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How can digital transformation and entrepreneurship influence business activities? A systematic analysis for cutting-edge economies

1. Introduction

Over the last three decades, new businesses have driven rapid economic growth (Nica 2020). Additionally, it helps labor markets create opportunities for employees, which in turn enhances productivity. However, the newly established firms work efficiently to enhance productivity; consequently, this firm's strategy contributes to rapid growth (Edwards 2021). It is a common certainty that entrepreneurship can better facilitate firms in raising their output level and becoming dominant in the domestic economy (Egere et al. 2022). Similarly, multinational companies also bring massive investment across nations, creating a bond between new firms and entrepreneurial activities. However, this term has been introduced by an inclusion at domestic level, which brings new business ideas, skills, and technology via different mechanisms (Lucas Ancillo de, Gavrila Gavrila 2023). Similarly, these mechanisms are known as backward and forward linkage (Mehta 2022).

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The forward links refer to international firms' consumers, who are the competitors of foreign firms. In contrast, the backward links are directly connected with the ratio of domestic firms as new suppliers. Besides the backward and forward linkages, the knowledge diffusion mechanism also involves the business sector. It refers to the entry of new firms at the domestic level under international standards and promotes the labor training, skills, and experiences. With such improvements, they can start their businesses when international firms leave the domestic market, as per the agreement. Thus, some leading mechanisms have been introduced in the literature focused on various empirical studies.

From a brief overview, it is clear that socio-economic and technical factors are crucial for new businesses. In the modern era, there has been a significant advancement in technology that supports the business sector in a green manner (Ancillai et al. 2023). Numerous technologies exist, but this study focuses specifically on information technology and its significance in human lives. Before we discuss the study's aims and contributions to literature, it is imperative to consider the evolution of IT over time. Since the start to its current peak, it has passed through five different stages. In the first stage, it was introduced during the Second World War via an electromagnetic calculator weighing approximately 5 tons. However, after the Great Depression and baby boom, its new form was introduced into adaptable (personal) computers. Therefore, in the era of recovery (from Great Depression), a special attention has been given to addressing human problems (asymmetric information regarding business activities). In late 1970's, the second form of IT began with the introduction of computers. Specifically, the transition has transformed outdated technology into chip and disc technologies that are more convenient for handling data and basic information. In the third phase, disc technologies have been transformed into microprocessors, which can reduce additional processing costs. Finally, this has reached "World in hand in one click (where populace can access the entire globe and get information as per need)." From such progress, it would not be an overstatement to say that the globe has become a village due to the removal of barriers across nations.

Since 1990, the world has undergone a significant transition in digitalization, and its appropriate use in daily human and economic activities may help solve the problems of future generations (Calderon-Monge, Ribeiro-Soriano 2024). The communication gap between organizations was significantly reduced due to IT facilities such as landline telephones, mobile phones, email, and fax (Brockhaus et al. 2022). The attention that nations and policymakers have offered has not reached its threshold level. More specifically, past studies have overlooked the role of IT in business activities, particularly in emerging economies. However, earlier studies from around the globe have differing opinions. For example, most economies have a similar ratio of IT usage, with 90% dedicated to searching and 10% to email activities. In contrast, the behavior of firms has also varied by 56%, 38%, and 10%, respectively,

in advertising, online sales, and purchase. However, its small share (just 10%) has been utilized by firms in training, downloading software, and skill learning (Leek et al. 2003). However, there may be a question of why this study focuses on IT and its spillover effect in the emerging seven economies. Therefore, elaborating on the significance of the study would be an advantage before moving to the study's contribution. In recent years, the selection and evolution of a business have been directly associated with IT, and a businessperson can alleviate all their concerns by seeking solutions that support long-term economic growth (Duvivier et al. 2017).

Simply put, a person in business can obtain information with a single click and may decide to invest in a mature and reliable company (Antonini 2024). In the emerging seven economies, China is a leading example for investment and revenue generation. From this country's example, we can understand the accurate information regarding business start-ups in other countries that are closer. In 2020, approximately 140 million small enterprises were noted and they contributed 60% of GDP, 50% of income tax, 79% of job creation, and 68% of exports. However, approximately 2.52 million companies registered, representing an immense number of new businesses, with twenty-two thousand companies being registered daily. The question of how they manage their production and consumption, both within and outside borders, can arise from such massive business activities. Thus, information technology (IT) has become a last resort for handling such hectic routines; otherwise, it would be impossible to manage all of it. For instance, to compete with existing firms, all products should be readily available to consumers, enabling them to make informed choices and place orders in a matter of seconds. Thus, the current study is significant for the present and future literature, as it highlights the importance of IT in the business sector.

Following a brief discussion of IT and its role in various business sectors, this study aims to highlight its critical contribution to the existing literature. This study focuses on the seven emerging economies (E7) that have a significant impact on the world's globalization activities. This study contributes in the following ways. Firstly, the current research considers income a leading factor in starting new businesses. In past studies, numerous factors have been identified as influencing business activities, including a firm's resources, management and technical capabilities, the location of business activities, a suitable business environment, and government support for new enterprises. However, in the case of the E7 economies, researchers have not attempted to attribute a leading role to income in business activities. This study strongly believes that income can be a key factor in business. Therefore, the present study utilizes income as a core factor in starting a new business, which would help clarify the association, especially in the specified economies. Secondly, this factor considers urbanization an essential element that can significantly impact the business sector. Over time, there has been a rising trend in population growth; consequently, population density in

cities has increased, whereas it has decreased in villages. Urbanization has several impacts, including increased energy use, health issues, educational problems, and other fundamental needs. There may be an opportunity to influence new business ratios in the domestic economy and vice versa. Therefore, to investigate its role in new business, the current study tries to reduce the ambiguity in the existing literature, especially in emerging economies. Hence, this empirical research aims to provide a clear and concise portrait to minimize ambiguity.

Thirdly, over time, there has been a significant variation in technology, and ultimately, the world has reached Industry 4.0, with its essential role in business activities. However, in the modern era, this is considered the Fourth Industrial Revolution, and the world is undergoing a revolution through artificial intelligence (Bailey, De Propris 2019). The intervention of IT in business activities not only enhances growth levels but also stimulates knowledge and new investment in various sectors of the economy. This phenomenon also brings innovation to domestic economies, helping them compete with other nations as they grow economically. Therefore, this empirical research focuses on including IT in business models in selected economies. For the first time, it attempts to provide an accurate picture and eliminates the ambiguity created by existing literature. Fourth, incorporating entrepreneurship into the business model may have a more significant impact on business activities. Generally, the world has considered entrepreneurship a crucial factor in dealing with economic, social, and political disparities. Therefore, most nations are striving to promote EP activities across various sectors of their economies to minimize gender disparities and foster new businesses, thereby creating job opportunities and contributing to poverty reduction. Therefore, the development of small and large companies absorbs the extra ratio of entrepreneurs, consequently increasing their production level. However, the question remains: Does it increase business activities in the specified economies?

Simply put, this study aims to assess the performance of entrepreneurship in new businesses for the case of seven emerging economies, and in terms of outcomes, it also guides policymakers in developing sustainable and efficient policies. Fifthly, the role of foreign direct investment (FDI) in the business sector has remained a contentious issue in the modern era of globalization. However, most studies have made significant efforts in the context of rapid growth driven by FDI. However, this study is of interest to those far from the macro perspective and aims to present the entire situation of economies, as well as the role of FDI in business growth. Although this process is complex, it aims to answer a straightforward question regarding the role of FDI in the business growth of emerging economies. However, the financial sector cannot be excluded from the business debate; thus, the present study also tries to add this factor to demonstrate the financial sector's role in business start-ups. Finally, this study uses an advanced series of estimators to demonstrate the study's objectives.

2. Literature review

As this study aims to highlight the true importance of information technology in business activities, it is crucial to incorporate the current literature on the subject. This initiative may support our key theme and help the reader understand the issues in a better way. It is a common belief that the information revolution was introduced during the Industrial Revolution era; however, every phenomenon does not materialize overnight. However, information is directly connected with the roots of the Industrial Revolution. The information age emerged during the Second World War, when the steam engine was the dominant technology. But later, IT has changed the way of thinking in human and economic activities. More interestingly, that era is notable because higher authorities have initiated several initiatives to invest in technological advancements. This sector was considered crucial by the end of World War II. Over time, this trend encourages the movement of perfect industrial information and evolves into a knowledge-based system (Kopf, Homocianu 2016). However, the information revolution was driven by technical innovations. Similarly, the significant advancements in electronic devices altered the economic structure. Therefore, due to the massive cost of information technology, economies have shifted their focus to excellent and intelligent technology, such as the Microsoft chip. Due to its considerable advantages, information technology has become a central component of human activities (Gabrys et al. 2016). Similarly, in the modern era of development, access to mobile phones and the internet has provided significant information about each business; this advancement has not been observed in past decades. Globalization among countries has become increasingly easy due to advancements in information technology. Therefore, advancements in IT have been incorporated as a fundamental factor in development plans across all regions, resulting in significant contributions to information technology. Besides a brief theoretical literature review on the evolution of information technology (IT), this study also aims to examine the empirical literature in depth.

Similarly, past studies have tried to demonstrate the role of IT and growth level on the performance of firms' output. For instance, Berné et al. (2015) investigated the role of IT in business performance for the Spanish economy. Outcomes demonstrated the cause-and-effect relationships among selected variables using structural equation models. Moreover, they concluded that IT is an essential factor that may spur business performance in the long run because it increases the binding of the supplier to the wholesaler. Additionally, they noted that the impact of IT on financial performance is more significant than its effect on market performance. Saleem et al. (2020) explained the crucial role of IT in business value perspectives by utilizing data from Saudi Arabia. The study's outcomes suggested that this revolution is not limited to social and economic development

but is also associated with all other sectors of development, such as infrastructure development and energy transformation. Lobo et al. (2017) described the long-term association between information technology and business performance in Australia. The selected Australian regions are well known for their organized businesses. Therefore, IT technology also enhances companies' performance. Similarly, a case study in Kenya Chege et al. (2019) demonstrated the long-term association between IT and business activities, considering 240 enterprise datasets. They employed the structural equation model to investigate the study's objectives. However, the outcomes showed significant variations in firm output due to technological advancement. Therefore, they recommended that the penetration of information technologies in the business activities of small and medium-sized enterprises is crucial. Brady et al. (2008) summarized the outcomes of IT and market practices. The study aims to summarize the empirical literature and utilizes the CMP marketing framework. They concluded that marketing also has its value, but the involvement of ICT in market practices is crucial for present and future generations. The study, which involved 257 Spanish small- to medium-sized enterprises, examined their performance in relation to information technology (Bayo-Moriones et al. 2013). They employed path and OLS analysis techniques to demonstrate the positive impact of IT on the enterprise's performance. Furthermore, a case study in Germany Rasel (2016) investigated the long-term association between IT and SME enterprises. However, they classified the firms' data into the manufacturing and services sectors. The study's outcomes revealed the dominant role of IT in the services sector, facilitating employees worldwide. E-commerce-intensive industries primarily rely on IT in their production and sales activities; however, a robust influence has been observed in the services sector compared to manufacturing. Similarly, Gërguri-Rashiti et al. (2017) investigated the contribution of IT and technical innovation to firms' performance. Outcomes from dynamic regression analysis showed a significant contribution of both explanatory variables to firms' performance.

Similarly, there has been another strand that has focused on information technology (IT) and E-marketing. For instance, El Kadiri et al. (2016) investigated the long-term association of IT with severe issues, including value chain management, product awareness, and human learning. However, the outcomes showed a significant contribution of IT in resolving such problems. In earlier decades, a case study examining the adoption of e-commerce and its driving factors was conducted for 84 firms (Ching and Ellis 2004). The hypothetical views highlighted decision-makers, innovation, and environmental factors as crucial in e-commerce. Racela and Thoumrungroje (2020) demonstrate the connection of the export market's development with IT, and the leading aim of that study was to examine the export performance on behalf of information technology. To investigate the primary

purpose of the study, the researchers employed a structural equation model and used data from 239 exporters. Outcomes showed a positive association between selected determinants of the study. Gebauer et al. (2020) focused on IT services and their long-term impact on business activities. For this contribution, they have selected 52 companies and summarized their core arguments in the following ways. For example, they have focused on industrial companies to demonstrate the role of IT in business-to-business models. Similarly, they pointed out the core importance of digital transformation in business models and growth activities. Besides the general arguments, they have not provided any empirical evidence of the contribution of IT to business models. Ranta et al. (2021) conducted a case study for Northern Europe and evaluated the core role of IT in business activities. However, they summarized fascinating outcomes, such as the fact that innovation in business activities under the circular economy was directly associated with digital transformation. Therefore, they recommended that managers utilize digital services to improve their knowledge and skills. Mostaghel et al. (2022) attempted to provide a comprehensive review of digitalization and innovations within business models. On behalf of 170 articles, they offered three distinct conclusions.

Firstly, most previous studies attempt to demonstrate the unique characteristics of digitalization that influence retail business innovations. Moreover, another group of studies has focused on the role of digitalization in business model innovations. Finally, they focused on future research directions related to innovations in retail business models. Wang et al. (2023) tried to focus on the digitalization role in business performance under the theme of innovation. They attempted to collect data for 1,663 A-share listed companies in Shanghai and Shenzhen. Under this theme, they focused on three perspectives: basic digital capabilities, digital operation capabilities, and digital integration capabilities. All these perspectives demonstrated a significant improvement in enterprise performance, as they effectively reduce asymmetric information regarding business activities. Additionally, innovations resulting from the mentioned capabilities significantly improve the company's performance. Kohtamäki et al. (2024) also attempted to summaries 101 studies to evaluate the role of digitalization in business activities. However, they also tried to summarize three different perspectives. Such as most studies have focused on digital business model innovations, digital business model innovations, and digital servitization models. However, they suggested promoting the role of digitalization in business activities in the long run. Dung (2024) demonstrated the green role of digital transformation on small and medium size enterprises, and they collected data from 210 SMEs. To demonstrate the study objectives, the researchers employed Confirmatory Factor Analysis within the Structural Equation Modelling (SEM) framework and found an indirect, inverse association between digitalization and SME businesses.

2.1. Literature gap

However, the existing literature has numerous drawbacks, and this study tries to fill such gaps. The current literature does not include the emerging seven economies in this exciting debate. However, such economies are the leading example of significant progress made after the Industrial Revolution. Additionally, specified economies have emerged as stars in business activities. Nowadays, the world is striving to adopt sustainable development models as it works to become more sustainable over time. E7 economies are trying to attain the peak level that no other economies have achieved in the business sector. In addition to such progress, the E7 economies are also competing with one another in digitalization. The current research tries to fill this gap and demonstrate the critical role of information technology in new businesses in emerging economies. Moreover, existing studies have employed internet use as a proxy of IT. Still, this study utilizes advanced-level proxies to demonstrate the disaggregated situation of selected economies regarding IT progress and its spillover effect on business sectors. Another key advantage of this study is the use of advanced estimators to investigate the study objectives, which can help control panel data problems. Similarly, this study also considers socio-economic factors to enhance the attractiveness of the results for the selected economies.

3. Data and methods

This section provides crucial information regarding the variable selection, data collection, model construction, and the most suitable estimation strategy. Consequently, this section has been divided into different sub-sections and organized well.

3.1. Theoretical background and variable discussion

It is a widely held view among researchers those new businesses often face numerous barriers to success and ultimately fail to thrive in the long run. However, for the first time, the Organizational Ecology theory was proposed by Hannan and Freeman (1989), and this well-developed theory refers to features of organizations and environmental conditions, such as the ratio of employees to capital. Moreover, this theory highlights the key factors that influence the establishment of new businesses. More specifically, this theory has focused on the evolutionary process among several organizations over the long term (Singh, Lumsden 1990). However, this theme was later observed as a function of large versus small business activities and their survival ratio in a competitive market

(Audretsch, Mahmood 1995). Thus, the new businesses have only two options in the theoretical background. Firstly, new companies with large setups may require fewer resources and achieve economies of scale at a lower average resource utilization cost. Secondly, small setup businesses may face numerous issues and struggle to compete with their larger rivals in the long run. Large companies work at their optimum point (economies of scale), but small businesses face many hurdles, such as scale diseconomies that increase production costs.

The rise in income, driven by significant improvements in economic growth and job opportunities, encourages ordinary people to invest in businesses to increase their earnings. However, to reflect his theme, for the first time Barro (1991), he described the connection between companies and income growth and attempted to elaborate on the actual production situation of goods and services through business activities. Similarly, numerous growth theories have supported the two-way association of income with businesses, and both are considered engines of growth (Acs, Szerb 2006; Thurik, Wennekers 2004). However, there may be differences between job opportunities and knowledge innovations, among other factors, due to their business structure (Audretsch 2009). Additionally, a trend in the economy's growth, characterized by increased income per capita and competitive business activities, has been emerging.

However, the theoretical link between urbanization and business activities remains unclear, and ambiguity persists. Limited studies have tried to explain this association empirically (Korunka et al. 2010; Shu, Simmons 2018). However, over the last three decades, E7 economies have made rapid progress in developing their urban areas, as people in these economies demand better facilities for new business activities, jobs, education, and healthcare. In this regard, the urbanized population has had better experiences in transitioning from agricultural setups to businesses and human capital (De La Roca, Puga 2017). However, this may help new companies survive. Thus, from such interesting comments, it is evident that entrepreneurship is a significant factor in boosting business and can help tackle hidden issues through its capabilities. Therefore, this study also considers this factor a determinant of new companies in the emerging seven economies.

Undoubtedly, foreign direct investment catalyzes economic growth, driving the overall progress of the economy. However, in the empirical literature, this has been connected with the Competitive Dynamic theory (Shapiro 1989). This theory refers to firms lobbying to influence the shape and regulations suggested by higher authorities (Becker 1983). However, such lobbies may affect the situation of FDI inflows and vary the profit of the host economy. Therefore, entrepreneurship and information technology are crucial factors to escape this trap. Finally, financial development is a critical factor that facilitates business activities, saving

time and reducing transaction costs. However, this study examines the leading factors of new businesses in emerging seven (E7) economies, including income, urbanization, information technology, entrepreneurship, foreign direct investment, and financial inclusion, from 2005 to 2021. However, the data information concerning unit, symbol, and source is given in Table 1.

Table 1

Description of variables

Variable	Unit	Source
BS	New businesses registered (number)	WDI
IN	Income per capita (US current $)	WDI
UB	Urbanization (% of total population)	WDI
IT	Individuals using the Internet (% of population)	WDI
EP	Total entrepreneurship activity	GEM
FDI	Foreign direct investment, net inflows (% of GDP)	WDI
FI	Automated teller machines (ATMs) (per 100,000 adults)	WDI

3.2. Data validity tests

This study conducts two basic tests for the validity of panel data: descriptive statistics and pairwise correlation analysis. According to outcomes in Table 2, there is no significant difference between mean and median values. Such robust findings support the conclusion that there is no chance of an outlier, and the data are strongly balanced. By having balanced data, this study performs a pairwise correlation test.

Table 2

Descriptive statistics

	ln*BS*	ln*IN*	ln*UB*	ln*IT*	ln*EP*	ln*FDI*	ln*FI*
Mean	4.9721	3.7559	0.1893	1.4919	1.0702	0.3366	1.6461
Median	4.9199	3.9327	0.3242	1.6177	1.1151	0.3485	1.7313
Maximum	5.6590	4.2034	0.5891	1.9172	1.4539	0.6584	2.2681
Minimum	3.7465	2.8515	−1.7641	0.3780	0.1789	−0.3121	0.3598

Similarly, Table 3 shows the significant and reliable outcomes regarding the pairwise correlation test. The results of all selected determinants of new business are positively correlated except for urbanization. Thus, it suggests that urbanization does not lead to the creation of new companies. Because every country has its own preferences, urbanization in selected economies may prioritize the education and health sectors over business activities. More interestingly, not a single variable has a correlation value greater than 0.80% with the explained variable, suggesting no chance of multicollinearity among the selected variables.

