this is known as the conditional posterior sign (CPS), which reflects the probability that the parameter of a particular determinant has a positive or negative sign, showing the direction of its effect. Consequently, for values of CPS equal or close to one, this impact is regarded as definitely positive, for values equal or close to zero, this impact is negative, whereas values around 0.5 are considered inconclusive.

Table 1. Potential explanatory variables for WTP1 (clean air) and WTP2 (RES)

Variable	Code	Variable scale	Mean	SD	Min	Max
General						
Age	G1	Ordinal (1-6)	2.96	1.30	below 25	65 and above
Gender	G2	Nominal (1, 2)	1.39	0.49	1 (F)	2 (M)
Education	G3	Ordinal (1-5)	4.33	0.76	1 (primary)	5 (tertiary)
Employment – private	G4.1	Nominal (0, 1)	0.45	0.50	0 (no)	1 (yes)
Employment – public	G4.2	Nominal (0, 1)	0.21	0.41	0 (no)	1 (yes)
Self-employed	G4.3	Nominal (0, 1)	0.09	0.28	0 (no)	1 (yes)
Unemployed	G4.4	Nominal (0, 1)	0.05	0.23	0 (no)	1 (yes)
Homeowner	G5	Nominal (0, 1)	0.93	0.26	0 (no)	1 (yes)
Property characteristics						
House thermal insulation	P1	Ordinal (1-5)	3.59	1.18	1 (uninsulated)	5 (very good)
House age	P2	Ordinal (1-6)	3.03	1.55	1 (before 1980)	6 (after 2020)
Heating source	P3	Nominal (0, 1)	0.56	0.50	0 (renewables)	1 (fossil fuels)
Installed photovoltaic panels	P4	Nominal (0, 1)	0.08	0.27	0 (no)	1 (yes)
Household size	P5	Ratio (integer)	3.56	1.22	1	10
Financial aspects						
Average heating bill	F1	Ratio	2274	2255.1	0	15000
Average electricity bill	F2	Ratio	301	309	5	3000
Average monthly expenses per resident	F3	Ordinal (1-4)	2.78	0.96	1 (below 500)	4 (over 1200)
Energy conservation for financial reasons	F4	Ordinal (1-5)	4.07	0.94	1 (definitely no)	5 (definitely yes)
Declared awareness of environmental actions						
Familiarity with RES	D1	Ordinal (1-5)	3.60	0.86	1 (very low)	5 (very high)
Attitude to increasing the share of RES in Poland's energy mix	D2	Ordinal (1-5)	4.13	0.89	1 (very low)	5 (very high)
Importance of environmental protection	D3	Ordinal (1-5)	4.23	0.84	1 (very low)	5 (very high)
Energy conservation for environmental reasons	D4	Ordinal (1-5)	3.89	0.99	1 (very low)	5 (very high)
Willingness to obtain information on activities that promote environmental protection	D5	Ordinal (1-3)	1.46	0.78	1 (low)	3 (high)

Note: We group the potential determinants listed above by category: general (G), property characteristics (P), financial aspects (F), and declared awareness of environmental actions (D); SD is the standard deviation.
Source: own study.

We rely on BMS since the existing WTP literature is largely inconclusive about the main factors that affect both WTP1 and WTP2. By stating so, we do not wish to imply that the theory is sparse. Quite the contrary. Many publications provide lists of potentially critical determinants of WTP, but their contents rarely overlap. Based on the literature review, we have compiled a shortlist of 22 of such determinants. Naturally, it makes little sense to combine all of them into a single regression model. Traditional model-building and specification-search procedures may also fail due to potential weaknesses of standard statistical tests (*e.g.*, due to the high dimensionality of the model and

the fact that asymptotic properties may not hold in finite samples). Furthermore, considering the scarcity of the joint literature on WTP1 and WTP2, we opt not to devise a model using largely ad hoc procedures and apply BMS to see what the data can tell us.