Table 3

Pairwise correlation test

Correlation	ln*BS*	ln*IN*	ln*UB*	ln*IT*	ln*EP*	ln*FDI*	ln*FI*	VIF	1/VIF
ln*BS*	1.000	–	–	–	–	–	–	–	–
ln*IN*	0.2698	1.000	–	–	–	–	–	5.21	0.1918
	0.003	–	–	–	–	–	–	–	–
ln*UB*	−0.5256	−0.4682	1.000	–	–	–	–	1.78	0.5621
	0.000	0.000	–	–	–	–	–	–	–
ln*IT*	0.4709	0.6362	−0.4267	1.000	–	–	–	5.28	0.1895
	0.000	0.000	0.000	–	–	–	–	–	–
ln*EP*	0.0983	0.2180	0.4607	0.1701	1.000	–	–	1.39	0.7198
	0.000	0.019	0.000	0.070	–	–	–	–	–
ln*FDI*	0.1043	0.1148	−0.0442	0.0161	0.1796	1.000	–	1.17	0.8549
	0.002	0.223	0.640	0.864	0.055	–		–	–
ln*FI*	0.5316	0.5803	−0.5276	0.5922	−0.1963	−0.0164	1.000	8.17	0.1224
	0.000	0.000	0.000	0.000	0.036	0.862	–	–	–
Mean VIF								3.83	

Additionally, this study presents some interesting figures that attempt to elaborate on the share of specified economies in new businesses, information technology, and entrepreneurship activities using 2020 data. Figure 1 describes the share of specified economies in new business registrations. For example, Figure 1 describes that Brazil has a major share in newly registered businesses, while Indonesia and Mexico have a lower share in newly registered business activities.

Figure 2 illustrates the leading share of E7 economies in information technology adoption rates. According to the given data, in 2020, Russia was dominant in information technology, while a lower adoption rate was observed in the Indian economy.

Figure 3 describes the leading share of E7 economies to entrepreneurship activity. According to the given data, in 2020, Brazil was dominant in entrepreneurship, while a lower adoption rate was observed in the Mexico and Indonesia economies.

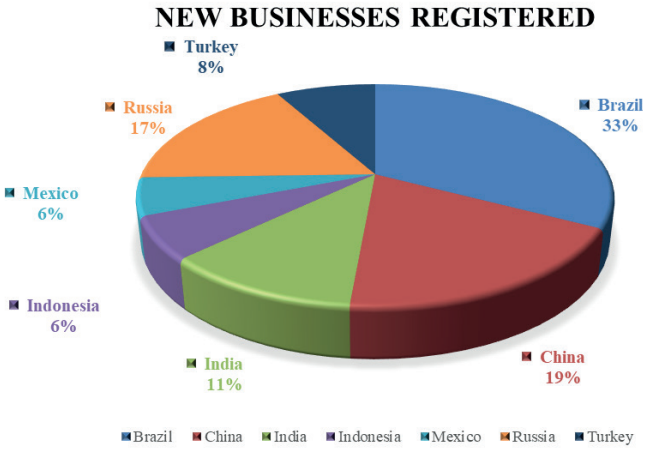

Figure 1. Share of E7 Economies to New Businesses

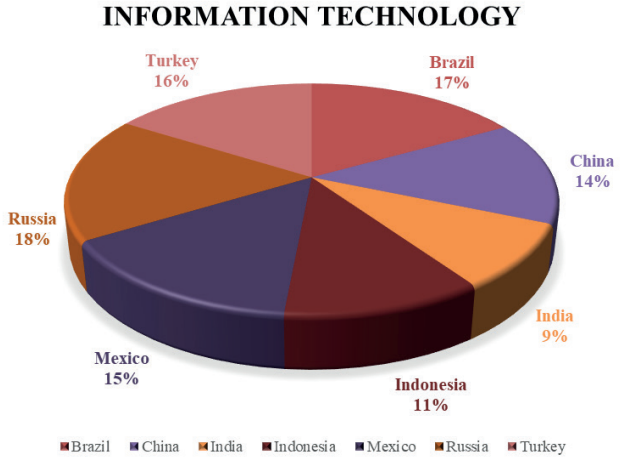

Figure 2. Share of E7 Economies to information technology

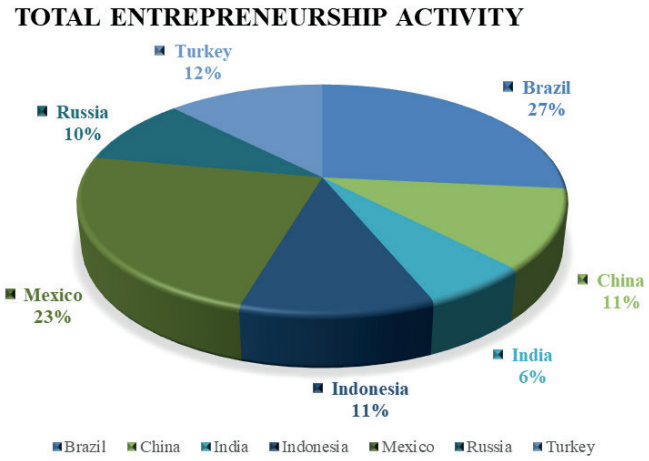

Figure 3. Share of E7 Economies to entrepreneurship activity

3.3. Study significance and selection of economies

It is essential to explain here why this study focuses on E7 economies and why it is important. Interestingly, this study attempts to address both questions through two distinct segments. Under the first segment, this study attempts to elaborate on the selection of economies based on some interesting arguments. Numerous reasons compel practitioners to conduct thorough examinations and offer their best insights under various scenarios. Firstly, these nations have made significant efforts to follow environmental standards suggested by the Sustainable Development Goals (SDGs), and the Paris Agreement. From this perspective, the adoption rate of green technologies by E7 economies is considerable, and the use of information technology (ICT) in daily human and economic activities is one of these. Specifically, these nations' focus on green business has become a leading strategy to boost overall economic growth. However, the adoption of ICT in entrepreneurship activities not only helps in efficient resource utilization but also encourages the overall growth level of new businesses (NB). Similarly, ICT inclusion at the domestic level may improve institutional quality, foreign investment transparency, and efficient financial resource allocation, which further helps to encourage business owners' interest. Additionally, its key role in trade activities from a business perspective would bring long-term benefits to domestic investors. Secondly, the specified nations (E7 Economies) have made significant efforts to promote foreign direct investment flows, aiming to increase the overall

growth level. For example, the specified nations have worked on various aspects to encourage foreign investment in support of new business activities. Moreover, foreign investment may bring several green tools, such as green knowledge, innovations, and skills, that can train the domestic labour force to run new business setups in efficient ways. Finally, under foreign investment, the specified nations have worked to strengthen international collaboration between foreign investors and local firms, which not only supports growth activities but also encourages efficient resource allocation. Thirdly, financial services have become a necessity of the time, and economies have worked well to encourage their financial sectors in terms of loan creation for business activities. Besides, most firm owners may face various issues, such as travel, transaction, and time costs, that reduce their investment interest. In doing so, the specified nations have upgraded their financial sectors to provide the best facilities for all investors. However, financial inclusion remains a crucial tool for addressing all business finance obstacles and facilitating efficient business activities.

Under the second segment, this study presents some key points that may help in understanding the significance of the study. Particularly, this study focuses on newly established businesses that gain new insights in front of legislators to reevaluate their business strategies and grow faster. However, numerous points may exist due to due to new businesses. Firstly, most nations have a common problem: there is always a mismatch between the supply and demand for labour. Such a mismatch may cause a decline in well-being and discourage overall labour force improvement. Thus, new business activities remain a last resort that not only promotes growth but also encourages the labour force to participate and earn a handsome amount. Secondly, new business owners have more capability to adopt the environmental standards and utilize innovative methods to ensure sustainable production and consumption. Through this step, new businesses may promote overall economic activities while also ensuring environmental sustainability. Therefore, this study not only attempts to highlight the importance of business in output level but also emphasizes environmental perspectives. Similarly, another important role of business setup is to offer a handsome amount to skilled labour and facilitate them with social benefits over time. There may be a chance of market competition, and new businesses may bid off skilled labour by offering a considerable amount. Such competition may not increase labour force importance, but it also spurs labour performance at the production level. Therefore, in-depth research into various socio-economic and technical factors is crucial. Finally, this study sheds light on instructional strengthening that may arise when new business owners attempt to follow environmental and other regulations. Consequently, a new business study would help portray the

overall economic performance of a country and suggest green implications for the environment.

3.4. Model construction

Similarly, the current study has robust and reliable data for the selected economies (E7); therefore, this study attempts to use business determinants in a function:

$$BS_{i,t} = f(\varphi_0\, IN_{i,t}^{\varphi 1}\, UB_{i,t}^{\varphi 2}\, IT_{i,t}^{\varphi 3}\, EP_{i,t}^{\varphi 4}\, FDI_{i,t}^{\varphi 5}\, FI_{i,t}^{\varphi 6}\, \mu_t) \quad (1)$$

Equation (1) lists the following terms: BS, IN, UB, IT, EP, FDI, and FI, which refer to business start-ups, income, urbanization, green technology, entrepreneurship, foreign direct investment, and financial inclusion. However, *i* refer to the number of cross-sections and *t* for time. Besides, φ_0, φ_1, …, φ_6 are respectively the intercept and slopes of the coefficients. Similarly, by taking natural log on both sides, the transform equation model can be written as:

$$\ln BS_{i,t} = \varphi_0 + \varphi_1 \ln IN_{i,t} + \varphi_2 \ln UB_{i,t} + \varphi_3 \ln IT_{i,t} + \varphi_4 \ln EP_{i,t} + \varphi_5 \ln FDI_{i,t} + \varphi_6 \ln FI_{i,t} + \mu_t \quad (2)$$

Eq. (2) illustrates the log-log model, assuming all variables are kept constant (business start-ups, income, urbanization, green technology, entrepreneurship, foreign direct investment, and financial inclusion). Similarly, the current study has several primary hypotheses to create attractive views for each variable concerning business start-ups. The present research suggests that income is the leading factor influencing business level. It imagines that with a significant rise in income, people have two choices: consume or invest for future returns (hint: Intertemporal Choice Theory). Therefore, with an increase in income, people invest in new businesses, leading to an expansion of the total economy's business sector. Hence, due to a significant rise in income, its slope would be positive in specified countries ($\varphi_1 > 0$). Similarly, urbanization can be effective in attracting new businesses, but in certain economies, urbanized individuals have other priorities than investing in business activities. Due to such human behavior, the urbanization sector in E7 economies may not prefer to invest in businesses with significant income share, and its coefficient would be less valuable ($\varphi_2 > 0$). Similarly, information technology (IT) is a crucial factor that can facilitate rational investment decisions by providing accurate information. Therefore, a rational investor has perfect information to invest in various business projects, and its coefficient would be positive ($\varphi_3 > 0$). Furthermore, entrepreneurship (EP) in the business sector is considered a crucial instrument for running a start-up business from its initial to peak level. The involvement of EP

would bring a significant rise in new businesses, and its coefficient would be positive ($\varphi_4 > 0$). Finally, the financial sector is being measured by two different proxies directly associated with new business, which include foreign direct investment and financial inclusion. These days, both instruments are surprisingly effective in facilitating human beings and impacting businesses efficiently. Thus, this study imagines their coefficient would be positive [($\varphi_5 > 0$) and ($\varphi_6 > 0$)].

In addition to its main effect, this study also examines the mediating role of information technology in influencing income, entrepreneurship, FDI, and financial inclusion. However, due to the significant contribution of income and information technology to the business sector, this study believes that the mediating role of IT would bring significant improvements in business activities if countries incorporate IT into rising income levels. Based on this supposition, this study has strong confidence that it can contribute to BS more robustly. Therefore, by keeping all things constant, the mediating effect of IT on income can be written as ($\ln IT \cdot \ln IN$).

$$\ln BS_{i,t} = \varphi_0 + \varphi_1 \ln IN_{i,t} + \varphi_2 \ln UB_{i,t} + \varphi_3 \ln IT_{i,t} + \varphi_4 \ln EP_{i,t} + \varphi_5 \ln FDI_{i,t} + \varphi_6 \ln FI_{i,t} + \varphi_7 \ln TIN_{i,t} + \mu_t \quad (3)$$

Similarly, entrepreneurship (EP) also significantly contributes to BS; however, this study re-calculates the penetration of IT in EP activities, and their role at the business level would be surprising. Thus, the mediating effect can be expressed as ($\ln IT \cdot \ln EP$).

$$\ln BS_{i,t} = \varphi_0 + \varphi_1 \ln IN_{i,t} + \varphi_2 \ln UB_{i,t} + \varphi_3 \ln IT_{i,t} + \varphi_4 \ln EP_{i,t} + \varphi_5 \ln FDI_{i,t} + \varphi_6 \ln FI_{i,t} + \varphi_7 \ln TEP_{i,t} + \mu_t \quad (4)$$

Furthermore, this study aims to demonstrate the mediating role of IT in foreign direct investment, as information technology can provide accurate information about the conditions of host economies. Therefore, it is a common belief that due to rationalization, foreign investors can get ideal information and invest in a suitable sector. Due to this behavior, its slope would be positive, and this term can be expressed as ($\ln IT \cdot \ln FDI$).

$$\ln BS_{i,t} = \varphi_0 + \varphi_1 \ln IN_{i,t} + \varphi_2 \ln UB_{i,t} + \varphi_3 \ln IT_{i,t} + \varphi_4 \ln EP_{i,t} + \varphi_5 \ln FDI_{i,t} + \varphi_6 \ln FI_{i,t} + \varphi_7 \ln TFDI_{i,t} + \mu_t \quad (5)$$

Finally, this study investigates the mediating role of information technology (IT) on financial inclusion, finding that its impact would be strong and positive

in specified economies. However, the general form of this mediating role can be written as:

$$\ln BS_{i,t} = \varphi_0 + \varphi_1 \ln IN_{i,t} + \varphi_2 \ln UB_{i,t} + \varphi_3 \ln IT_{i,t} + \varphi_4 \ln EP_{i,t} + \varphi_5 \ln FDI_{i,t} + \varphi_6 \ln FI_{i,t} + \varphi_7 \ln TFI_{i,t} + \mu_t \quad (6)$$

Systematic model construction

This study has the advantage of building on the existing literature by investigating different measures of IT and their roles in business activities. All things remain constant; firstly, this study uses internet users as a measure of IT, and it may have the dominant support in ease of business activities. However, its coefficient would be positive ($\varphi_{3A} > 0$) and it can be written as IT_1.

$$\ln BS_{i,t} = \varphi_0 + \varphi_1 \ln IN_{i,t} + \varphi_2 \ln UB_{i,t} + \varphi_3 \ln IT_{1,i,t} + \varphi_4 \ln EP_{i,t} + \varphi_5 \ln FDI_{i,t} + \varphi_6 \ln FI_{i,t} + \mu_t \quad (7)$$

Secondly, this study employs mobile cellular subscriptions (MCS) as a measure of IT, and due to the significant rise in information technology, it may also enhance business activities. It's denoted with IT_2 and model can be expressed as:

$$\ln BS_{i,t} = \varphi_0 + \varphi_1 \ln IN_{i,t} + \varphi_2 \ln UB_{i,t} + \varphi_3 \ln IT_{2,i,t} + \varphi_4 \ln EP_{i,t} + \varphi_5 \ln FDI_{i,t} + \varphi_6 \ln FI_{i,t} + \mu_t \quad (8)$$

Moreover, this empirical research also uses a third measure (fixed broadband subscription) to demonstrate the IT_3 role in business promotion and imagines this form also supports the business activities; thus, its slope would be positive ($\varphi_{3C} > 0$).

$$\ln BS_{i,t} = \varphi_0 + \varphi_1 \ln IN_{i,t} + \varphi_2 \ln UB_{i,t} + \varphi_3 \ln IT_{3,i,t} + \varphi_4 \ln EP_{i,t} + \varphi_5 \ln FDI_{i,t} + \varphi_6 \ln FI_{i,t} + \mu_t \quad (9)$$

Finally, this study employs fixed telephone subscription (FTS) as a fourth proxy for information technology (IT_4) and its coefficient would also be positive ($\varphi_{3D} > 0$).

$$\ln BS_{i,t} = \varphi_0 + \varphi_1 \ln IN_{i,t} + \varphi_2 \ln UB_{i,t} + \varphi_3 \ln IT_{4,i,t} + \varphi_4 \ln EP_{i,t} + \varphi_5 \ln FDI_{i,t} + \varphi_6 \ln FI_{i,t} + \mu_t \quad (10)$$

However, the conceptual framework of the study is given in Figure 4.

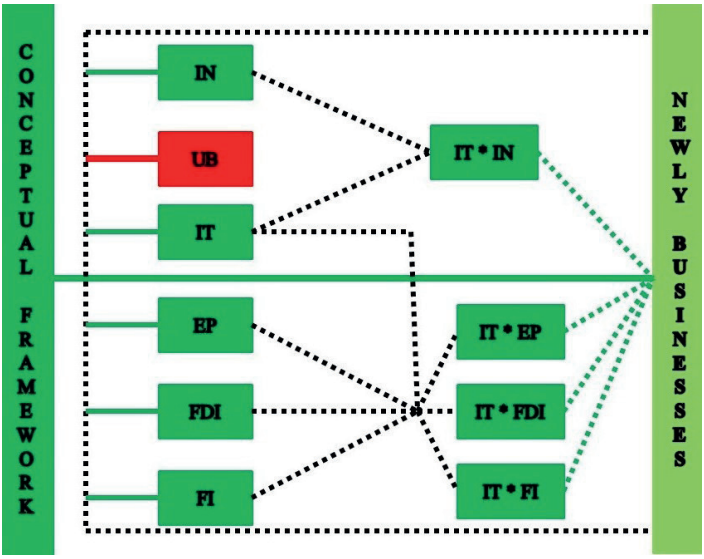

Figure 4. Conceptual framework of the study

3.5. Estimation strategy

In the era of information technology, economies worldwide have sought to achieve globalization and draw closer together. Therefore, there may be cross-sectional dependence in the panel data. To validate this argument, we employ three different CSD tests proposed by Frees (1995), Friedman (1937), and Pesaran (2004). Similarly, this study also employs the homogeneity slope to investigate whether the selected data support our further analysis (Pesaran, Yamagata 2008). Additionally, this study employs the data integration tests (CADF and CIPS) proposed by Pesaran (2007). More interestingly, in the presence of CSDs and the slope of homogeneity, the first-generation cointegration tests are not applicable; therefore, this study employs an advanced series of cointegration tests (Westerlund 2007).

Furthermore, this study also employs an innovative series of estimators to investigate the critical objectives of the study. In the presence of CSDs, traditional estimators do not address panel data problems; therefore, it would be most suitable for this study to employ the Mean Group estimators (Kapetanios et al. 2011). Thus, the present study employs the Common Correlated Effect Mean Group (CCE-MG) approach to address CSDs and heterogeneity issues (Dong et al. 2018). Similarly, the general form of the CCE-MG estimator can be written as:

$$Y_{it} = \tau_{1i} + \delta_i x_{it} + \gamma_i f_t + \alpha_i \overline{y}_{it} + \beta_i \overline{x}_{it} + \varepsilon_{it} \tag{11}$$

However, Equation (11) illustrates the combination of dependent and independent variables, in which the explanatory variables have been arranged to examine their response to new businesses. Moreover, the augmented mean group (AMG) is also used in this study to validate the outcomes of the CCE-MG estimator. However, the AMG estimator employs a two-step process to investigate the connection among selected variables. Similarly, the first stage can be expressed as:

$$Y_{it} = \alpha_i + \beta_i \Delta \bar{x}_{it} + \gamma_i g_t + \sum_{t=2}^{T} \eta_i \Delta R_t + \varepsilon_{it} \tag{12}$$

Similarly, in the second step, the general form of AMG estimator can be written as:

$$\hat{\beta}_{AMG} = N^{-1} \sum_{i=1}^{N} \hat{\beta}_i \tag{13}$$

Finally, we further employ the Dynamic Common Correlated Effect (D-CCE) to validate the outcomes of CCE-MG and AMG estimators. Figure 5 shows the graphical presentation of the estimation strategy.

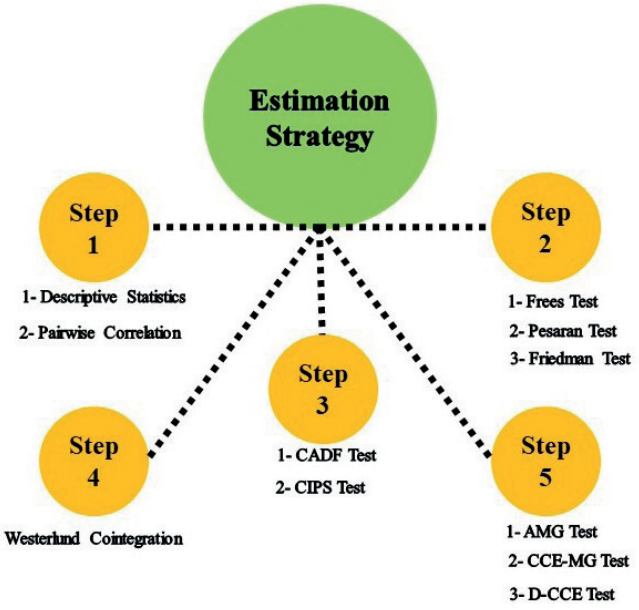

Figure 5. Estimation strategy

4. Results and discussion

Similarly, this study investigates some advanced primary tests to demonstrate data reliability, including CSDs and the slope of homogeneity. Table 4 consists of lower and upper panels. However, the upper panel described the outcomes of CSD tests and investigated the results, showing reliable findings for each variable that met the study's prior expectations. Moreover, the lower panel of Table 4 presents the homogeneity slope results, which support the CSD tests.

Table 4

CSDs and slope of homogeneity test

Upper panel			
Variable	Pesaran	Frees	Friedman
ln*BS*	3.776*	2.289*	34.409
ln*IN*	12.458*	2.062*	65.120*
ln*UB*	9.982*	2.872*	37.615
ln*IT*	18.179*	6.452*	111.238*
ln*EP*	2.799*	1.782*	13.669**
ln*FDI*	3.115*	2.136*	16.213**
ln*FI*	11.686*	3.814*	70.286*
Lower panel			
	Delta		P-value
Delta	45.413		0.000
Delta Adj.	11.919		0.000

Note: * and ** show the significance level at 1% and 5%, respectively

Similarly, Table 5 presents the outcomes of data integration through advanced tests (CADF and CIPS). According to the results, all variables are integrated at the first difference, except for foreign direct investment under both specifications. Similarly, new businesses have different data integration properties, such as under CADF, which integrates at the first difference, while under CIPS, it integrates at the level. However, this behavior is attributed to different lags under the CADF and CIPS tests.

Table 5

Data integration tests

Variable	CADF Unit Root		CIPS Unit Root	
	Level	1st Difference	Level	1st Difference
ln*BS*	–	−3.821*	–	−3.821*
ln*IN*	–	−2.877*	–	−2.877*
ln*UB*	–	−3.877*	–	−3.877*
ln*IT*	–	−3.940*	–	−3.940*
ln*EP*	–	-3.818*	–	-3.818*
ln*FDI*	−3.324*	–	−3.324*	–
ln*FI*	–	−2.988*	–	−2.988*

Note: * and ** show the significance level at 1% and 5%, respectively

Furthermore, the outcomes of long-term cointegration among the selected variables are investigated using an advanced technique proposed by Westerlund (2007). Similarly, the outcomes presented in Table 6 are robust and reliable.

Table 6

Cointegration test

Statistics	Value	Z-value	P-value	Robust P-value
G_t	−5.862	−7.679	0.000	0.000
G_a	−0.372	5.697	1.000	0.000
P_t	−4.048	3.786	1.000	0.000
P_a	−0.599	4.723	1.000	0.000

4.1. Long run outcomes by CCE-MG estimator

This study employs the Common Correlated Effect Mean Group (CCE-MG) estimator to investigate the long-run behavior of explanatory variables (see Table 7). According to the outcomes, the income slope positively correlates with new businesses (BS) across all selected models. It implies that any significant

change in income per capita would result in a considerable rise in BS. Similarly, the urbanization (UB) coefficient value shows a positive but insignificant association with new businesses. The leading determinant of BS is information technology (IT), and its coefficient value indicates a positive impact on new businesses. Furthermore, the coefficient value of entrepreneurship (EP) presents a positive association with new businesses (BS). It infers that any significant change in this factor would increase BS by 0.005%, 0.059%, 0.020%, 0.054%, and 0.046%, respectively, under the specification of the CCE-MG estimator. Moreover, the given coefficient values for foreign direct investment (FDI) indicate a positive association with business activities across all models. Finally, the coefficient value of financial inclusion (FI) positively contributes to new business activities, implying that any significant change in this factor would increase the business size (BS) by 0.208%, 0.941%, 3.587%, 2.065%, and 3.139%, respectively. Besides its leading role, this study also aims to investigate the mediating role of information technology (IT) in influencing income, entrepreneurship, foreign direct investment, and financial inclusion, as well as their impact on business progress. Firstly, the mediating role of IT on income shows a positive contribution to business activities. Any significant change in this mediating effect would increase BS by 7.600% under the CCE-MG estimator. Undoubtedly, a rise in income level increases business activities, but the intervention of IT in income level brings a surprising shock and spurs new business activities more than triple time. Having income in hand is not a pivotal indicator of when to invest in certain businesses; therefore, information technology guides the right path to invest in suitable business activities. Furthermore, the second mediating effect of IT on entrepreneurship (EP) activities also shows a significant improvement in business activities. However, the primary role of EP shows a considerable contribution to BS. Still, when it adopts information technology in business activities, it spurs the crucial role of EP up to an expected standard. Therefore, the involvement of IT in EP would be an actual direction to tackle future business problems. However, its mediating role in foreign direct investment is exciting because foreign investors can review the business trends, relevant advantages, and potential losses. Due to reduced asymmetric information regarding business activities, IT indirectly urges foreign investors to invest in host economies. Finally, the indirect effect of information technology on financial inclusion and its impact on BS also give us a revelation. Due to information technology, the financial sector can easily facilitate investors in quickly obtaining and investing in such loans for productive activities. Such activities can never be separated from information technology; hence, rational consumers get information from online platforms via IT to start a new business.

Table 7
Outcomes of CCE-MG estimator

Variable	Model 1	Model 2	Model 3	Model 4	Model 5
ln*IN*	0.2901*	1.3762**	2.5562**	1.3517*	0.9787*
ln*UB*	0.9872***	0.7694***	3.4974***	1.2419***	1.2139***
ln*IT*	0.7229*	2.6079**	3.8719*	3.6079**	2.3033*
ln*EP*	0.0050**	0.0591**	0.0203**	0.0549*	0.0469**
ln*FDI*	0.1150*	0.5081*	0.0929**	1.8651**	0.2371*
ln*FI*	0.2088**	0.9416**	3.5874*	2.0659**	3.1392**
ln*TIN*	–	7.6007*		–	–
ln*TEP*	–	–	3.1590*	–	–
ln*TFDI*	–	–	–	1.2872*	–
ln*TFI*	–	–	–	–	6.5282*
Cons.	2.0235**	3.5425**	3.8690*	4.2000*	5.2998*

Note: *, **, and ***, show significance level at 1%, 5%, and 10%, respectively

4.2. Heterogeneity robust check

The current study also tries to re-validate the outcomes of CCE-MG using the Augmented Mean Group (AMG) and Dynamic Common Correlated Effect (D-CCE) estimators. Table 8 presents the results of the AMG estimator. According to the given outcomes, income per capita increases the business activities in the emerging seven economies. Similarly, the role of urbanization remains positive but insignificant across all models, and the prior investigation obtained by the CCE-MG estimator is validated. However, the impact of information technology on the variables explained shows a positive dominant role in the specified economies. Similarly, entrepreneurship in new business activities is crucial and supports the expectations of prior studies. Finally, the primary role of the financial sector, including financial innovation and foreign direct investment, also significantly contributes to the creation of new businesses. On the other hand, the mediating role of information technology (IT) on income, EP, FDI, and financial innovation significantly contributes to business activities, and information technology has become a proper instrument for resolving business issues.

Table 8
Outcomes by AMG estimator

Variable	Model 1	Model 2	Model 3	Model 4	Model 5
ln*IN*	0.1817**	2.4539**	0.1110*	0.1047*	0.0832**
ln*UB*	0.2760***	0.3994***	0.2071***	1.1181***	0.5066***
ln*IT*	1.1774*	4.9074*	0.4957*	1.3959*	3.8140*
ln*EP*	0.0716**	0.0230**	0.0710**	0.0456**	0.0396**
ln*FDI*	0.0781**	0.0106*	0.0619**	0.4309*	0.0720*
ln*FI*	0.1797*	0.1896**	0.4515*	0.1160**	1.8457**
ln*TIN*	–	1.5012*	–	–	–
ln*TEP*	–	–	0.5025**	–	–
lnT*FDI*	–	–	–	1.2787*	–
ln*TFI*	–	–	–		7.0154*
Cons.	5.0276*	2.9147*	4.9890**	5.2319**	9.0128*

Note: *, **, and ***, show significance level at 1%, 5%, and 10%, respectively

However, Table 9 presents the outcomes regarding the D-CCE Mean Group estimators, which are also used to demonstrate their long-term association. Similarly, the investigated results show the contribution of per capita income in new businesses (BS), while urbanization remains insignificant in the overall models. Moreover, the EP and information technology are surprisingly connected with BS in the emerging seven economies. However, the connection between FDI and new businesses suggests that any significant change in FDI would have a positive impact, increasing the ratio of new businesses. Similarly, financial inclusion contributes to the growing ratio of business start-ups in mentioned economies. Besides, the mediating role does not significantly deviate from the prior estimations by AMG and CCE-MG.

Table 9
Outcomes by D-CCE estimator

Variable	Model 1	Model 2	Model 3	Model 4	Model 5
ln*IN*	0.2901*	1.3762**	2.5562**	1.3517*	0.9787*
ln*UB*	0.9872***	0.7694***	3.4974***	1.2419***	1.2139***

Table 9 cont.

ln*IT*	0.7229*	2.6079**	3.8719*	3.6079**	2.3033*
ln*EP*	0.0050**	0.0591**	0.0203**	0.0549*	0.0469**
ln*FDI*	0.1150*	0.5081*	0.0929**	1.8651**	0.2371*
ln*FI*	0.2088**	0.9416**	3.5874*	2.0659**	3.1392**
ln*TIN*	–	7.6007*	–	–	–
ln*TEP*	–	–	3.1590*	–	–
ln*TFDI*	–	–	–	1.2872*	–
ln*TFI*	–	–	–	–	6.5282*
Cons.	2.0235**	3.5425**	3.8690*	4.2000*	5.2998*

Note: *, **, and ***, show significance level at 1%, 5%, and 10%, respectively

4.3. Systematic analysis

This study takes an additional step to describe the systematic analysis by using four different proxies of information technology, such as internet users ($\ln IT_1$), mobile cellular subscription ($\ln IT_2$), fixed broadband subscription ($\ln IT_3$), and fixed telephone subscription ($\ln IT_4$), respectively (see Table 10). According to the given outcomes, the four proxies of information technology perform well in organizing new businesses. However, this study also attempts to provide a general discussion regarding this connection. For instance, information technology in the business sector is considered a crux in modern development. Thus, the availability of advanced information technology has transformed the business environment, particularly in offices, trade, and the selection of goods at both domestic and international levels. Additionally, following the Industrial Revolution, information technology received significant attention from higher authorities to invest in such technology projects, aiming to reduce transaction, time, and travel costs across regions. Moreover, in the modern era, the expansion and innovation of information technology help businesses quickly resolve their hidden problems. Nowadays, various forms of information technology assist people with business activities, price determination, financial transactions, and the supply of goods and services. In a nutshell, information technology has changed human life from outdated to modern one.

Table 10

Systematic analysis outcomes

Variable	Model 1	Model 2	Model 3	Model 4
ln*IN*	0.1817**	0.2367*	0.2451*	0.1501**
ln*UB*	0.2760***	0.4417***	0.9143***	0.6077***
ln*EP*	0.0716**	0.0354**	0.0373*	0.0892**
ln*FDI*	0.0781*	0.0747*	0.0525**	0.0126*
ln*FI*	0.1797**	0.5379**	0.6267*	0.7865**
$\ln IT_1$	0.1774*	–	–	–
$\ln IT_2$	–	0.0974*	–	–
$\ln IT_3$	–	–	0.0636**	–
$\ln IT_4$	–	–	–	0.7441*
Cons.	5.0276*	5.0861*	4.8376*	5.5203*

Note: *, **, and ***, show significance level at 1%, 5%, and 10%, respectively

4.4. Discussion of the results

In general, income is like a crux of daily human expenditures. Therefore, with a significant increase in income level, people have two choices: either they consume or invest in long-term projects (hint: Intertemporal Choice theory (Rae 1834)). Due to a significant rise in income, people are trying to invest in business activities and shift their consumption from the present to the future. Such rational behavior on the part of ordinary people significantly contributes to the new business ratio. Furthermore, logic suggests that this behavior may be explained by the fact that higher authorities have provided human-friendly tools to facilitate the start of a new business. In such initiatives, policymakers insist that higher authorities provide a suitable place for businesses to understand the market situation and product availability. Additionally, a considerable increase in income may lead to stress on product supply, consequently increasing the risk of shortages and inflation. Thus, to escape this trap, the governments of emerging economies prefer to offer some human-friendly tools to capture income from business activities. Besides the general discussion, a rise in per capita income describes the progress of economies that is indirectly associated with the performance of all sectors. However, the business sector has increased in importance in the emerging seven economies to compete with other nations. In the actual term, with a rise in income level, cash holders try to invest in earning activities that create job opportunities

and further spur the economy's wealth. This outcome aligns with the findings of (Fritsch et al. 2014; Stoica et al. 2020).

Surprisingly, the urbanization sector does not significantly impact business start-ups; however, this association can be explained in greater depth. Firstly, the migration from rural to urban areas is driven by three key aspects: health, education, and employment opportunities. Generally, economies across the globe have different priority goals, as developed economies have generally achieved sustainable development well. However, emerging economies have quickly settled their targets to transition and become part of developed nations. Therefore, such economies are attempting to transition in every sector of the economy. Secondly, due to a significant rise in income, people's living standards also increased, and they sought to move from rural to urban areas in pursuit of a better life. The population of the selected countries has not prioritized business activities because they have other life priorities, such as education, health, and employment. Most people do not have sufficient income to start a new business; thus, urbanization has a minimal impact on particular economies due to other life priorities. However, this outcome aligns with the findings of (Ding, Zhao 2014; Amezcua et al. 2020).

The connection of information technology can be explained with some core logic behind the scene. It performs well in transforming the organization's condition. During such transformation, it can vary and quickly respond to changes in growth. Moreover, it plays a crucial role in organizing administrative activities and managing the scope of new business ventures. However, the hidden properties in processing, analyzing, and understanding have become more accessible due to the availability of good information via information technology. In the era of digitalization, information technology serves as a middleman, providing information at the lowest possible cost between business setup and perfect information. Undoubtedly, IT is a powerful agent for social and economic change. Therefore, IT applications such as databases, networks, and telecommunications have become a need of time to facilitate humankind in the business arena. Nowadays, IT provides accessible information regarding the business start-up's chances of profit and loss in the long run; thus, an ordinary consumer can obtain accurate information via IT and make informed decisions about secure business investments. Due to such a positive response, business activities in emerging economies are increasing, and economies are very close to take-off. This finding also supports the views of (Abed 2021; Hensen, Dong 2020).

Surprisingly, entrepreneurship has a positive impact on enhancing business activities in emerging economies. However, this connection can be explained from theoretical and logical perspectives. Firstly, to demonstrate the critical role of EP in new businesses, the economic literature has introduced two different theories, i.e., the leadership imperative theory and the collective entrepreneurship theory

(Miller 1983; Reich 1987). Neither theory properly explains EP's contribution to business activities. However, this empirical study describes the core involvement of EP to enhance business activities in selected regions. However, later on, theoretical views expressed that in emerging markets, products and technologies were deeply associated with EP and business innovation (Miller 1983). Similarly, the logical arguments also support our outcomes, such as those of emerging economies, which aim to enhance their entrepreneurial quality to address issues related to business sectors. Such intention may be due to the significant behavior of EP towards BS, which fulfils all needs and successfully meets the person's expectations in the business's perception. Similarly, in specified economies, education plays a significant role in facilitating the establishment of new businesses. However, EP education excelled in teaching the young labour force about the challenges and their best solutions for entering the labour market and addressing business issues. Furthermore, the transition to a market economy also required a well-trained labour force to address the socio-economic challenges that new business owners face. Interestingly, after the Industrial Revolution, specific economies implemented several reforms to improve the quality of EP further. Additionally, EP can impact business activities in emerging economies in three ways. Firstly, the education level promotes brainpower, and it is a common phenomenon that a well-organized education system enhances the capabilities of EP to combat business challenges. Therefore, emerging economies have also proposed several initiatives to protect their populace from the trap of unemployment. They have trained their citizens through skillful techniques to earn a living that meets their basic needs; consequently, the business ratio has increased. Secondly, selected countries have robust business regulations that facilitate the effective intervention of EP in the business sector, thereby enhancing its productivity level. Finally, under the theme of the SDGs, the emerging seven economies have followed the UN's suggested goals, particularly in promoting gender equality. Due to the significant decline in gender inequality, many business sectors are now run by women, and China is a leading example in this regard. This outcome is in support of (Vodă, Florea 2019).

Any significant change in this factor would significantly increase the business sensitivity (BS) for emerging economies. However, in the business area, this association can be explained on behalf of the Portfolio Allocation Theory, as suggested by (Fedderke 2002). In the light of this theory, the FDI is a function of rate of return and risk. Therefore, FDI inflows are directly associated with the rate of return and vice versa for risk. Consequently, in selected countries, there has been a secure environment for new businesses, and investors have experienced minimal losses on their investments. Thus, the dominant behavior of return on risk encourages investors to invest in emerging economies and maximize profits from their investments. Similarly, host economies also offered some business-friendly

initiatives to catch their interest for investment; as a result, the employment level increased in the domestic market. Besides the theoretical, there may be logic that foreign investors are only interested in capturing profits from host economies, and the emerging seven economies are considered a hub for all businesses. For this hosting, the selected economies have solid contracts and access to trade across borders. Moreover, the emerging seven economies offer easy entry and exit from the business market. Such positive responses from host economies attract foreign investors, resulting in substantial FDI inflows and increased business activity. This outcome also supports the views of (Contractor et al. 2020; Dimitrova et al. 2022). Finally, the connection between financial inclusion and the specified economies is that they are more sensitive to providing financial services to new businesses at a minimum cost. However, financial penetration in business activities is astounding; it helps establish new companies and facilitates human and economic activities within the domestic economy. Therefore, specified economies must focus increasingly on financial facilities to secure the business sector at all levels, and this initiative may further bring business projects that will spur growth and create job opportunities. Undoubtedly, the specified economies have already made their best efforts to secure the business sector, and this study's outcome is leading evidence supporting government initiatives. This study's outcome aligns with the findings of (Tang et al. 2022).

5. Conclusion and policy recommendations

For the first time, this study introduces a new research theme in emerging economies, focusing on new business start-ups and socio-economic influential factors from 2005 to 2021. However, different estimators have been applied to investigate the study's objectives. Similarly, the basic model indicates that income, information technology, and entrepreneurship have a significant impact on business activities. However, urbanization has a positive but insignificant role in the business sector. Furthermore, the financial industry demonstrates the positive impact of FDI and financial inclusion on business start-ups. Similarly, the current empirical study employs the heterogeneity roust analysis to re-validate the estimated outcomes using the basic regression model. Similarly, to nominate the importance of information technology in daily life, this study also performs a systematic analysis. It supports the significant response of each IT proxy towards the new business.