RESULTS AND DISCUSSION

Approximately 82.3% of the respondents are willing to pay extra for renewable energy sources, while 77.4% are willing to contribute financially to clean air. Those willing to pay more for clean air (WTP1) declare PLN221.33 (USD 53.98) per month on average, which is approximately PLN120 (USD29.30) more than they are willing to pay for renewable energy (WTP2; PLN98.65 on average, or approximately USD24.06 per month). The median for WTP1 is PLN100 (USD24.39), which is PLN50 more than WTP2. Therefore, clean air and renewable energy seem important to them, although they are willing to pay substantially more for clean air than for renewable energy. The trend intensifies in the tails of the distributions of both variables, *i.e.*, the difference between means is higher than that in medians, which also indicated the asymmetry of these distributions. Indeed, the skewness of the distribution for WTP1 is 2.2 and for WTP2 − 2.0. Moreover, both the WTP1 and WTP2 distributions are characterised by a very high concentration of values around the modal. Kurtosis is 5.44 and 4.06, respectively, which shows that although the range of both variables is quite large (1−1600, and 1−500, respectively), a relatively large number of responses groups around the central tendency (*i.e.*, a larger proportion than would result from an approximation by a normal distribution; see Figure 1 for the histograms for WTP1 and WTP2, respectively). Hence, both distributions are far from the 'normal' curve. It may also be argued that Figure 1 shows several outliers. However, because of the high kurtosis (*i.e.*, the concentration of the distribution around their modal), the distributions may simply be heavy-tailed (*e.g.*, Laplace-like distribution), which is quite common.

We find that the majority of the respondents have opted for WTP1 and WTP2 and that the declared values are rather large given the income of households in Poland at the time (*i.e.*, median annual disposable household income in 2021 was 19.1 thousand USD in PPP; see OECD, 2023). Therefore, we confirm hypothesis H1. Since we find the values for WTP1 to be substantially higher than for WTP2, we also confirm hypothesis H2. Improving air quality in Poland tends to be perceived in terms of switching energy carriers or the substitution of hard coal in domestic boilers with less polluting but more expensive fuels. As a result, the payments to improve air quality currently take the form of purchasing more expensive energy carriers. In this instance, each user makes their own decision, which reduces the risk of purposefully misreporting the actual WTP.

Table 2. Statistics for WTP1 (clean air) and WTP2 (RES) in PLN

Variables	Average	Median	Mode	SD	Kurtosis	Skewness	Min	Max	Count
WTP1	221.33	100	100	269.16	5.44	2.2	1	1600	621
WTP2	98.65	50	50	108.74	4.06	2.03	1	500	673

Source: own study.

We specify relevant determinants in BMS based on the 0.2 cut-off level for PIP. This is for two reasons. First, given the above-mentioned literature, we have found that most regression models for similar analyses consist of at least five explanatory variables. This is somewhat reflected in the PIP≥0.2 criterion. We assume that *a posteriori* the probability of a given variable being part of the model should be about 1/5, which is the inverse of the expected number of explanatory variables in the model. Second, empirical results have shown that PIP values drop substantially after about 0.2 (*e.g.*, to about 0.1, which means that the next predictor is about twice less likely). Furthermore, before BMS, it is advisable to check for possible multicollinearity between the potential explanatory variables. This is because highly correlated variables could affect the regression results. Fortunately, we find that the highest absolute value for the correlation coefficient does not exceed 0.6 (we provide correlation tables in the Appendix). This reassures us that BMS results are not distorted by the potential multicollinearity.