5.1. Policy recommendations

Based on the investigated outcomes, this study also proposes some key policy implications to attract investors to new businesses. Firstly, an increase

in income raises the businesses' activities, which shows the rational behavior of domestic income holders. Under the Intertemporal choice theory, when a cash holder has money in liquid form, he has two choices: to invest in a decent business and decline today's consumption to a future one. When consumers exhibit such rational behavior, higher authorities must focus on these comments to further influence the rational consumer's mindset. Thus, the government should introduce measures to facilitate loan creation and further advance the business sector's progress. Moreover, the government should offer some green initiatives to attract domestic income holders and divert their attention away from the overexploitation of natural resources. They must try to invest in business activities. Additionally, unnecessary barriers in the business sector should be removed to increase investor interest in business activities.

Secondly, urbanization attempts to promote new businesses, but its impact remains insignificant across all models and estimators. This condition for emerging economies is shocking because the urbanized sector has not paid considerable attention to new business. In the real world, the populations of specified countries have different priorities rather than trying to invest their significant income share in the business sector. In reality, the identified urbanized population has problems related to education, health, and other basic needs. Consequently, higher authorities must focus on providing social welfare initiatives to offset additional expenditures, such as health, education, and housing. With such initiatives, the government of specified countries can divert their attention to new business, which may significantly impact the long run. Overall, the primary and mediating role of information technology (IT) was found to be surprising in the selected economies. However, there is a further need to expand the reach of information technology across all sectors of the economy to become more dominant globally. Furthermore, the overall progress of entrepreneurship remains good, but its coefficient values have been minor; thus, entrepreneurship activities can perform well via the intervention of IT. Therefore, it is necessary to involve IT in significant business activities that enable entrepreneurs to understand business-related issues efficiently. Furthermore, foreign direct investment also promotes the level of business activities, and it is a green single for host economies to attract foreign investors to invest in their homeland. However, this attraction can be introduced via the ease of financial services and their accessibility to business zones. Similarly, host economies should relax their strict regulations to promote business and cooperate with foreign investors to ensure better access to essential goods, such as health, food, and other necessities. Additionally, if proper business information is transferred via information technology, it could help attract more investors due to perfect knowledge.

5.2. Study limitations

Finally, the current study has some limitations that should be addressed in forthcoming studies. The present study focuses on the seven emerging economies with the most favorable business environments. Therefore, future studies must consider other groups to compare their outcome with the current analysis. Secondly, due to the regression constraint, this study does not consider core factors such as political factors, including corruption, government stability, and the rule of law. Therefore, future studies should consider these factors to examine responses to the business environment. Thirdly, the current empirical analysis employs a limited number of estimators to demonstrate the study's objectives; it would be interesting if future studies considered other estimators to validate our outcomes. Fourthly, due to data constraints, this study was compelled to use financial inclusion; however, if possible, future studies should consider green finance for the business environment. Lastly, this theme should also be examined in other regions, such as the Middle East and North Africa (MENA) economies.

Abbreviations

BS: New Businesses, IN: Income per capita, UB: Urbanization, EP: Entrepreneurship, IT: Information technology, FDI: Foreign direct investment, FI: Financial inclusion, CSD: Cross-sectional dependence, CIPS: Cross-Sectionally Augmented panel unit root test, CADF: Covariate-Augmented Dickey-Fuller test, AMG: Augmented Mean Group, CCE-MG: Common Correlated Effect Mean Group, D-CCE: Dynamic Common Correlated Effect Mean Group, E7: Emerging Seven Economies.

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Summary

Over the last few decades, the business landscape has undergone significant changes, and new investors have faced severe challenges in achieving their desired goals. The business sector has compelled practitioners to introduce some innovative methods that promote the business's activities at lower intrinsic costs. Thus, the inclusion of digital transformation in business activities has been proposed as the best solution to avoid the business loss trap. In the era of development, digital transformation has received immense attention from higher authorities to spur information technology in business activities. It behaves in a friendly manner across different regions of the globe in problematic situations such as pandemics, financial crises, and energy shocks. Therefore, for the first time, this study tries to demonstrate the critical role of information technology in new business activities for **seven emerging economies** from 2005 to 2021. However, this study employs different estimators to evaluate its objectives. The results of the basic model indicate that income, information technology, foreign direct investment, and financial inclusion make significant contributions to business start-ups. The entrepreneurial role remains positive and significantly contributes to new businesses by 0.005%. However, urbanization shows a positive but insignificant role in business activities. Additionally, this study examines the mediating role of information technology on income, entrepreneurship, foreign direct investment, and financial inclusion, revealing a significant impact on business start-ups. Finally, the systematic information technology analysis supports business activities in specified countries. Based on the findings, this study proposes some imperative implications for attracting investors to invest in new business projects.

JEL codes: M21, P25, P44, F35, L26

Keywords: *information technology, New Business, entrepreneurship, foreign direct investment, financial inclusion*

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Research trends and trajectories in quality management in the age of Industry 4.0 – the current state of knowledge

1. Introduction

There has been a major shift towards automation and digitization in all business processes, related to the development of Industry 4.0 (Clancy et al. 2023). Digitalization can help reduce uncertainty in business processes and manage environmental complexity. Specifically, it can contribute to cost reduction, improved organisational efficiency and performance, increased output quantity and quality, decreased lead time, enhance customer responsiveness, competitiveness, business growth sustainability, smoother information flow and better customisation capabilities (Margherita et al. 2022; Broday 2022; Mtotywa 2022; Agarwal et al. 2022; Antony et al. 2023; Sureeyatanapas et al. 2023; Psomas et al. 2023). Additionally, tasks performed by people become automated, almost entirely eliminating human participation (de Souza et al. 2022).

To gain competitive advantage, companies must adapt to environmental changes and address current challenges in deploying Industry 4.0 (Csiki et al. 2023; de Souza et al. 2022; Majernik et al. 2023). This also includes the area of quality management. Technological advances and increased environmental turbulence require a transition in quality management (Mtotywa 2022). Although the Industry 4.0 concept has recently gained significant attention from academics and practitioners, it remains relatively a new area of research requiring further in-depth study, particularly within the field of quality management. Specifically, research on Quality 4.0 has gained traction in the last few years, driven by technological advances linked with Industry 4.0 technologies, as well as the COVID-19 pandemic,

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which changed the face of society and the workplace (Mtotywa 2022). For example, authors have called for an exploration of how Industry 4.0 technologies support workers' engagement in soft total quality management practices for organisational performance or how Industry 4.0 impact organisational performance indicators (Yadav et al. 2020; Margherita et al. 2022).

Given the lack of recognition of the developmental trajectories of scientific research themes on quality management in the context of Industry 4.0, a research gap was identified in this field. For example, it is not clear what is the current state of knowledge on quality management in the age of Industry 4.0: How has the research area developed over a time? Are there distinct phases, trends, or turning points? What are the future research directions and trajectories?

Additionally, the emergence of a new area for research in quality management, related to the development of up-to-date technologies connected with digitalization, requires further exploitation through intensive research and description. According to Kumar et al., there is a need for research in this area, because research on Quality 4.0, in the larger context of Industry 4.0, is still in its nascent stage (Kumar et al. 2022). There is also a need for tools that facilitate management in the context of Industry 4.0 (Montoya-Quintero et al. 2022). Antony et al. also emphasised that Quality 4.0 is still an understudied area (an emerging and nascent area) and there is a lack of studies in terms of understanding the effect of Quality 4.0 on other quality management tools and methodologies or on quality costs or on financial performance (Antony et al. 2023).

A strong, dynamic increase in the number of publications that have been recently published on Industry 4.0 in a context of different areas, can also be observed. However, there is still a lack of studies specifically on quality management field in the age of Industry 4.0. According to Yildirim et al. the lack of the accumulated theoretical approaches or applications means that today organisations have to follow intuitive methods where the digitalization ideas emerge from "a black box", rather than analysing the actual needs of the organisation's strategies and processes (Yildirim et al. 2022). Therefore, this field requires detailed examination. Although new studies have been recently published, they were not included in previous publications and literature reviews. Consequently, they could deliver new relevant research results and therefore should be taken into consideration promptly. There are also publications where the authors are aware that their studies are only a beginning of research and their results can be used to deepen knowledge in further studies. For example, Ferrigno et al. collected the dataset through Scopus and indicated that other databases, such as Web of Science, can be used to deepen the focus of quantitative bibliometric analysis (Ferrigno et al. 2023). As a consequence, the following questions arise: What is the current state of knowledge on quality management in the age of Industry 4.0? What are the

main themes and trends in this field? What are the future research directions and trajectories?

To address this gap in the literature, this study provide an overview of relevant themes on quality management in the age of Industry 4.0, trace research themes' evolution and evaluate the state of knowledge on this topic. Especially, it indicates trends and trajectories in current quality management field. The study is based on articles published in two leading databases: Web of Science (WoS) and Scopus, in field of quality management and Industry 4.0, published up to the end of 2023, using literature review methodology based on bibliometric analysis, especially word co-occurrence analysis and longitudinal thematic map analysis, aiming to answer the following main questions: (1) How did scientific production on quality management in Industry 4.0 grow in recent years? (2) What main themes in literature on quality management in age of Industry 4.0 did emerge till the end of 2023? (3) How did these themes evolve through the studied period? (4) What are the future research directions (trajectories)?

The paper is structured as follows. In Section 2 theoretical background regarding quality management and its evolution is presented; Industry 4.0 and technologies specific to changing ages; and the interactions between them. Section 3 includes an overview of the research methodology indicating the applied research strategy and research protocol with data gathering procedure. Section 4 provides detailed description of research results. It includes results of the analysis of the most relevant sources of publications, the most relevant authors, and also a word cloud analysis, as well as a co-word network analysis to trace the most relevant themes, trends, documents, and asses thematic evolution over time. First part of this section deals with the base research results, the second one enlarges previous results to broader view. The final Section 5 includes conclusions of this publication, research limitations and future research directions.

2. Theoretical background

2.1. Quality management

The quality management field has been studied for more than 100 years (Hamid et al. 2019). Observing its development, the concept of quality has clearly changed over time, with the focus initially being on the quality control process. Inspections were therefore the primary interest of practitioners and researchers aiming to detect a defect or deficiency in the product, which later evolved into eliminating the cause of the defects (Park et al. 2019; Park et al. 2017; Mtotywa 2022). Over time, quality control was replaced by quality assurance.

Subsequently, Total Quality Management (TQM) emerged as a phenomenon in the 1980s and has continued to evolve to this day.

TQM refers to a quality-focused management method based on the engagement of all employees, aiming for long-term success by prioritising the customer and offering benefits to the organisation and society, and is a recognised, sustainable application for competitive advantage (Mtotywa 2022).

In fact, it has recently entered a new breakthrough stage, related to digitalization development (Quality 4.0). According to Park et al. there are four stages of quality development with different goals and strategies (Park et al. 2017; Park et al. 2019). The changes in quality goals are as follows: quality control (QC), quality assurance (QA) and quality management (QM), management quality (MQ) and quality responsibility (QR). Additionally, there are quality strategies aligned with these quality goals, which can be described as follows: inspection, audit standard, innovation, open quality. In particular, the importance of the last stage is underlined by authors in the field. It shows that the recent research focus should be aimed to clarify the responsibility (or accountability) of quality (Park et al. 2017; Park et al. 2019).

Although enterprises can use different tools to deal with some problems more properly, a lot of difficulties from the past still exist and require new solutions (e.g. customer satisfaction). This explains the demand for new technologies and attempts to implement them also in the quality management field. Therefore, academics and practitioners have recently developed a new quality concept called Quality 4.0. This new concept emerged in response to a changing environment, particularly due to advancements in technology, with the previous understanding of quality concept being modified and aligned with the challenges and requirements brought by Industry 4.0. Therefore, Quality 4.0 is in the spotlight of many researchers and their publications in leading international journals (e.g., Bandeira da Silva et al. 2023; Broday 2022; Carvalho et al. 2021b; Jakovic et al. 2023; Khourshed et al. 2023; Kumar at al. 2022; Maganga et al. 2023a, 2023b, 2023c; Sony et al. 2020; Sony et al. 2021; Thekkoote 2022; Wawak et al. 2023; Yadav et al. 2021).

This relatively new concept refers to the digitalization process that aims to cover almost all areas of modern enterprises functioning in the contemporary environment, including the quality management field. In fact, the impact of digitalization process on quality management is crucial to the competitive advantage of each enterprise. Chiarini emphasizes that Quality 4.0 refers to the digitalization of quality of design, quality of conformance and quality of performance using modern technologies (Chiarini 2020). Moreover, he notes that it focuses on connectedness, intelligence and automation to improve performance and timely data-driven decision-making, engaging all stakeholders and providing greater

transparency (Jamkhaneh et al. 2022a). Maganga et al. add that Quality 4.0 refers to a modern quality management approach that uses Industry 4.0 technologies, integration and digitalization (Maganga et al. 2023a).

Broday notices that it is time for Quality 4.0 or the concept of Digital Quality Management (DQM), which was introduced by Romero et al. in 2018 (Broday 2022). DQM refers to cyber-physical production assets through intelligent products, operators and machines and aims to provide information in real time according to pre-defined quality standards, alerting users to deviations that make the process generate non-compliance. This alignment allows companies to achieve higher quality, lower costs and decrease lead times (Broday 2022). In turn, according to de Souza et al., it is time for the new concept of TQM 4.0 as a way of adapting quality management in Industry 4.0 (de Souza et al. 2022). Although literature on Quality 4.0 phenomena is still evolving, researchers emphasise that it is mostly conceptual in nature, requiring further research (Prashar 2023ab).

2.2. Industry 4.0

To better understand the concept of the fourth industrial revolution (also called Industry 4.0 or 4IR), it is necessary to understand how industry has evolved from Industry 1.0 to Industry 4.0 and what the characteristics of each are. The four stages of the industrial revolution are aligned with different periods of time and production strategies (Park et al. 2019; Broday 2022). Industry 1.0 is connected with the age of steam; Industry 2.0 with the age of electricity, Industry 3.0 with age the of information and Industry 4.0 with cyber physical systems. Each era brings different challenges and responds to them in different ways. The question is: How have the key motor elements changed over time?

Mechanical manufacturing systems were the corresponding production strategies in the age of steam, meaning that machine production was crucial at that time. The next challenge was mass production, which was made possible by the discovery of electricity. After that, ICT systems and automation development was possible and led to a focus on lean production. Nowadays, the development of cyber physical systems has changed the rules on the market and is driving mass customization (Park et al. 2019). Significantly, the concept of Industry 4.0 was introduced in 2011 in Germany, as an initiative by the German Government to increase competitiveness through the use of innovative tools and technologies (Kumar et al. 2022). Since that time international journals have published several scientific studies on Industry 4.0, although an increase in interest in the quality management field in the age of Industry 4.0 has only been evident for the last few years (Mtotywa 2022).

According to Maganga et al. the Industry 4.0 involves multiple technologies: the Internet of things (IoT), machine learning (ML), artificial intelligence (AI), mixed reality (MR), virtual reality (VR), connected enterprise, augmented reality (AR), 3D printing, cloud storage, cloud computing, quantum computing, smart sensors, virtual factory, horizontal and vertical systems integration, autonomous robots, big data analytics, etc. (Maganga et al. 2023a). These new technologies have had a crucial impact on the corporate world and have dramatically changed previous approaches to business operations. The goal of Industry 4.0 is to transform industrial manufacturing through digitalization and exploit the potential of new technologies (Zulfiqar et al. 2023).

2.3. Quality management and Industry 4.0

In recent years, Industry 4.0 has become one of the most discussed topics by academics and professionals. Subsequently, the Quality 4.0 concept was created in the field of quality management in response to emerging environment changes that profoundly affected enterprise processes. In fact, with the technological advances and the advent of the Industry 4.0, the focus on quality shifted toward Quality 4.0 (Mtotywa 2022).

The use of new technologies appropriate to the current era is not an easy process, but rather a huge challenge at all times. Technological changes affect various segments of the economy and provide new modifications in business processes and become a source of new solutions. Therefore, the quality management field has changed dramatically over time and changes in priorities for improvements in processes and products can be traced. This refers to the changing understanding of quality and its evolution from Quality 1.0 to Quality 4.0 paralleling the development of industry.

Initially, quality was focused on craftsmanship, raw material, functionality and the understanding of quality was less standardized, and more subjective (Frick et al. 2023). In the mass production age, the concept of quality included consistency and uniformity in mass-produced goods and began a more systematized and standardized approach to quality. Consequentially, the interest moved from the defect detection process to proactive quality assurance, continuous process improvement and Total Quality Management (TQM). Afterwards, the shift was towards total customer satisfaction and experience — even exceeding customer expectations — along with innovation, waste reduction and efficiency improvement simultaneously. Finally, in the current age of digital transformation, the quality management field is focused on using advanced technologies to predict customer needs and personalize experiences on a large scale. It includes continuous monitoring, predictive analytics and real-time adjustments (Frick et al. 2023).

Broday indicates that Quality 4.0 refers to, inter alia, the digitalization of quality management, which aims to improve the culture, organization, skills and leadership of organization (Broday 2022).

All this means that the adoption of Industry 4.0 technologies may affect the quality management field in different ways and with varying degrees of intensity. They may allow enterprises to make current processes more efficient and accurate but also may lead to a reshaping of their business models through the process of implementation of innovations (Ferrigno et al. 2023). For example, the extremely fast development of artificial intelligence and its utilisation in business stands out from other new challenges, e.g. Chat GPT, as a free-to-use AI system, has only been available since 2022. Artificial intelligence (AI) and machine learning are used to define the product inspection strategy or regarding validation, they are utilized to reflect beneficial effects on industrial operations (Jokovic et al. 2023; Mtotywa 2022).

3. Methodology

A literature review methodology, based on bibliometric analysis, is believed to represent an appropriate solution to achieve the aims of this study. Thus to answer the research questions posed, a literature review engaging bibliometric analysis was conducted. As mentioned above, the selected methodology includes several detailed approaches such as: "an annual scientific production analysis", "a word cloud analysis" and "a co-word network analysis", to analyse the research field in depth.

According to Snyder, a literature review, as a research method, is more relevant than ever and can broadly be described as a more or less systematic way of collecting and synthesizing previous research (Snyder 2019). In particular, a systematic literature review is used for an exhaustive search of the past and current published papers on a research topic. In fact, bibliometric analyses are increasingly employed in literature reviews due to the technological development of tools that can support broader, detailed analysis of publications. Consequently, it creates new study opportunities for researchers, previously unavailable and is an expression of technological development in science. Currently, bibliometric approaches are often used to identify emerging themes versus declining ones in the broader research field.

There are several steps that can be identified in the literature review process. According to Snyder, the process of conducting a literature review involves four phases: (1) designing the review, (2) conducting the review, (3) analysis, and (4) writing up the review (Snyder, 2019). Based on this approach, the literature review methodology process was created and applied in this study (see Figure 1).

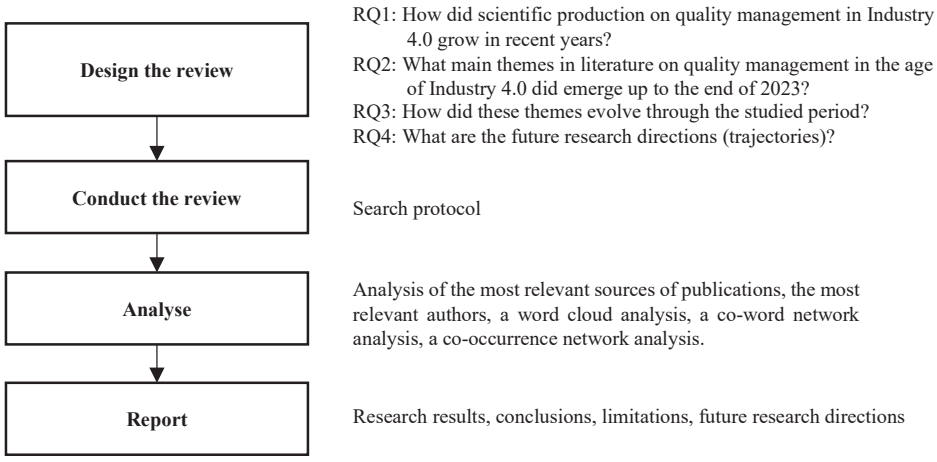

Figure 1. The literature review methodology process applied in this study

Management scholars can use different literature reviews as a research methodology. In particular, they can use approaches such as narrative or integrative reviews; systematic reviews, semi-systematic reviews and meta-analysis or morphological analysis (Snyder 2019; Prashar 2023a). There are many other forms of literature reviews which can combine different approaches or be adaptation of the first one (Snyder 2019; Palmatier 2018). The research strategy, performed in this study, was based on bibliometric review. Especially the open-source R-package called bibliometrix was used. This tool is used by scientists for quantitative research in scientometrics and bibliometrics. The tool was created by Aria and Cuccurullo and provides a set of tools for scientific research especially for science mapping (Aria, Cuccurullo 2017). This bibliometric analysis of scientific literature allowed to perform complete content analysis on the researched topic. The research allowed for the characterization of sources of publications, time of publication, main authors, leading topics, etc.

The research combines results from two sources and therefore consists of two parts. In the first part, the publications included in Web of Science (WoS) database were involved. WoS includes several relevant literature databases supported scientific and scholarly research. Journals in this database are globally recognized by the scientific community as the most essential for publishing and include the most relevant research results, thus this was the reason for the selection of this database. To build the research sample, papers from the WoS database were selected. Initially the research was based on three main keywords:

"quality management", "industry 4" and "fourth industrial revolution". Due to the large number of results, the search was limited to two combinations of keywords. Keywords involved in this research were combine with each other as follows: "quality management" AND "industry 4", "quality management" AND "fourth industrial revolution". Subsequently, the following exclusion criteria were incorporated: only two WoS Categories (Management, Business), English language only, and only article, proceeding paper and review article document types. Then the results were reviewed and duplicate documents were removed. Next, abstracts of these papers were reviewed to ensure the analysis focused on the field of quality management in Industry 4.0 and on this basis articles suitable for bibliometric analysis were identified.

In the second part, the research was expanded and previous results were confronted with the results coming from a search of a second database, SCOPUS. Scopus provides a comprehensive overview of worldwide research output in different fields and includes scientific journals, books, and conference proceedings. The reason for searching documents in the second database was a desire to widen the research results and confront them with a broader view. The searches on the databases ware done in the fourth quarter of 2023 year and updated in January 2024. The whole incorporated search protocol can be seen in Figure 2.

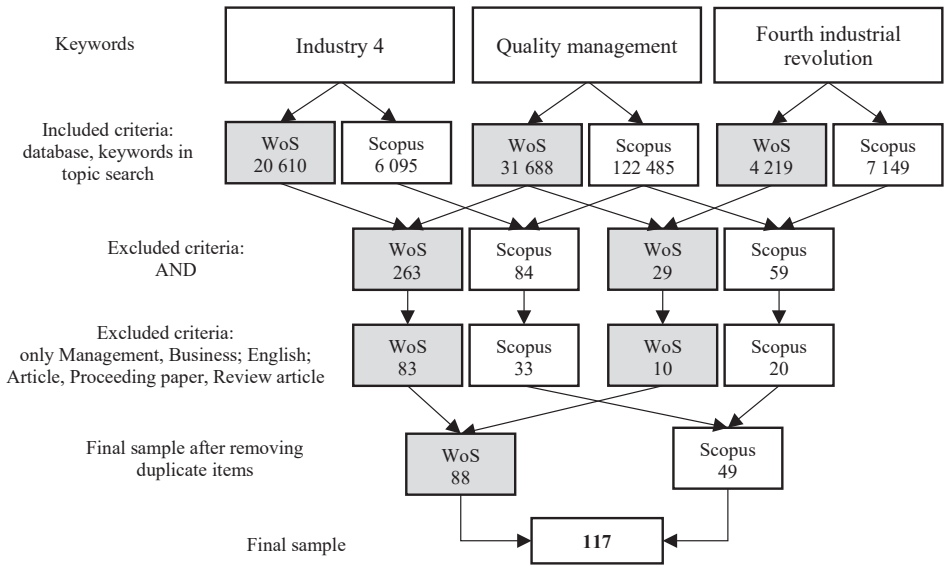

Figure 2. Web of Science and Scopus search protocol

Appendix 1 presents a list of publications selected for the study and sorted by date. Afterwards the papers were loaded into the bibliometrix tool and the content analysis was carried out. This means that the final samples, with selected papers, were evaluated and the results of this assessment are presented in the next section of this paper. Additionally, the presentation of research results was divided into three particular subject subsections: research results review (4.1); research results of word cloud analysis (4.2); research results of co-word network analysis (4.3). Each subsection contains results based on both databases.

4. Research results

4.1. Research results review based on Web of Science and Scopus

Based on three main keywords: "quality management", "industry 4" and "the fourth industrial revolution" and through the combination of these keywords, 88 papers were selected from the WoS database and 49 papers from Scopus database. Table 1 present the results of the descriptive analysis of selected publications from both databases.

Table 1

Results review from WoS and Scopus databases

Description	WoS results	Scopus results
Documents	88	49
Timespan	2017–2023	2016–2023
Document types	article (53), article; early access (13), article, proceedings paper (2), proceedings paper (9), review (10), review; early access (1)	article (32), conference paper (11), review (6)
Average citations per doc	13.88	13.39
Sources (journals, books, etc)	36	25
Authors	221	142
Authors of single-authored docs	8	6
Co-authors per doc	2.86	3.18
International co-authorships [%]	28.41	26.53
References	5026	–
Author's keywords	325	168

The analysis of the data obtained from WoS shows that all documents were dated from 2017 to 2023, although there was no time limit applied in the research. The year 2011 is considered to be a starting point for Industry 4.0, thus it is surprising that no publications linking it to quality management were found from earlier than 2017. It was expected that the first publications would have appeared shortly after 2011 or within the first few years. This means that the concept of Industry 4.0 slowly entered the area of interest of quality management researchers. Interestingly, substantial growth of number of articles can be observed from 2022, approximately ten years after the term Industry 4.0 was first introduced, and is constantly growing. Figure 3 presents annual scientific production.

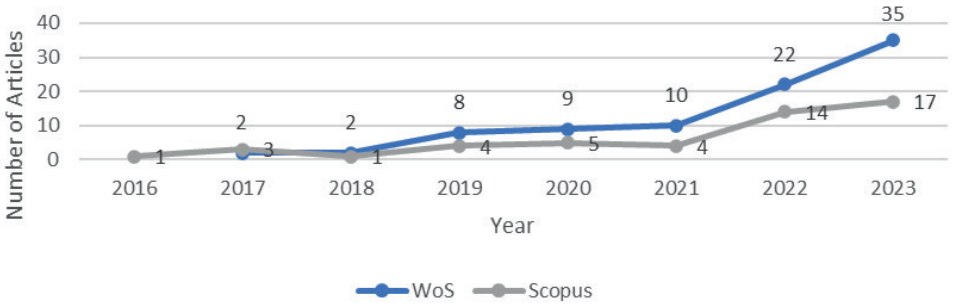

Figure 3. Annual scientific production

Similarly to the results from WoS, data from Scopus indicates that all papers were published between 2016 and 2023 and the number of publications increased substantially in 2022. This confirms that interest in the literature on quality management topic in the context of Industry 4.0 emerged relatively recently (since 2017 in WoS, since 2016 in Scopus) and indicates a great potential that is still not being fully exploited.

Research results also indicate that among gathered documents there are different types of publication. Most of them are articles (WoS – 66, Scopus – 32), but there are also proceeding papers (WoS – 11, Scopus – 11) and reviews (WoS – 11, Scopus – 6). Average citations per document is 13,88 in WoS and 13,39 in Scopus.

All of the selected documents come from 36 different sources, but only ten have published more than one paper (see Figure 4). Among them are many well-known in quality management scientific world international journals which published articles on researched topics.

In WoS, the most relevant source is the *TQM Journal* (with 21 articles). At the top are also: *Total Quality Management and Business Excellence* (with 10 articles)

and International Journal of Quality and Service Sciences (with nine articles). These journals are among the most relevant sources examining the relationship between quality management and Industry 4.0. In Scopus, all of the selected papers were published in 25 different sources (e.g., journals, proceedings), in total. Only seven of them published more than one selected document. Surprisingly, the most relevant source was Proceedings on Engineering Science (10 articles). Although the Scopus database also contains other journals typical for the quality management research field, they turned out to be far behind. This is probably due to greater interest in proceedings, on the one hand, and the topic of Industry 4.0, on the other. Other important sources were: *Total Quality Management and Business Excellence* (five articles), *International Journal of Quality and Reliability Management* (four articles), *International Journal of Quality and Service Sciences* (four articles), Proceedings of the International Conference on Industrial Engineering and Operations Management (three articles) and *TQM Journal* (three articles).

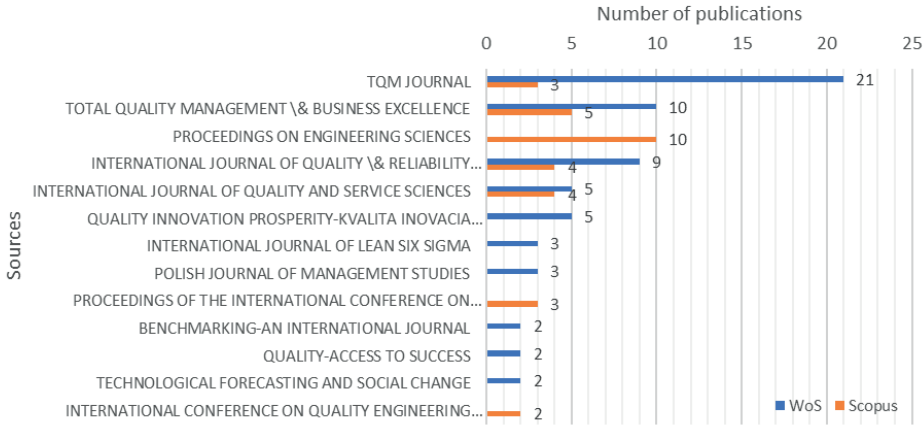

Figure 4. Most relevant sources

Additionally, it is worth noting that the publication dynamics of three leading international journals indexed in WoS are notably high and clearly distinguishable from other sources (see Figure 5).

In contrast to the research results based on the WoS database, Scopus indicates that the production dynamic of leading sources is not so high, apart from Proceedings on Engineering Science, with greater growth in 2023 (Fig. 6).

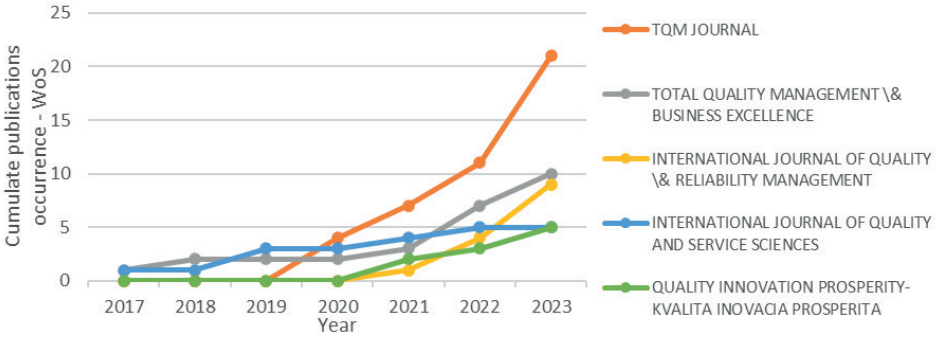

Figure 5. Source growth of publications – WoS

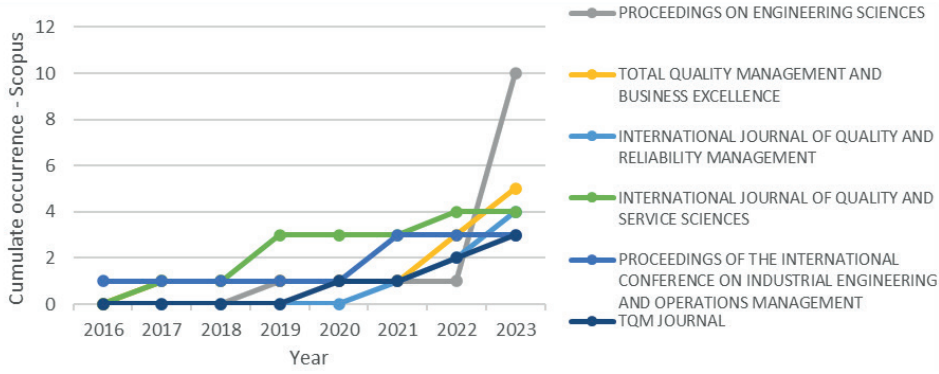

Figure 6. Source growth of publications – Scopus

There are 221 people involved in authorship of 88 selected documents from WoS database. It means that there are 2,86 co-authors per document (circa 28% is international co-authorships). Among them, eight individuals appear as the authors of sole-authored publications. In the Scopus database, 142 authors of selected publications were identified which indicates 3,18 authors per document, with six sole-authored documents and nearly 27% of the international co-authorships.

In WoS, the most relevant corresponding author's countries are: India and United Kingdom. Research based on WoS shows that Antony (with six publications), Sony (with four publications) and Maganga, Sampaio and Taifa (with three publications) have the highest productivity during the researched period (Fig. 7). In Scopus, the analysis indicates that Savelyeva and Sozinowa are the

most relevant authors (four publications). Thus, the highest productivity in the Scopus database during the researched period was an author with four publication, which is similar to previous result (in WoS it was six), but no author appears in both databases at the same time. Eight authors published two papers and the other only one paper.

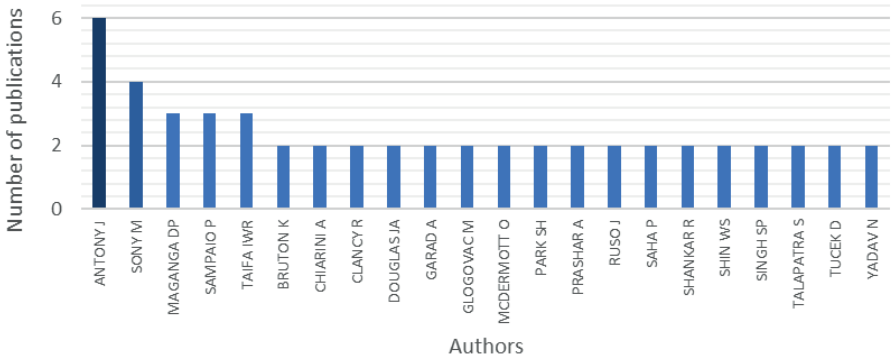

Figure 7. Most relevant authors

In addition, authors of researched publications from WoS database used 5026 references in total and provided 325 author's keywords. In comparison, authors provided 168 author keywords in Scopus.

4.2. Research results of word cloud analysis

The word cloud analysis was carried out after a short review of the most important data from selected documents, in order to detect the most used keywords in the selected documents. Word cloud is a classic text visualization technique and is widely applied in many situations in facilitating semantic understanding (Yang et al. 2020). In this case, word cloud analysis was used to highlight the most prevalent words in representative journals in the researched field.

Figure 8 presents the word cloud with the main keywords provided by the authors in selected documents. It presents collected data as a cloud where the words which are used most frequently are increased in size. It helps to quickly highlight keywords that came into focus in the selected documents. The bigger the word appears, the more often it is mentioned and this keyword is more significant than others.

In the research results from WoS, the biggest words are: "implementation", "quality management", "impact" and "framework", but there also appear

keywords such as: "industry 4.0", "industry", "big data", "total quality management", "performance", "big data analytics", "artificial-intelligence". The word size is proportional to word occurrence. It means, that the word cloud indicates important themes in selected documents and illustrates farness between significant themes in the middle of the word cloud and other themes outside. In this case, a relationship between quality management and other concepts related to Industry 4.0 can be observed, that is distinctive and relevant in this field.

a)

b)

Figure 8. Word clouds comparison – WoS (a) and Scopus (b)

Interestingly, the word cloud from selected documents from the Scopus database differs from previous one from WoS. In this case, the word cloud analysis shows that the most important and the most recent themes are Industry 4.0 and quality management. They are centrally located and are the largest words in the word cloud, therefore they are highly visible. Table 2 presents detailed data about the most frequent words used by the authors of selected documents in the WoS and Scopus databases.

Table 2

Most frequent words comparison

	Words	Occurrences	Words	Occurrences
WoS	implementation	19	industry	8
	quality management	16	firm performance, technologies	7
	impact	15	context, design, integration, sustainability, tqm	6
	framework	14	big data analytics, culture, total quality management	5

Table 2 cont.

	Words	Occur-rences	Words	Occur-rences
WoS	systems	13	analytics, barriers, business performance, challenges, maturity, methodology, organizations, system	4
	future, innovation	12		
	big data, performance	11	artificial-intelligence, iot, adoption, companies, knowledge, knowledge management, lean production, opportunities, servitization, technology, tools	3
	management, model	10		
	industry 4 0	9		
Scopus	industry 4 0	13	construction industry, customer satisfaction, information management, inspection, internet of things, management quality, project management, quality assurance, quality improvement, sustainable development, total quality management	2
	quality management	7		
	design/methodology/ approach, quality 4 0	4		
	artificial intelligence, competition, industrial research, industrial revolutions, literature reviews, quality control, surveys	3		

More information about thematic interest in a particular scientific field can provide also detailed co-word analysis presented below.

4.3. Research results of co-word network analysis

Co-word analysis uses the most important words or keywords of the documents to study the conceptual structure of a research field (Cobo et al. 2011). It can be used to quantify and visualize the thematic evolution of a scientific field. The results of co-word analysis include the results of the co-occurrence network analysis, the thematic map analysis, and the longitudinal thematic map analysis based on data derived from both of databases.

4.3.1. Co-occurrence network analysis

Figure 9 presents results of co-occurrence network analysis for keywords from selected documents based on the WoS database.

The co-word network analysis indicates nine clusters in total. Each colour represents a cluster of word (a "topic"). There are three relevant areas of topic

connections that noticeably stand out from the rest. They are focused on keywords such as: "implementation", "performance", "future", etc. (the first cluster shown in red); "impact", "framework", "innovation", "industry 4.0", etc. (the second cluster shown in blue) and quality management, systems, big data, etc. (the third cluster shown in green). The remaining clusters are: adoption, opportunities (the fourth cluster); methodology, environment (the fifth cluster); capabilities, dynamic (the sixth cluster); context, barriers (the seventh cluster); technology (the eighth cluster) and conceptual framework (the ninth cluster). In the context of this research, clusters, pointed as second and third, are significant. Keywords such as: "quality management", "systems", "big data", "management", "industry", "technologies", "sustainability", "analytics", "artificial-intelligence", "IOT" (Internet of Things), "lean production" are close to each other because a large proportion of selected articles merge them together. The same applies to keywords such as: "impact", "framework", "innovation", "Industry 4.0", "firm performance", "integration", "big data analytics", "total quality management", "system", "knowledge", "knowledge management", "servitization", "tools".

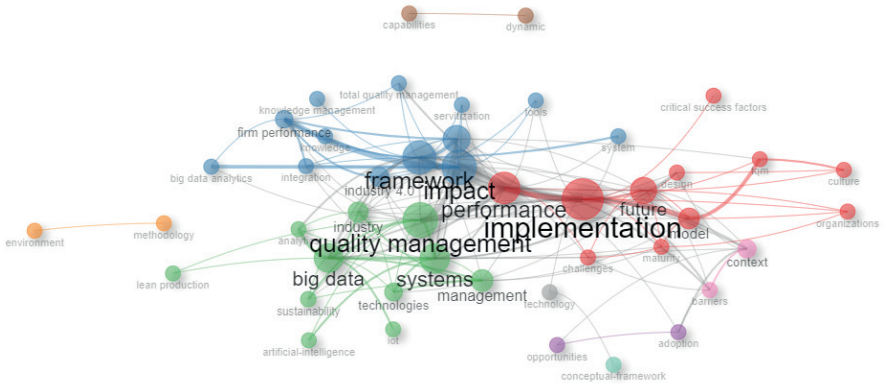

Figure 9. Co-occurrence network – based on WoS database

Similar to the research results based on WoS database, the results of co-word analysis based on Scopus database revealed several clusters, with two of them the largest. Figure 10 presents more detailed information on that analysis.