The results of BMS show interesting correspondences and some differences between the potential determinants of WTP1 and WTP2. In the case of the WTP1 model, the posterior inclusion probability (PIP) is at least around 0.2 (1/5) for four potential explanatory variables, all of which have a positive impact on WTP1 (the exact values of each variable are shown in Table 3). People are willing to pay more for clean air if: 1) they pay more for heating anyway; 2) they declare that the environment is more important to them; 3) they are senior citizens, and if 4) they declare a greater familiarity with renewable energy sources. This is slightly different in the case of WTP2, in the case of which we identify six determinants with PIPs in the 20% range (Table 4 shows the exact values for each variable).[2] According to our findings, the following factors positively affect WTP2: 1) the size of energy bills; 2) declared strong commitment to environmental protection; 3) familiarity with RES, and 4) age (younger people tend to exhibit a higher WTP2). On the contrary, factors such as 5) educational level and 6) attitude toward expanding the share of RES, have a negative impact on WTP2. Table 5 compares the impact of potential determinants with a PIP of at least 20% in the two models (for WTP1 and WTP2). The common determinants common of both WTP1 and WTP2 are: 1) declared concern for the environment and 2) familiarity with renewable energy sources. Furthermore, heating and energy bills can be viewed to some extent as a common determinant, since changes in the former affect WTP1, while changes in the latter affect WTP2. The age of the respondents also has an impact, but interestingly, the causations are reversed: older respondents tend to be willing to pay more for clean air, while younger ones tend to pay more for RES. Other characteristics described above seem to be specific to the type of WTP. Overall, we find hypothesis H3 to be confirmed to some degree. That is, there are indeed similar determinants for WTP1 and WTP2, although some factors are specific to only one of the two.
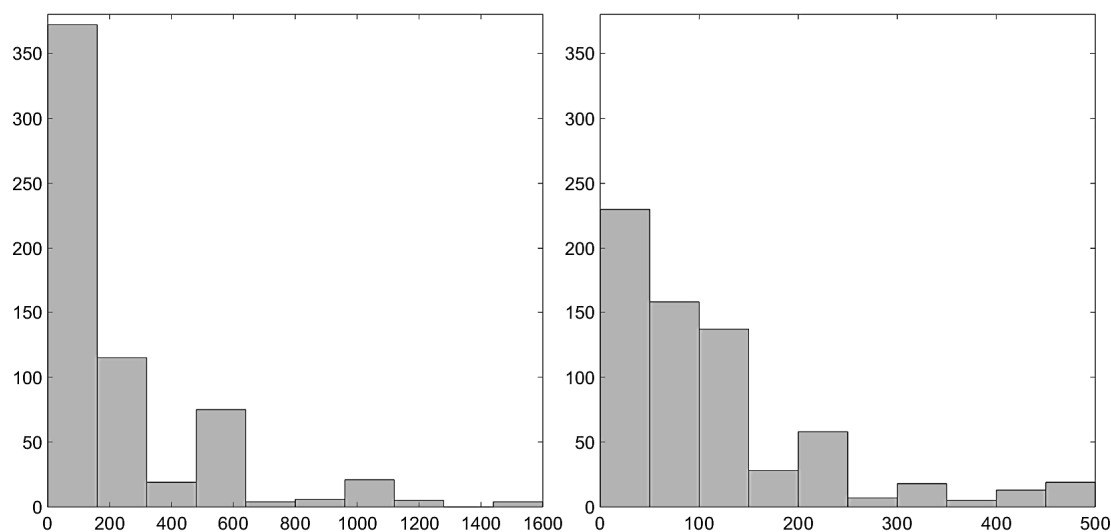
Figure 1. Histograms for declared WTP1 (clean air; left) and WTP2 (RES; right)
Note: The x-axis represents the amounts to be paid within a specific band (in PLN); the y-axis represents the number of people.
Source: own elaboration.

To sum up, the study has indicated that people in Poland are largely willing to pay extra for clean energy and that WTP1 (clean air) is greater than WTP2 (RES). This provides support for hypotheses H1 and H2 formulated in Section 2. Our findings are consistent with other studies that report increasing social understanding of the importance of air quality in Poland (Król & Gomola, 2022). According to the European Commission, about 45% of Poles in 2019 were aware that air quality deteriorates (European Commission, 2019b). The literature suggests that Poles are aware that low emissions are generated by households burning coal (Ligus, 2017). In addition to acknowledging local air pollution issues, they understand the necessity of energy transition, with around 74% favouring a gradual shift awa

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[2] For WTP2, 'familiarity with RES' has a PIP of just under 20%, very close to the adopted cut-off criterion. That is why we have decided to include it in the analysis. This variable is also present in other studies.