In total, co-word analysis confirmed the existence of four clusters containing the following main themes. The first cluster (blue cluster) includes: "Industry 4.0", "quality management", "Quality 4.0", "artificial intelligence", "competition", "literature reviews", "quality control", "customer satisfaction", "inspection", "internet of things", "management quality", "quality assurance", "quality improvement", "sustainable development. "

Figure 10. Co-occurrence network – based on Scopus database

Interesting is that the edge size between themes is the same apart from: (1) "quality management and Industry 4.0", (2) "Quality 4.0 and Industry 4.0", (3) "quality management and artificial intelligence", (4) "Industry 4.0 and design/methodology/approach". Due to the strength of the edges highlighting the co-occurrence of related themes, the four relationships identified could be indications for further research interest. The second cluster (the green cluster) merges such themes as: "industrial revolution", "total quality management", "industrial research and design/methodology/approach". The third focuses on construction industry and surveys. The final isolated cluster refers to information management and project management and does not possess any relationship with other themes.

Additionally, due to the fact that each identified cluster ("topic"/"theme") in this analysis can be represented on a plot, a particular plot known as Thematic map is presented below (Cobo et al. 2011). Consequentially, the thematic map was created by using centrality and density as the main measures, helping to shed new light on the results.

4.3.2. Thematic map analysis

A thematic map, known also as strategic diagram, is a two-dimensional space built by plotting themes according to different measures extracted using a post network analysis (Cobo et al. 2011). It highlights different topics of a given domain applying two different criteria: centrality and density. Centrality is understood as a measure of the topic's relevance and density is understood as a measure of the topic's development (Cobo et al. 2011). Figure 11 and Figure 12 present the results of the analysis performed.

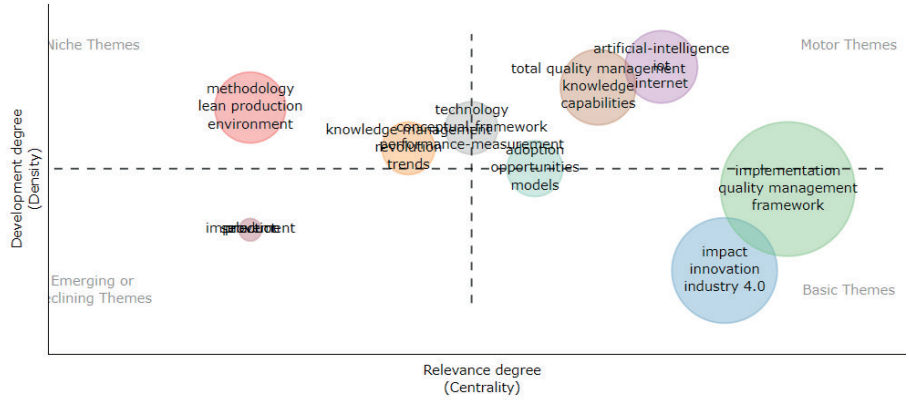

Figure 11. Thematic map based on WoS

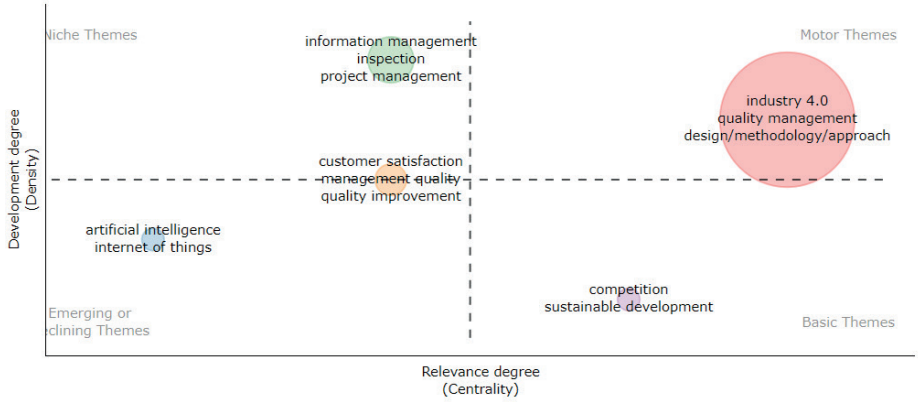

Figure 12. Thematic map based on Scopus

Each bubble represents a different cluster. The bubble size is proportional to the cluster word occurrences. There are four different domains presented in Figure 10 and Figure 11, and they are termed as follows: niche themes (highly developed and isolated themes), emerging or declining themes, basic and transversal themes, and motor themes. There are several clusters in each domain in both figures. In Figure 11, significantly relevant clusters are in the two domains on the right side of the chart. They are the driving force in contemporary research topics. Two clusters in the field of basic themes are the largest. They include concept such as: "quality management" and "Industry 4.0". Basic themes signifies that there is a great potential for further development in these areas. These concepts can be

widely known and extensively used by both academics and researchers in the foreseeable future and over time they may become motor themes. On the other hand, concepts such as: "total quality management", "knowledge", "Artificial-Intelligence (AI)", "Internet of Things", "Internet" currently occur as motor themes. This means that a significant portion of publications are actually focused around these themes, representing current topics of interest.

Figure 12 provides a detailed analysis highlighting the appearance of specific cluster with artificial-intelligence and internet of things which settled in the emerging themes field. Although the results derived from the Web of Science database emphasize the existence of a similar cluster, the results from Scopus shows that it appeared in an another field — as a motor theme. It signifies that this is a current science trend and the themes of AI and IoT will most certainly be the subject of interest of contemporary scientists in the quality management field in the foreseeable future. Secondly, it confirmed that the themes of quality management and Industry 4.0 are not the only motor themes, but also that customer satisfaction or quality improvement themes still should not be forgotten due to them emerging as emerging themes. There is a constant need for performing further research in these areas in context of developing technologies.

Sustainable development theme represented as a small bubble in the basic themes field also seems to be interesting. This shows the potential for further development of this theme although the bubble size, which is proportional to the cluster word occurrences, is not large. In addition, the sustainable theme was also recognised and noticed by researcher in publications from Web of Science. For example, the sustainable theme belongs to the biggest cluster on the thematic map in the domain of basic themes. This points to the fact that sustainable development as a theme might be advisable in future research, including in the quality management context.

4.3.3. Longitudinal thematic map analysis

The next step of this analysis was to trace topic evolution based on data from both WoS and Scopus databases and using a longitudinal thematic map analysis. To achieve this goal, the entire time span (2017–2023) in the WoS database was divided into different time slices. This allowed for studying and plotting the topic evolution. Based on the annual production of selected documents two breakthrough years were identified: 2020 and 2022. The first one is related to the beginning of the increase in the number of selected publications and at the same time the outbreak of the COVID-19 pandemic, and the second one is related to another observed dynamic increase in the production of selected publications. Using these two cutting points, three thematic maps with corresponding clusters can be observed (see Figure 13).

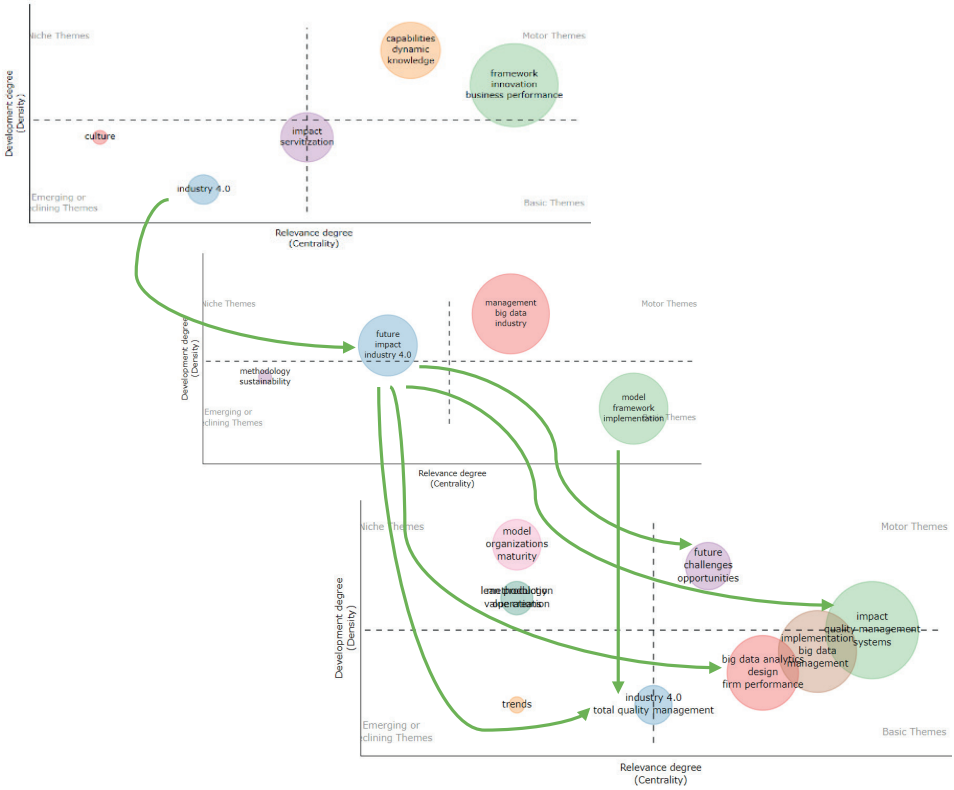

Figure 13. Thematic evolution – three time slices based on WoS database

The results of these three maps analysis shows the research trajectories in quality management and Industry 4.0. Most of all, the trace of evolution indicates that before 2020 year, the concept of Industry 4.0 in selected documents from WoS appeared as an emerging topic rather than something exploited on a broad scale. Then, between 2020 and 2022, the interest increased and slowly begun leaning towards leading, mainstream themes area. And finally, after 2022, it reached the basic themes field.

It is important to emphasize that the tendency of Industry 4.0 topic to divide into several themes can be observed. Significantly, visible is a split the one emerging cluster, identified in second time slice, into four other clusters, identified in the last time slice. It can be observed that it emerged between 2020 and 2022, and it concerned three main themes: future, impact and Industry 4.0. Subsequently, it split into four other clusters. Two of them are directly connected with leading

identified topics (future and impact) and the next two are the results of the further Industry 4.0 theme's split. Interestingly, all of them became fast a basic themes or even motor theme in the third time slice.

As mentioned before, the first theme, specified as "future", became a basis for creation of a new cluster in the last time slice with such themes as: "future", "challenges", "opportunities", etc. The second theme, namely "impact", created a foundation for the biggest cluster at the last thematic map and appeared as the new cluster between basic and motor themes. It means that theme's relevance and theme's development were relatively at a noticeably high level at that time. The next theme of mentioned cluster refers to "Industry 4.0". In this case, thematic evolution proved to be even more sophisticated and extensive. As a result, two clusters were established. The first one with themes such as: "Industry 4.0", "total quality management", etc. and the second one with the following themes: "big data analytics", "design", "firm performance", etc. It should be emphasised that their creation was related to other previous leading themes as well.

Looking at the distribution of publications per year in the Scopus database, however, a burst in publications occurred in 2021. Therefore, the whole collection of publications was only divided into two time slices setting one cutting point in 2021. This allowed us to plot, trace and study the topic evolution using a longitudinal thematic map analysis. On this basis, two thematic maps with corresponding clusters were created (Fig. 14).

Detailed analysis of the data indicated that before 2021 topics such as: "artificial intelligence", "Internet of Things", "quality", "digital transformation", "Quality 4.0" were niche themes rather than motor themes or basic themes. After 2021 this changed significantly. The digital competitiveness and total quality management topics became motor themes in publications from the Scopus database. Industry 4.0, Quality 4.0, quality management and sustainability topics appeared as basic themes. Additionally, total quality management topic that before 2021 occurred as emerging or declining theme (the left lower quadrant of the thematic map) evolved after 2021 and split into several themes directly connected with digitalization and Industry 4.0. It is worth emphasizing that at the same time there was a clear shift towards basic and motor themes. This means that there was a breakthrough in the development of TQM. The concept was renewed in the context of ongoing digitalization and gained importance again among researchers.

This aligns with results of conducted thematic evolution analysis based on data from WoS where quality management theme was rediscovered by researchers and faced many new challenges in the new contemporary context of Industry 4.0. Therefore, it is a good opportunity and also a great challenge for the researchers to develop and find new solutions incorporating an expansion of Industry 4.0 new technologies in quality management field and to move it forward.

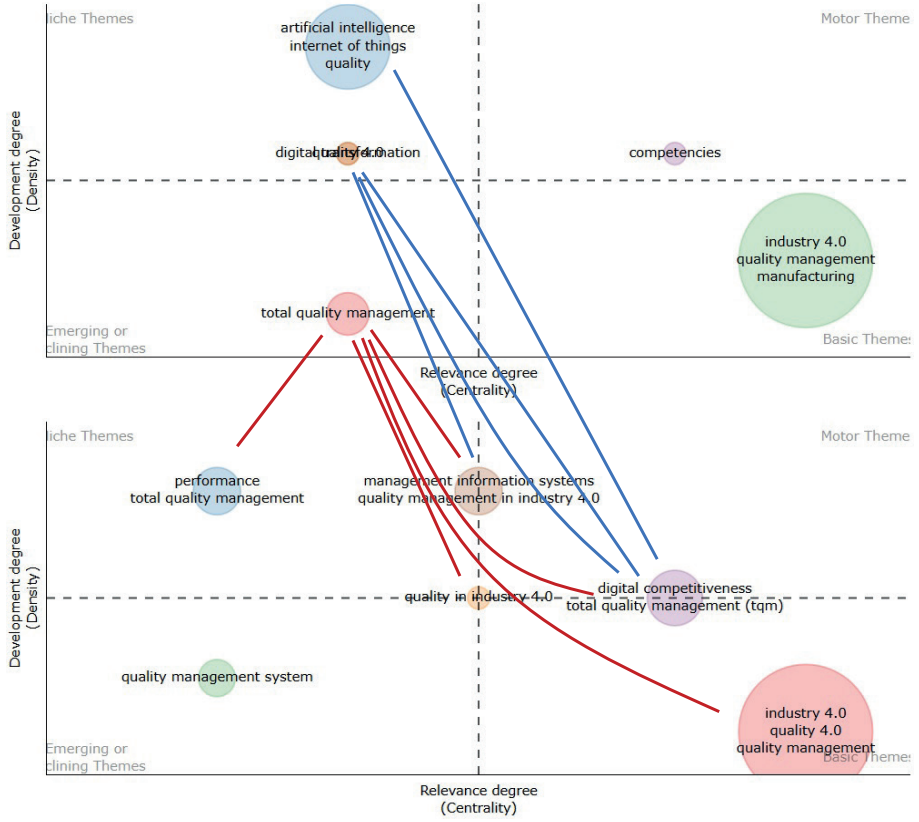

Figure 14. Thematic evolution – two time slices based on Scopus database

Furthermore, total quality management topic began to be linked to the performance topic and appeared as niche theme. Interestingly, the quality management systems appeared among the emerging topics. This may directly refer to the high level of the development (density) of the management information systems topic. This may also be linked to the search for effectiveness and efficiency in management using standardized management systems.

Research trajectories discovered in the analysis of thematic evolution can also be presented in a different way. Noticeably, they highlight the tendencies of some themes to split into other themes, but also to merge together. For instance, in WoS (see Figure 15) the cluster with Industry 4.0 and total quality management, etc. is based on two other previous clusters with themes such as: "future", "impact", "industry", "on the one hand and model", "framework", "implementation", etc., on the other.

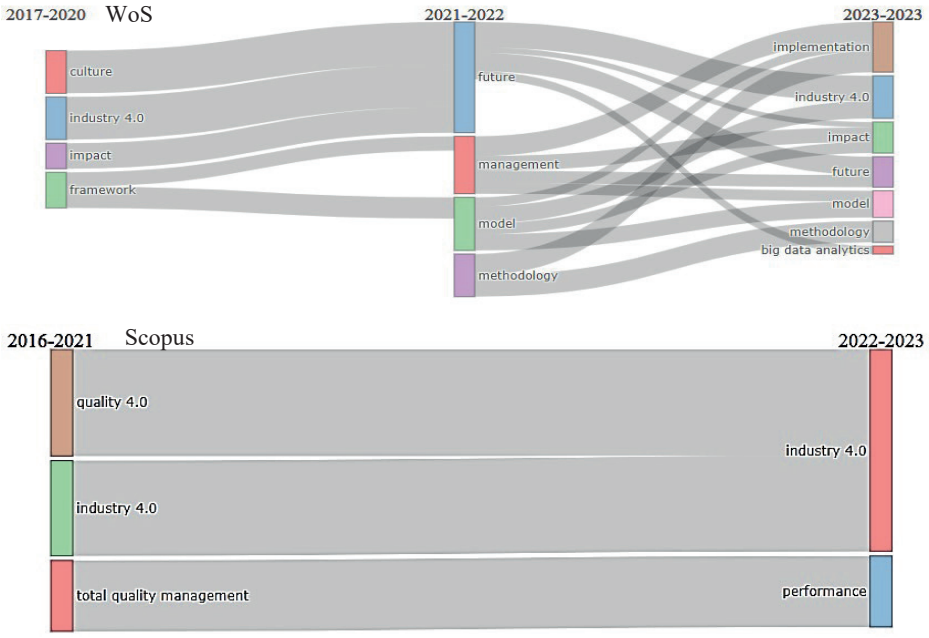

Figure 15. Thematic evolution – research trajectories based on WoS and Scopus databases

The results show also that the "future" theme seems to have been crucial during the years 2021 and 2022 and can be easily related to the COVID-19 pandemic situation at that time. Concerns about the future have become a leading topic for many researchers from various specialties. At the same time, this theme became a source for contemporary fields of interests and research topics such as Industry 4.0 or big data analytics. Results based on the Scopus data indicated that the quality 4.0 and Industry 4.0 themes merged together and the total quality management theme developed gradually into a more complex form enriched with the performance theme. Figure 14 presents all of the research trajectories identified.

Co-word network analysis may be supplemented by an analysis of the intellectual structure and social structure of the scientific research field. For example, co-citation analysis can be used to analyse the intellectual structure of a scientific research field (Cobo et al. 2011). However, due to the limited scope and length of this publication (i.e., the limited number of research questions addressed), the results of this particular analysis have not been included. Nonetheless, the findings did indicate the presence of two distinct and relevant clusters related to the themes of Quality 4.0 and Industry 4.0 (i.e. Zonnenshain et al. 2020; Gunasekaran et al. 2019).

The social structure of the scientific field was analysed with the use of collaboration network analysis. Generally, this can be performed by using different units of analysis in the author's affiliations: co-institution, co-university, or co-country (Cobo 2011). The results, by using the author's affiliations (co-country), indicate that the international dimension of this research is broad and wide. Nine clusters were identified with one standing out from the rest. It pointed to significant international collaboration among authors coming from India, United Kingdom, Ireland, South Africa, United Arab Emirates, Bangladesh, Namibia and the Netherlands. The detailed analysis also confirmed a close collaboration between e.g. M. Sony and J. Antony (Sony et al. 2020; Sony et al. 2021; Antony et al. 2022; Antony et al. 2023), which was reflected in the close collaboration between Liverpool John Moores University and Heriot–Watt University (Edinburgh, UK).

5. Conclusions, future research directions and research limitations

In this paper, a number of research questions were investigated. The first research question referred to scientific production on quality management in the age of Industry 4.0. The research results showed that a significant growth in the number of articles is observable from 2022, which was more than 10 years after the concept of Industry 4.0 was introduced in 2011. Interestingly, this production dynamic is constantly growing, and in last two years it increased dramatically and was at really high level compared to previous years. This provides the opportunity to gain a broader insight into areas of research interest, recent findings and further developments. The fact that all the publications selected for the study were dated from 2016 regarding Scopus database and from 2017 regarding Web of Science database was also surprising. This may confirm why there is currently a relatively high amount of interest in the literature in the results of the study on quality management in the age of Industry 4.0 (as in an unexplored field).

The second and third research question concerned the main themes that had emerged by the end of 2023 in literature on quality management in the age of Industry 4.0 as well as their evolution throughout the studied period. The research helped identify the number of themes from the published articles representing different stages of development in the literature.

The results showed that motor themes are directly linked with the theme of quality management and Industry 4.0. The research helped identify the following motor themes: "quality management", "Industry 4.0 and design/methodology/approach theme"; "the management, big data and industry theme"; and "the

future, challenges and opportunities theme". This is a promising and broad area of research that has begun to be strongly exploited by researchers and is reflected in the literature. There are also three relevant basic themes as: quality management, impact and system theme; implementation, big data and management theme; and big data analytics, design and firm performance theme. Artificial-Intelligence (AI), Internet of Things (IoT), sustainable development as well as customer satisfaction and quality improvements themes are included in the emerging themes. Finally, inspections and project management themes were identified as niche themes.

The evolution of different themes shows that in recent years it was possible to trace a tendency of some themes to split into other themes and also other to merge together. Especially, the results from the WoS database show themes which appeared as basic clusters of topics. For example, it led to the emergence of clusters such as: big data analysis theme in a context of design and firm performance theme or implementation theme with links to big data and management themes or impact theme connected with quality management and systems themes. These fields of interest were identified as basic themes. Additionally, the analysis performed on data from the Scopus database showed that there is one more field of interest, i.e. the sustainable development theme with competition that were identified as basic themes, as well. However, in turn, the results from the WoS database indicate that this theme is still an emerging field. Thus, there is no doubt that the sustainable theme has been recognised by researchers and has great potential for further development. Sustainable development as a theme should also be used in future research in the quality management context.

Artificial-Intelligence (AI) and Internet of Things (IoT) were identified as other emerging themes and it is expected that these new fruitful science trends will increase in importance in the quality management context in the coming years. Interestingly, the research results show that there are also some topics which may potentially become emerging themes, noticeably the customer satisfaction and quality improvements themes. Evolution analysis showed that the quality management theme was rediscovered by researchers and faces many new challenges in the context of Industry 4.0. New research gaps have emerged and fresh evidence and approaches are needed. Therefore, it is both a good opportunity and great challenge for researchers to develop and to find new solutions incorporating the expansion of new Industry 4.0 technologies in the quality management context. This includes customer satisfaction field or quality improvements. These are not new fields of interest but they have been enriched with new opportunities which can improve the quality management field and the whole organization.

The last research question referred to future research directions and trajectories. Figure 16 presents emerging trends and future research directions in quality management in the age of Industry 4.0.

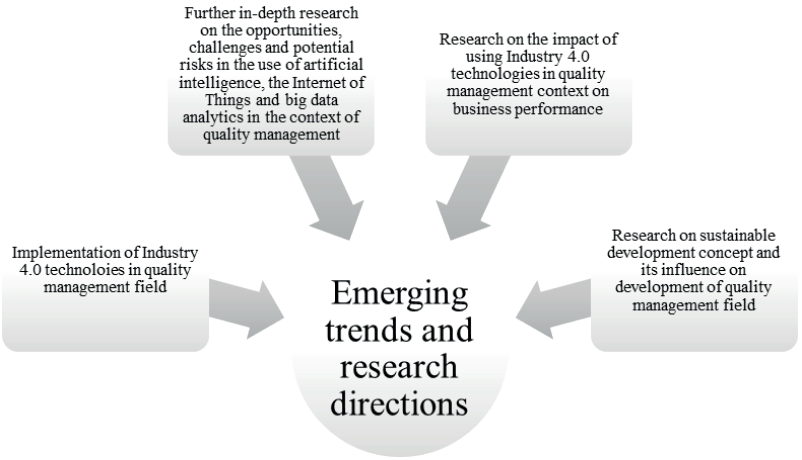

Figure 16. Emerging trends and research directions in quality management in the age of Industry 4.0

Based on the research results, the following emerging trends and future research directions can be indicated: (1) further research should concern the implementation of Industry 4.0 technologies in the quality management field, including basic and also more sophisticated available solutions; (2) using Artificial-Intelligence, Internet of Things and big data analytics in the quality management context requires further in-depth study with an indication of opportunities, challenges and potentially threats; (3) further research should also concern the impact of using Industry 4.0 technologies in the quality management context on business performance (4) additionally, further research should concern the sustainable development concept and its influence on the development of the quality management field.

This study is subject to the following four main limitations.

First, due to the large number of results, the search was limited to two specific combinations of keywords. Keywords involved to this research were combined with each other as follows: "quality management" AND "industry 4", "quality management" AND "fourth industrial revolution".

Secondly, the scientific literature included in the study is derived from two databases, namely Web of Science and Scopus. Therefore, the conducted research could be extended to include data from other databases, which may contribute to a more in-depth bibliometric analysis.

Moreover, several exclusion criteria were applied in this study, and a number of other publications may not have been included in the analysis. For example,

only papers written in English and limited to the fields of management and business were considered.

Lastly, due to the large scope of the different detailed analyses and the limited volume of publications, not all of the results were presented, i.e. the results of co-citation network analysis and historiographic mapping analysis were excluded from this publication.

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Summary

This study aims to analyse publication activity and identify development directions of scientific research themes in the area of enterprise quality management in the context of Industry 4.0, based on a bibliometric analysis of scientific literature from the Web of Science and Scopus databases up to the end of 2023. The article employs a systematic literature review method. The research included a bibliometric analysis of scientific literature sourced from the Web of Science and Scopus databases. Based on a predefined combination of keywords, a set of articles was selected, which – after initial screening and justified exclusions – was accepted for further analysis. The study enabled the characterization of, among others, publications production, sources of publications, time of publication, main authors and leading topics. Next, a word co-occurrence analysis and longitudinal thematic map analysis were conducted to examine the research field in depth and to identify research trends and trajectories in quality management in the age of Industry 4.0.The conducted research shows that the number of publications on quality management in the context of Industry 4.0 is constantly growing, and the topics are progressively evolving towards issues such as: the Internet of Things (IoT), Artificial Intelligence (AI), Big Data, digitalization. These technologies are seen as key enablers for enterprises to cope with the growing uncertainty and complexity of the business environment and to achieve a competitive advantage. The study indicates that AI, IoT, big data analytics, and sustainable development are among the most rapidly growing and prominent themes in the literature on quality management in the Industry 4.0 context. Identifying research gaps and potential directions for scientific development in the field of quality management may contribute to the creation or improvement of new tools, approaches, and concepts including those based on Industry 4.0 technologies.

JEL codes: L25, L15, M14, O14, Q56

Keywords: *quality management, Industry 4.0, Quality 4.0, Artificial-Intelligence (AI), Internet of Things (IoT), sustainability*

Appendix 1

List of publications selected for the study

Year	References
2016	Eleftheriadis et al. 2016
2017	Park et al. 2017; Schlter et al. 2017; Štofová et al. 2017
2018	Anttila et al. 2018; Demartini et al. 2018; Simion et al., 2018
2019	Beard-Gunter et al. 2019; Garad et al. 2019; Hake et al. 2019; Hamid et al. 2019; Martynov et al. 2019; Liczmanska-Kopcewicz et al. 2019; Park et al. 2019; Ralea et al. 2019; Stefanović et al. 2019; Trinks et al. 2019
2020	Angioni et al. 2020; Asif 2020; Beckers et al. 2020; Chiarini 2020; Ghobakhloo et al. 2020; Kisel'akova et al. 2020; Moldabekova et al. 2020; Skuza 2020; Sony et al. 2020; Vo et al. 2020; Tikhonov et al. 2020; Yadav et al. 2020
2021	Babatunde 2021; Carvalho et al. 2021; Carvalho et al. 2021a; Carvalho et al. 2021b; Corti et al. 2021; Efimova et al. 2021; Okwu et al. 2021; Kannan et al. 2021; Nguyen et al. 2021; Sony et al. 2021; Teplicka et al. 2021; U-Dominic et al. 2021; Vinodh et al. 2021; Yadav et al. 2021
2022	Agarwal et al. 2022, Aichouni et al. 2022; Ali et al. 2022; Balouei Jamkhaneh et al. 2022; Broday E.E. 2022; Clancy et al. 2022; de Souza et al. 2022; Elibal et al. 2022; Glogovac et al. 2022; Gyurak Babelova et al. 2022; Jamkhaneh et al. 2022a; Jamkhaneh et al. 2022b; Jamwal et al. 2022; Johannsen 2022; Kumar et al. 2022; Lardosa Rebelo et al. 2022; Margherita et al. 2022; Milosevic et al. 2022; Montoya-Quintero et al. 2022; Mtotywa 2022; Nasir et al. 2022; Ranjith et al. 2022; Sader et al. 2022; Santhi et al. 2022; Schmied et al. 2022; Silva et al. 2022; Thekkoote 2022; Yildirim et al. 2022; Yu et al. 2022; Zhu et al. 2022
2023	Akhmedova et al. 2023; Alieva et al. 2023; Antony et al. 2023; Ashmarina et al. 2023; Bogoviz et al. 2023; Canbay et al. 2023; Chiarini et al. 2023; Clancy et al. 2023; Csiki et al. 2023; Bandeira da Silva et al. 2023; Ganjavi et al. 2023; Jokovic et al. 2023; Karbekova et al. 2023, Khourshed et al. 2023; Kucinska-Landwojtowicz et al. 2023; Laskurain-Iturbe et al. 2023; Maganga et al. 2023a; Maganga et al. 2023b; Maganga et al. 2023c; Majernik et al. 2023; Mondal et al. 2023; Naidoo et al. 2023; Narkhede et al. 2023; Nayal et al. 2023; Nguyen et al. 2023; Popkova et al. 2023; Prabhu et al. 2023; Prashar 2023a; Prashar 2023b; Psomas et al. 2023; Raj et al. 2023; Saha et al. 2023a; Saha et al. 2023b; Saihi et al. 2023; Sharma et al. 2023; Shrivastav 2023; Singh et al. 2023; Solovyov et al. 2023; Sozinova et al. 2023a; Sozinova et al. 2023b; Sureeyatanapas et al. 2023; Tolmachev et al. 2023; Wang et al. 2023; Wawak et al. 2023; Zulfiqar et al. 2023

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Segmenting SMEs in Central Europe's coal mining region based on green finance awareness

1. Introduction

The global shift toward sustainability necessitates unprecedented financial commitments. According to the European Commission, at least €1 trillion in sustainable investments will be needed over the next decade. At least 30% of that amount will be dedicated to climate-related problems (Fetting 2020). Additionally, the United Nations Climate Change Conference 2022 concluded with a decision to phase out coal mining, necessitating the transformation of mining regions. The green transition is a global movement towards a more sustainable future, and Central Europe is no exception. The countries in this region face unique challenges when it comes to financing the green transition due to their economic history and current political landscape. Given the scale of the challenge, it is crucial to engage the private sector, particularly small and medium enterprises (SMEs), in the transition towards a greener economy.

Central and Eastern Europe (CEE) regions, in particular, are facing significant challenges in financing the green transition due to a variety of factors, including the economic and political context, institutional frameworks, and market conditions. In that theme, green financing refers to the process of providing capital to finance environmentally friendly projects. This type of financing is becoming increasingly popular as countries and regions move towards sustainable development (SD). SD is defined as development that meets the needs of the present

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without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development, 1987). The Sustainable Development Goals (SDGs) were adopted by the UN General Assembly in 2015, but they are not legally binding like the climate agreement. Therefore, in the same year, the international community created a new climate agreement in Paris. The SDGs are important for the 2030 Agenda, which guides global environmental and development policy, but their goals can be unclear. The Paris Agreement, on the other hand, has clear goals and assumptions, with the main aim being to limit the increase in Earth's temperature to below 2 degrees Celsius compared to pre-industrial levels. The importance of the problem also increases with the introduction of the European Green Deal (EGD) which aligns with the objectives of the Paris Agreement and SDGs (Liobikienė, Miceikienė 2023).

Unlike SDGs that cover a wider range of global development goals including social, economic, and environmental aspects, the EGD places focus on policies related to climate change in the European context. EGD outlines specific targets such as greenhouse gas emissions reduction by 2030, decarbonization of the energy system, and making Europe climate neutral, meaning net-zero greenhouse gas emissions (Fredriksson, Zachmann 2021; Lapčík et al. 2022). It requires substantial funding and policy instruments to reach its ambitious targets, it is contingent on factors such as EU budget negotiations, national governments approval, and mobilising private sector capital investment (Busse et al. 2021; Filipović et al. 2022). The Deal also impacts many sectors, not only those related to energy consumption and utilisation, but also agriculture by aiming to reduce the use of pesticides and promoting organic agriculture (Pańka et al. 2021). Regardless of the chosen targets, the effect of the EGD reaches numerous sectors, many areas of life, and economic activity, posing a major challenge for CEE economies.

In this context, regions, cities, and especially SMEs are pivotal. SMEs are considered as the backbone of the European economy, accounting for 99% of all businesses in the EU and employing around 100 million people. According to the OECD (2020), increasing spending and matching investment pathways by 2050 within climate neutrality goals should be an important part of the transformation process. Reducing carbon dioxide emissions is clearly beneficial for the environment, but it can have a negative impact on the economy. Therefore, it is important to study the sources of financing for the green transformation and analyse the potential effects of policy actions on both the environment and the economy. The financial sector can play a vital role in achieving climate goals and implementing applicable regulations, which is why it has been emphasised in the key assumptions of the Paris Agreement. We consider that research in this area is crucial, as it can lead to insights that can guide policymakers and financial institutions in

supporting SMEs in their green transition efforts (Alsaleh et al. 2021; Bhattacharyya 2022; Cifuentes-Faura 2022).

While existing studies have explored the influence of green finance on businesses, a gap remains in the literature regarding the segmentation of SMEs based on their attitudes toward green finance and their financial situation. This topic is particularly relevant for coal-intensive CEE regions, offering a path to address local environmental issues, support energy transformation, and foster sustainable regional development. Moreover, alignment with EU policies provides additional opportunities for funding pro-environmental projects, further accelerating their transition. This paper seeks to address this gap. Our aim is to investigate the awareness of green finance tools among SMEs, leading to the following research question: How does awareness of green finance tools vary among SMEs, and what are the differentiating characteristics between companies with diverse approaches to green financing? To answer this, we first conducted a literature review on green finance sources and then proceeded with the identification of SME segments based on similarities and differences.

2. Literature background

The transition toward a sustainable, low-carbon economy has become a central challenge for businesses of all sizes. SMEs while representing a crucial part of the economic structure and employment, face unique challenges in this process. This section aims to provide an overview of the main factors influencing SMEs' participation in the green transition, the availability of green finance instruments, and the existing research gaps identified in this field.

2.1. Challenges and drivers for SMEs in green transition

SMEs significantly impact the environment in different ways. It could be emission pollution, discharges to rivers and seas, waste production, and soil contamination. Despite their considerable contribution to global carbon emission, according to studies, SMEs also face limitations in financial resources (Chien et al. 2021; Wang et al. 2023) as well as a lack of knowledge, skills, and experience necessary to address environmental issues effectively (Ghazilla et al. 2015; Journeault et al. 2021). These barriers extend beyond financial constraints and are also related to regulatory barriers (Chien et al. 2021) and the lack of management commitment to implementing green practices (Karuppiah et al. 2020; Khan et al. 2023). This reluctance can be driven by the uncertainty of the economic benefit of it (Khan et al. 2023) which leads to the conclusion about the importance of expertise

required to implement green initiatives (Ghazilla et al. 2015; Wang et al. 2023). Beliefs about the justification of the actions taken also play an important role. Lack of understanding, perceived benefits, and supply chain complexities hinder SMEs' engagement in managing carbon emissions and adopting environmental management systems (EMS). It is shown in the example of UK SMEs' scepticism in the work of Afolabi et al. (Afolabi et al. 2023). It seems that companies of this size view environmental investments as a cost rather than an investment. SMEs encounter difficulties because they have limited awareness of the impact and benefits linked to sustainable investment (Journeault et al. 2021).

However, despite their demanding requirements, green investments can also bring benefits to businesses. Starting with the stream of literature that promotes sustainable economic growth (Sulaksana 2022), Green Entrepreneurial Orientation has a positive influence on not only environmental impact but also on financial performance (Liu et al. 2024; Meng, Hao 2024). This can be framed within the context of dynamic capabilities that foster exploitation of new ideas and catch potential opportunities (Jiang et al. 2018). It promotes the advancements in technology to make it clean and energy-efficient (Jaiwant, Kureethara 2023). Its impact is also shown as significant in the context of SMEs in developing countries. The impact of green financing on SMEs in developing countries, as highlighted by Asad et al. (2023), correlates positively with financial literacy and contributes to green economic recovery, as noted by Hou and Fang as an example of China's economy (Hou, Fang 2023). The questions in that place could be related to the factors that drive the green practices from the SMEs' point of view. Management commitment is consistently identified as a key internal factor, alongside external pressures such as regulation, cost considerations, organizational mission, and consumer pressure (Ha et al. 2024; Lutfi et al. 2023; Subramanian, Suresh 2023; Tyler et al. 2024). Empirical evidence on examples of Canadian SMEs together with interviews highlight the individual values and internal and external interpersonal connections and social environment that influence SMEs' involvement in sustainability initiatives (Westman et al. 2019). The view of SMEs as social actors highlights the importance of relationships and awareness of sources of financing that support green transformation initiatives. In general opinion, SMEs often focus on low-cost, low-tech products to emphasise the attraction of low prices (Awaluddin et al. 2021), but green initiatives can also be an answer to consumer needs (Hafish et al. 2024).

2.2. Availability of green finance instruments

The extant literature presents the possibilities of green finance instruments, however, most of the papers are focused on energy policy and climate policy, as stated by Zhang et al. (Zhang et al. 2019), who provide an extensive bibliometric

analysis on the green finance topic. Another review was done by Akomea-Frimpong et al., who conducted a review focused on green finance in the banking sector, identifying seven main categories: green loans/bonds, green investment, climate finance, green infrastructure bonds, green insurance, green securities, and carbon finance (Akomea-Frimpong et al. 2022). Berrou et al. present the main types of green finance products and services (Berrou et al. 2019). The most innovative were classified as Green Bonds which are instruments that are used to finance specific projects with positive environmental impact. This product is to be used by international financial organisations, large corporations, banks, and even national governments and municipalities, but not SMEs, which are the centre of interest of this article. Green Loans represent the next most common green finance product, dedicated to smaller-scale investments and widely offered by commercial banks. While they require substantial screening and disclosure, green loans are considered the most accessible instrument for smaller entities. The next presented instrument is Green Project Financing Operations, it involves a number of equity investors (the sponsors) and a pool of banks or other financing institutions (the syndicate). It is used for large, long-term investments. There are no guidelines on what can be considered a "green", it only deals with the sponsors and the syndicate. There are also some private green products, the most significant of which is private equity (PE). Private Equity green investing is driven by a need for new value-creation sources and increased risk management, and is characterised by investor engagement. Unfortunately, the potential of PE is not fully realized in the regions relevant to our research, although continued long-term growth is expected (Poświata et al. 2022). Regardless, PE is unlikely to be a primary source of green transition funds chosen by SMEs.

2.3. Research gap and contribution

This paper is linked to a stream of literature focusing on the corporate capital structure, and sustainability issues represented mostly by the global requirements for the green transition and fiscal policy of relevant countries. Key inspirations include the work of Akomea-Frimpong et al. (Akomea-Frimpong et al. 2022), who explore banking green finance and identify research gaps, and Lee and Lee (Lee, Lee 2022), who analyse the effect of green finance on total factor productivity in China. Zhang et al. provide a valuable bibliometric analysis of the field (Zhang et al. 2019). To the best of our knowledge, no authors have focused specifically on the Central European region, taking into account their coal mining and heavy industry historical background. Moreover, according to our knowledge, the SMEs' awareness of potential financial sources for the green project has not been examined before, therefore we aim to contribute to the current literature on

the availability and use of green finance sources/instruments by SMEs. There is no doubt that it is important to make urgent efforts to support investments in projects aimed at these actions related to green transforming regions and cities. During the study of relevant literature, we identified a knowledge gap concerning the source of finance for green projects in the Czech Republic, Slovakia, as well as in Poland. There are some papers targeting each country separately that we identified: Laskowska, for example, focuses their research to Poland but limiting it to only 2 banks is not sufficient in our opinion (Laskowska 2018).