Table 3. BMS results for WTP1 (clean air)

Variable name	PIP	Post. mean	Post. SD	Cond. post. sign
Average heating bill	0.7196	0.0848	0.0632	1
Importance of environmental protection	0.4689	0.0486	0.0590	1
Age	0.3746	0.0359	0.0529	1
Familiarity with RES	0.2343	0.0198	0.0412	1
Average electricity bill	0.1000	0.0059	0.0221	1
Willingness to obtain information on activities that promote environmental protection	0.0884	0.0049	0.0203	1
Employment – public sector	0.0832	-0.0043	0.0185	0
House thermal insulation	0.0813	0.0041	0.0182	1
Average monthly expenses per resident	0.0735	0.0034	0.0165	1
Employment – private sector	0.0717	0.0033	0.0163	1
Gender	0.0604	-0.0024	0.0138	0
Household size	0.0562	-0.0019	0.0127	0
Energy conservation for financial reasons	0.0554	0.0020	0.0130	1
Education	0.0548	0.0019	0.0122	1
Self-employed	0.0500	-0.0013	0.0108	0
Energy conservation for environmental reasons	0.0461	0.0008	0.0111	0.6525
Attitude to increasing the share of RES in Poland's energy mix	0.0441	0.0001	0.0099	0.4964
Homeowner	0.0438	0.0010	0.0097	1
Installed photovoltaic panels	0.0428	0.0008	0.0091	1
Unemployed	0.0422	-0.0008	0.0091	0.0020
House age	0.0419	0.0008	0.0093	0.9720
Heating source	0.0396	0.0001	0.0080	0.6363
(Intercept)	1	0.2550	NA	NA

Source: own study.

Table 4. BMS results for WTP2 (RES)

Variable name	PIP	Post. mean	Post. SD	Cond. post. sign
Average electricity bill	1	0.4213	0.0353	1
Importance of environmental protection	0.5593	0.0578	0.0596	1
Age	0.4304	-0.0370	0.0484	0
Attitude to increasing the share of RES in Poland's energy mix	0.2729	-0.0236	0.0441	0
Education	0.2427	-0.0176	0.0357	0
Familiarity with RES	0.1937	0.0139	0.0329	1
House age	0.1037	0.0056	0.0203	1
Average heating bill	0.0945	-0.0048	0.0187	0
Willingness to obtain information on activities that promote environmental protection	0.0793	-0.0037	0.0167	0
Household size	0.0717	0.0031	0.0148	1
Energy conservation for financial reasons	0.0519	-0.0015	0.0108	0.0046
Energy conservation for environmental reasons	0.0489	0.0005	0.0112	0.6360
House thermal insulation	0.0486	-0.0011	0.0096	0.0271
Homeowner	0.0462	-0.0011	0.0091	0
Unemployed	0.0442	-0.0009	0.0086	0
Employment – public sector	0.0436	-0.0009	0.0085	0.0002
Heating source	0.0420	0.0008	0.0082	0.9982
Self-employed	0.0403	0.0005	0.0075	0.9997
Employment – private sector	0.0380	-0.0003	0.0072	0.1629
Installed photovoltaic panels	0.0375	-0.0002	0.0068	0.1061
Gender	0.0374	-0.0004	0.0073	0.0858
Average monthly expenses per resident	0.0362	-0.0001	0.0068	0.3469
(Intercept)	1	0.4365	NA	NA

Source: own study.

Table 5. Comparison of significant determinants for WTP1 (clean air) and WTP2 (RES)

Variable name	WTP1	WTP2
Heating bills	Yes (1)	No (0)
Electricity bills	No (1)	Yes (1)
Importance of environmental protection	Yes (1)	Yes (1)
Familiarity with RES	Yes (1)	Yes (1)
Age	Yes (1)	Yes (0)
Education	No (1)	Yes (0)
Attitude to increasing the share of RES in Poland's energy mix	No	Yes (0)

Notes: The Table shows those variables in the model for which the posterior inclusion probability (PIP) is at least 20% for WTP1 and WTP2 in Poland; 'Yes' – PIP of at least 20%; 'No' – PIP below 20%, (1) represents a predominantly positive relationship between the factor and WTP (CPS close to or equal to 1); (0) represents a negative relationship (CPS close to or equal to 0). Source: own study.

from a coal-based economy in 2021, compared to 61% in 2015 (Herudziński & Swacha, 2022). This indicates a growing social acceptance of changes in the energy sector. Over 60% of young Poles declare that in the future they will be active energy prosumers, which shows a strong interest in renewable energy sources (Gryz & Kaczmarczyk, 2021). The above-mentioned results from previous studies on environmental awareness and attitudes are consistent with a relatively high WTP1 and WTP2 found in this study (*i.e.*, relative to average or median household income in Poland at the time). We may attribute differences in the declared amounts to the greater immediate impact of air quality on individual respondents, particularly their health. Finally, all consumers easily understand the term 'clean air,' while 'renewable energy sources' may raise interpretive issues.

Using BMS, we have also established a set of determinants common to WTP1 and WTP2 (hypothesis H3). We have confirmed that WTPs for clean air and RES were higher for those who declare a better understanding of the environment and see its condition as important. Climate change awareness has been reported to have a positive impact on WTP for RES (Zografakis *et al.*, 2010). Interestingly, the analysis has shown that senior citizens are willing to pay more for clean air, whereas younger people are willing to pay more for energy from renewable sources. The fact that we have focused the regression analysis on people who are willing to pay at all (WTP>0) may account for the high positive relationship between the bills paid and the WTP.

Given these findings, we recommend to promote awareness of current environmental issues through marketing initiatives. It also appears necessary to assist nongovernmental organisations such as the Polish Smog Alert. Various initiatives should be taken to foster closer bonds between people and their environment to make them feel more responsible for the shared goal. This could be achieved through programmes, in which households receive guidance on energy-saving strategies in the form of nudges (*e.g.*, visual cues). Effective measures can also involve well-designed buildings thermo-modernisation programmes, with a particular emphasis on increasing the energy efficiency of single-family homes. Promoting the use of smart meters, which allow real-time energy consumption monitoring, could further enhance energy efficiency efforts.

Since the regression analysis did not account for those who declared 'no' (*i.e.*, zero) for both WTP1 and WTP2, these recommendations apply to people who are willing to pay. To devise appropriate recommendations for those unwilling to pay more for clean air or RES, it is necessary first to determine whether their decisions are motivated by a lack of knowledge, indifference to the environment, or financial concerns. For example, in Poland in 2017, exposure to hidden energy poverty was 23.7% and it was linked to a certain extent to income poverty (Karpinska & Śmiech, 2020). This figure nearly matches the 22.7% and 17.7% of respondents in our survey who reported zero for WTP1 and WTP2, respectively, and may imply that energy poverty is the reason why some respondents declared their unwillingness to pay at all. It would be unreasonable to expect people who are facing energy poverty to be willing to spend extra money on renewable energy (Mamica *et al.*, 2021).

Undoubtedly, one of the limitations of the study reflects the limitations of survey-based research methodologies in that respondents may manipulate data by indicating their aspirational behaviours,

which often would not align with the actual experience. Consequently, these findings may not indicate the amounts that households can actually pay, nor do they provide any reliable guidance in this regard. With the caveat that these findings only represent the expressed preferences, the key conclusion is that such payment declarations reveal both the need for change and the readiness of single-family households to fund it, at least to some extent. Conversely, the higher reported willingness to pay for clean air shows that Poles are more concerned with the immediate, tangible, and local aspects of energy transformation. Another potential limitation comes from the fact that to study potential determinants of the WTP variation, the BMS procedure excludes respondents who declare zero willingness to pay. In doing so, it overlooks the perspectives of those unwilling or unable to pay, which may be driven by factors like the above-mentioned energy poverty. In theory, the entire dataset could be analysed by developing a BMS procedure for tobit-class models. However, such procedures are not yet available.

CONCLUSIONS

The respondents are generally willing to pay more for the sake of the environment, and in particular to spend more on clean air than on renewable energy. Furthermore, the values declared in both cases are relatively large given the median household income in Poland at the time of the survey. The notion that low emissions are harmful to health may partially explain why clean air is linked to a higher WTP. Many of the initial 22 determinants have relatively low posterior inclusion probabilities (PIP). Nonetheless, we may draw certain conclusions from the analysis. First, factors such as the size of energy bills, the importance of the environment to the respondents, and their familiarity with RES influence both WTP1 (clean air) and WTP2 (RES). The positive relationship between the payment of higher energy bills and WTP1 and WTP2 can probably be explained in terms of the financial situation and composition of the survey group. That is, higher energy bills may indicate wealthier households, and wealthier households can afford a higher WTP when measured in currency values. The study supports the notion that there is an impact on awareness about the importance of environmental protection on WTP for clean air and RES.

Finally, we would argue that increasing the WTP requires first and foremost raising environmental awareness and promoting its benefits among the general population. Since the WTP studies are based on the respondents' declarations, their actual willingness to bear the costs of energy transition may be lower. The analysis was carried out before Russia invaded Ukraine. On the one hand, this may have driven WTP even lower due to the considerable increases in the prices of energy, food, and other commodities since 2021. On the other hand, if higher RES is associated with a decreased dependency on Russian oil and gas this may have driven WTP in Poland higher, at least in terms of WTP2. The net effect is difficult to ascertain.

The study closes a research gap by examining the willingness to pay for clean air and renewable energy in the same sample of respondents. Future research should use empirical methods to assess why some groups are unwilling to pay more for 'environmental initiatives' and whether this is associated with energy poverty. The government should provide aid in the thermo-modernisation of buildings and increase investments in diverse, clean, renewable energy (solar, wind, biomass, *etc.*), even if it generates transitional costs. To address energy poverty, policymakers should focus on minimalizing the burden of increasing energy costs for the least well-off. Since environmental awareness and knowledge about RES positively influence WTP, educational campaigns that raise public awareness about RES and environmental protection are also crucial. These campaigns should target different groups based on their preferences (*e.g.*, younger for RES vs. older for clean air).

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Appendix A: Correlation coefficients between potential determinants of WTP

Table A1. Spearman's rank correlation coefficients between variables in ordinal or ratio scale

Variable	Code	G1	G3	P5	D3	D1	D2	F4	D4	F3	F2	F1	P2	P1
Age	G1	1												
Education	G3	-0.04	1											
Household size	P5	-0.20	-0.06	1										
Importance of env. protection	D3	0.10	-0.02	0.04	1									
Familiarity with RES	D1	-0.01	0.00	0.11	0.37	1								
Attitude to increasing the share of RES in PL energy mix	D2	0.07	0.04	0.03	0.40	0.25	1							
Energy conservation for financial reasons	F4	0.09	0.02	0.01	0.23	0.16	0.40	1						
Energy conservation for environmental reasons	D4	0.05	0.00	0.03	0.48	0.30	0.60	0.47	1					
Avg. monthly exp. per resid.	F3	0.11	0.12	-0.05	0.08	0.09	0.11	0.07	0.12	1				
Average electricity bill	F2	-0.12	-0.01	0.23	0.05	0.05	-0.03	-0.06	0.00	-0.03	1			
Average heating bill	F1	0.17	0.10	0.00	0.05	0.02	0.16	0.13	0.12	0.10	0.12	1		
House age	P2	-0.13	0.23	0.05	0.04	0.12	-0.02	-0.03	-0.01	0.13	0.07	-0.07	1	
House thermal insul. status	P1	-0.02	0.10	-0.03	0.22	0.22	0.12	0.08	0.15	0.18	-0.05	0.04	0.33	1

Note: Spearman's rank correlation coefficient is used because most variables are in ordinal scale (*e.g.*, Likert's scale). For Pearson correlation coefficients the results remain virtually unchanged. Grayscale identifies higher correlation values in absolute terms. Source: own elaboration.

Table A2. Kendall's τ coefficients between dichotomous (nominal scale) variables

Variable	Code	G2	G5	D5	P4	G4.1	G4.2	G4.3	G4.4	P3
Gender	G2	1								
Homeowner	G5	0.01	1							
Willingness to obtain inf. on activities that promote environmental protection	D5	-0.05	0.15	1						
Installed photovoltaic panels	P4	-0.01	0.04	0.07	1					
Employment – private sector	G4.1	-0.09	0.05	0.10	0.02	1				
Employment – public sector	G4.2	0.08	0.08	0.03	0.02	-0.45	1			
Self-employed	G4.3	-0.08	0.05	-0.06	0.00	-0.26	-0.15	1		
Unemployed	G4.4	0.12	-0.12	-0.05	-0.02	-0.21	-0.13	-0.07	1	
Heating source	P3	0.04	-0.02	0.02	-0.03	-0.07	0.01	-0.05	0.04	1

Note: Grayscale identifies higher correlation values in absolute terms. Source: own elaboration.

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Use of Artificial Intelligence

The authors declare that AI was not used in any way in the generation of the paper.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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