The exploratory nature of this study, coupled with resource constraints and sample availability limitations, led us to concentrate the geographical scope on the Upper Silesian Coal Basin (USCB) in Poland. This specific concentration is justified by the dominant and unique role of the Polish coal sector in the European Union (EU) and Central and Eastern Europe (CEE), where the Polish section of the historical coal region constitutes the largest physical area of the coal basins. Also the Polish economy remains significantly more dependent on coal extraction and consumption than the economies of the Czech Republic and Slovakia. Statistical evidence (Eurostat 2025) clearly reflects this reliance: Poland accounted for 97% of the total EU hard coal production (44 million tonnes), and along with Germany was responsible for almost two-thirds of its consumption (43%). Furthermore, Poland was the second-largest consumer of brown coal (lignite) in the EU (21%), after Germany (46%). Therefore, focusing on the USCB allows this exploratory study to examine the region facing the most immediate and complex economic and social challenges within the EU's climate policy framework, making it the most appropriate area for an in-depth analysis.

3. Research design

We formulated the following research question: "How does awareness of green finance tools vary among SMEs, and what are the differentiating characteristics between companies with diverse approaches to green financing?". This question was addressed by conducting a tailored survey to assess SMEs' readiness for green financing and their financial health. The analysis aimed to determine the similarities and differences between companies with varying levels of green finance awareness and overall financial strength, thereby allowing us to create distinct market segments of SMEs from coal mining regions. The detailed methodology is presented below.

The survey aimed to assess the green finance awareness of SMEs, as well as to identify differences between companies in terms of their financial health and engagement in sustainable investments. The questionnaire comprised seventeen

closed-ended questions divided into two main thematic sections. The first section, Awareness and Level of Engagement with Green Financing (ten questions), focused on key aspects such as general knowledge of green finance instruments, assessment of current implementation, future intentions, and barriers to access. The second section, Financial Health and Business Performance (seven questions), examined the firms' financial stability and overall performance indicators. The full set of questions as an element of cluster analysis is presented in Table 3. The survey was conducted as part of the ExCORE project, a collaborative initiative between young researchers from the University of Economics in Katowice, VSB Technical University of Ostrava, and the Technical University of Kosice. The project focuses on the green transition of coal-intensive regions, with specific emphasis on economic consequences, social implications, energy poverty, and the implementation of new technologies (Funding: The Polish National Agency for Academic Exchange (NAWA) Strategic Partnerships Programme, Project No. BPI/PST/2021/1/00007).

The data was collected from 200 Polish companies operating in the Silesian region in 2023. As shown in Table 1, 61% of firms are classified as small firms in terms of the number of employees, the remaining 39% of companies are considered to be medium-sized. The largest representation is of service-oriented companies (46%), followed by production companies (39.5%) and finally business companies (14.5%). Family-owned firms dominate the sample (61%).

Table 1

Sample structure

Category	Group	Share [%]
Business form	Limited liability	56.5
	Partnership	6.0
	Other	37.5
Main business profile	Service	46.0
	Production	39.5
	Business	14.5
Number of employees	10–49	61.0
	51–100	23.0
	101–150	4.0
	151–200	7.0
	More than 201	5.0

Table 1 cont.

Category	Group	Share [%]
Energy costs (% of total operating costs)	1–10	57.0
	11–20	28.0
	21–30	8.0
	31–40	5.0
	41–50	1.0
	More than 51	1.0
Family business	Yes	61.0
	No	39.0

Before creating the SME segment based on their attitudes towards green financing, factor analysis was first applied, which allows the variables to be reduced to a few factors before performing the cluster analysis, which can be named and described. Factor analysis does not distinguish between dependent and independent variables, but rather deals with the interdependence between variables. When used for market segmentation, the analysis helps identify variables that can be used to divide customers into individual groups (Aljandali 2017).

To apply factor analysis, certain conditions must be met. The first is Cronbach's Alpha, which measures the consistency and reliability of individual items on the scale and their relationship to the battery. Its value should be above 0.7 (DeVellis, Thorpe 2021). The next condition is the KMO Index, which assesses the suitability of factor analysis and should be between 0.5 and 1.0. Values lower than 0.5 indicate that factor analysis is not appropriate. The last test before using factor analysis is Bartlett's test of sphericity. This shows whether factor analysis can be performed with regard to the correlation of variables. The null hypothesis (H0) is defined as there being no correlation between variables. The alternative hypothesis (H1), on the other hand, states that there is a correlation between variables. For the purposes of factor analysis, a variable can correlate with itself, but it should not correlate with other variables (Malhotra 2017).

There are several methods of factor analysis, namely principal component analysis, the least squares method, or common axis factoring. The factors can then be rotated using Varimax orthogonal rotation, and in this rotation, each original variable tends to join with one (or a small number of) factors, and each factor

consists of only a small number of variables. The factors generated by this method are easier to interpret (Abdi 2003). The final number of factors can be determined by Eigenvalue, also known as Kaiser's rule. Eigenvalue is a value that represents the total variance explained by individual factors. According to Kaiser's rule, those factors with an Eigenvalue greater than 1 are determined as final factors, which was used as a basis for this project (Malhotra 2017).

The second used method is the cluster analysis, which classifies objects into groups based on their similarity. Objects within a single cluster are more or less homogeneous and differ from objects in other clusters. According to this analysis, each object belongs to only one cluster, and these clusters do not overlap (Hennig 2015). Clustering methods are divided into hierarchical and non-hierarchical methods. One of the hierarchical clustering methods is Ward's method, which, compared to other methods, produces compact, relatively small clusters of roughly equal size (Everitt et al. 2001). Important are methods of distance measurement between the clusters, one of the most common is the Euclidean distance, which is the square root of the sum of the squares of the distances between the coordinates of the objects (Bouhmala 2016).

The second approach is called non-hierarchical clustering. In this case, the number of clusters is known, and other objects are gradually accumulated towards the centre of each cluster. One of the non-hierarchical clustering methods used is the K-Means method, which starts with random centres that are recalculated until their position is stable. Objects are assigned to the cluster whose centre is the closest to them (Malhotra 2017).

4. Results

To enhance the clarity and comprehensibility of the findings, the results section is divided into subsections presenting the main stages of the analysis, including factor analysis, cluster analysis, and the description of the identified segments.

4.1. Factor analysis and dimensionality reduction

Prior to cluster analysis, which was used to create segments of companies in the green finance market, factor analysis was used to reduce the sub-variables of a smaller number of factors. The conditions for using factor analysis were met. The Kaiser–Meyer–Olkin test measuring data consistency showed a value of 0.781, which is above the required value of 0.5. Also, Bartlett's test of sphericity confirmed

that there was a correlation between the variables, the p-value of the test was 0.001 (Tab. 2). Thus, the null hypothesis was rejected, and the alternative hypothesis which claims that the variables are correlated, was accepted (Malhotra 2017).

Table 2

KMO and Bartlett's test results

Indicator		Results
Kaiser–Meyer–Olkin measure of sampling adequacy		0.781
Bartlett's test of sphericity	approximate Chi-Square	1489.556
	degrees of freedom	136
	significance	<0.001

The extraction method used was Principal Component Analysis. The factors were subjected to Varimax rotation, a process that facilitates interpretation by maximizing the loadings for a single variable within a given factor (Abdi 2003). The number of factors was determined by the Eigenvalue, according to this rule the final model included the components whose variance (eigenvalue of the correlation matrix) is greater than 1, which was by five factors. As shown in Table 3, the 17 original variables were reduced to five outcome factors. According to Hair et al. (2009) for the sample size of 200, factor loading higher than 0.4 is considered to be significant. Therefore, two statements had cross-loadings and one had two significant cross-loadings. Following the suggestion of Dang and Pham (2022), these variables were retained as they indicate a dual effect on different factors. Each variable was ultimately assigned to the factor for which the loading coefficient was higher. These reduced variables then served as the input factors for the subsequent cluster analysis.

Table 3

Rotated component matrix with factor loadings

Survey question	Component				
	1	2	3	4	5
1.05. We know how to apply for green financing instruments	0,806	–	–	–	–
1.03. We sought expert financial advice on the green financing options available to our company	0,789	–	–	–	–

Table 3 cont.

1.02. We know the benefits of using green financial instruments	0,784	–	–	–	–
1.01. We believe that we are well-informed about the different types of green financial instruments	0,775	–	–	–	–
1.04. We have received support and information on financing options for our company's green transformation process from external parties	0,756	–	–	–	–
2.05. Our company maintains liquidity at a good and stable level	–	0,890	–	–	–
2.04. Our company remains viable (profitable)	–	0,872	–	–	–
2.06. The overall financial situation of our company is good	–	0,863	–	–	–
2.07. We are satisfied with the operating profit margin achieved	–	0,698	–	–	–
1.08. We plan to use green financial instruments in the future	–	–	0,828	–	–
1.06. We believe that green financing instruments are essential to maintain competitiveness in our sector	–	–	0,765	–	–
1.07. Green financing is more costly compared to standard	0,330	–	0,639	–	–
2.02. We have increased our market share	–	–	–	0,850	–
2.01. We have increased the number of employees	–	–	–	0,839	–
2.03. Our sales revenues have increased	–	0,494	–	0,621	–
1.09. We have encountered difficulties in finding suitable green financial instruments that are in line with the specific needs and objectives of our company	–	–	–	–	0,818
1.10. We believe that our company is excluded from green financing opportunities	–	–	–	–	0,776
Extraction method: principal component analysis. Rotation method: varimax with Kaiser normalization Rotation converged in six iterations					

4.2. Cluster analysis and segmentation

Both hierarchical and non-hierarchical clustering were used to create clusters to compare the two methods. Hierarchical clustering was used first since the number of clusters was not known in advance. Two clusters were created using Ward's method and as a method of distance measurement Euclidean distance was used. The results were also confirmed by a dendrogram and the agglomeration schedule coefficient. For hierarchical clustering, the number of clusters from the previous method was worked with. Due to the sample size, which was 200, hierarchical clustering was preferred, as more equal in size and better interpretable clusters were created by this method. However, both methods produced two well-described clusters. Finally, as it can be seen in table 4, these two clusters were validated using the ANOVA test to confirm whether the mean values of variables for the observed clusters are identical or not. There were identified significant differences regarding the mean values of variables at a significance level of 0.05. The number of clusters can be therefore assessed as correct and confirmed. The newly formed clusters were named according to how firms responded to statements about their financial situation and to statements regarding their attitudes towards green finance and awareness of these instruments.

Table 4

ANOVA test between created companies segments in the green finance market and five reduced factors

Segments		Sum of squares	Degrees of freedom	Mean square	F	Significance
1) Awareness and interest in green finance	between groups	28,426	1	28,426	32,997	0,000
	within groups	170,574	198	0,861	–	–
	total	199,000	199	–	–	–
2) Liquidity, profitability and margin (financial company growth indicators)	between groups	36,746	1	36,746	44,842	0,000
	within groups	162,254	198	0,819	–	–
	total	199,000	199	–	–	–
3) Potential and future use of green finance	between groups	4,135	1	4,135	4,201	0,042
	within groups	194,865	198	0,984	–	–
	total	199,000	199	–	–	–

Table 4 cont.

4) Market share and employees (other company growth indicators)	between groups	37,899	1	37,899	46,579	0,000
	within groups	161,101	198	0,814	–	–
	total	199,000	199	–	–	–
5) Difficulties and unavailability of green finance	between groups	8,700	1	8,700	9,052	0,003
	within groups	190,300	198	0,961	–	–
	total	199,000	199	–	–	–

4.2.1. Segment 1: passive idealists

The first segment, labelled passive idealists, included 47% of the surveyed firms. 70.2% of this segment are medium-sized firms and 29.8% are small firms. According to their self-assessments (Fig. 1) their level of awareness of green financial instruments is not that high (48.17%) and so is their knowledge of the benefits of using these products (48.50%). They also did not seek much expert advice on this topic (29.67%) and did not receive much information about their options for green transformation (24.83%).

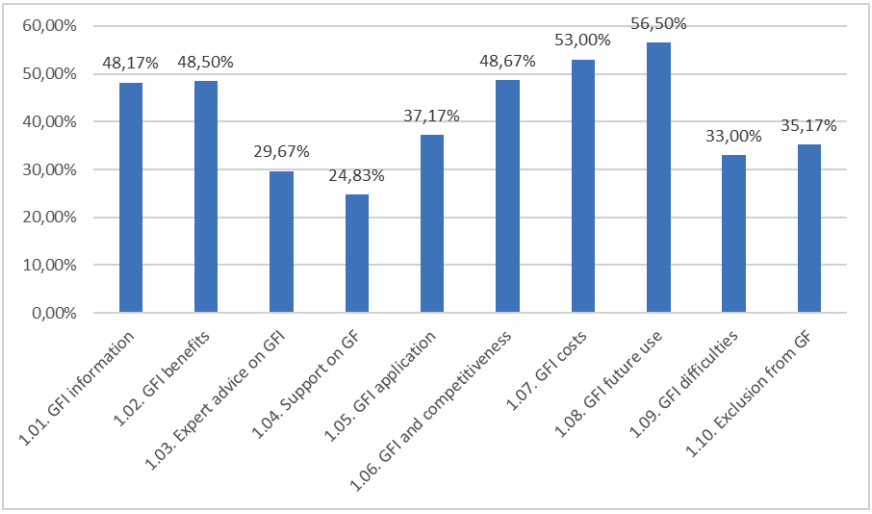

Figure 1. Passive idealists cluster green finance statements agreement rate

Moreover, regarding their self-evaluation of financial situation (Fig. 2), it is perceived very positively – their company is evaluated as profitable (82.50%), their liquidity is said to be at a stable level (80.50%), and they are not in threat of

bankruptcy (82.33%). Their market share (30.83%) or the number of employees (27.33%) did not increase as much as they are mostly small companies. They are also quite satisfied with their operating profit margin (62.50%).

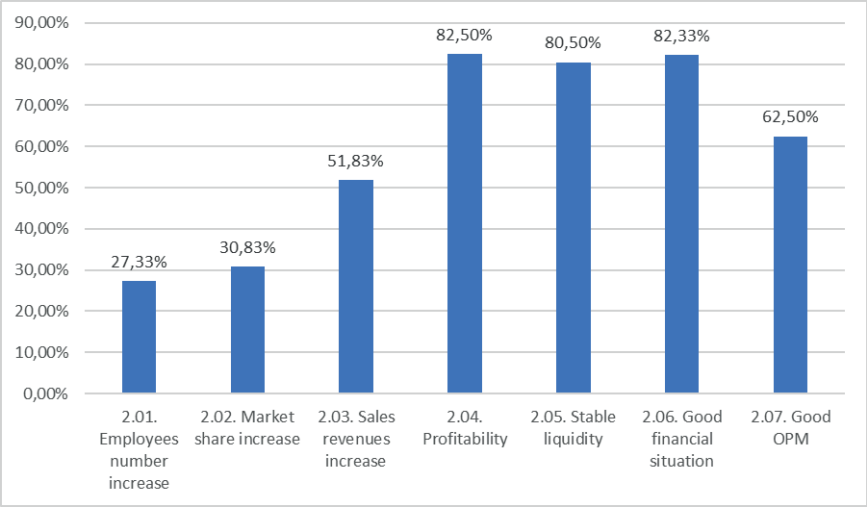

Figure 2. Passive idealists cluster financial situation agreement rate

4.2.2. Segment 2: informed realists

The second segment of so-called informed realists consists of 54.7% medium-sized companies, 45.3% small companies. It also consists of more family companies (63.2%) than the first segment (58.5%). This segment (Fig. 3) is better informed about green finance instruments (58.67%) and also about their benefits (61.17%). Some of them have already sought expert advice (49.83%) and informed themselves about applications for green finance instruments (53.50%). They are more engaged in this topic, so they found some difficulties in finding suitable instruments for their company specifically (45.83%).

Regarding the financial situation that companies themselves evaluated (Fi. 4), it is also rated quite positively but they are not as idealistic about it as the previous segment. They managed to increase the number of their employees (42.33%), including their market share (53.17%). Companies from this segment also evaluate their profitability relatively positively (64.83%), their liquidity as stable (63.17%) and they also perceive their financial situation quite well (67.00%), however, these areas are not evaluated so optimistically compared to the first segment. In this case, of course, it is a self-assessment of the financial situation

from the perspective of companies, which will not be very objective from this point of view, as companies may tend to overestimate their financial situation.

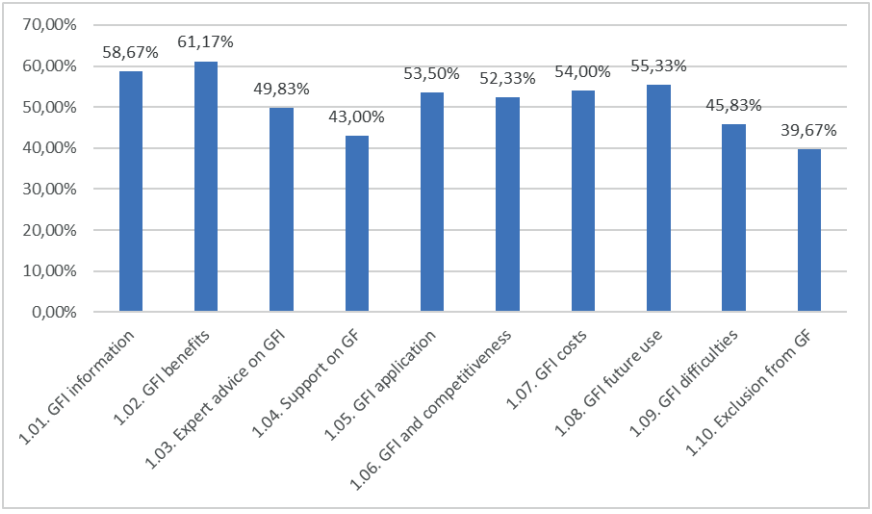

Figure 3. Informed realists cluster green finance statements agreement rate

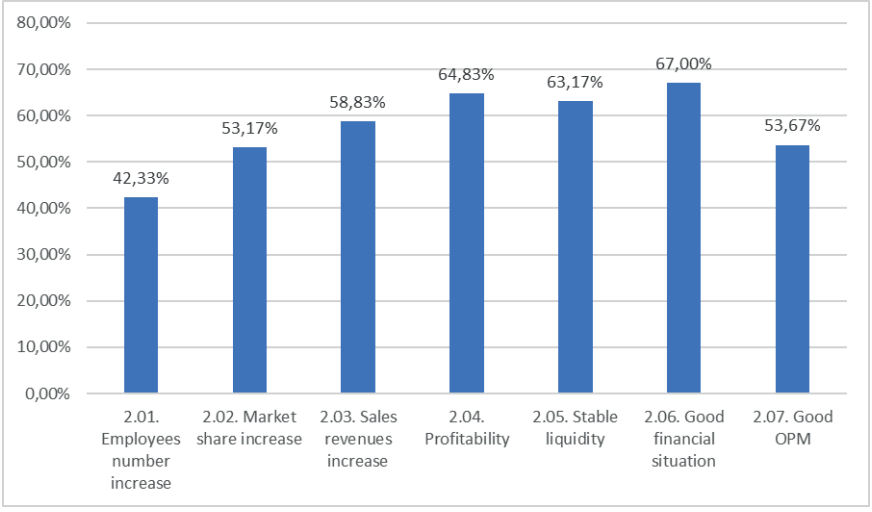

Figure 4. Informed realists cluster financial situation agreement rate

5. Discussion and conclusions

In line with the structure used in the previous chapters, this section is divided into several parts for clarity and consistency. It begins with a summary of the identified segments, followed by a discussion of key challenges and implications for policymakers and financial institutions, and concludes with the study's limitations and suggestions for future research.

5.1. Segment characteristics summary

This paper aimed to explore the awareness and readiness of SMEs in CEE for green financing. By analysing their attitudes towards green financing, alongside other characteristics, the study was able to segment these businesses into categories. Outcomes demonstrate that the segmentation uncovers unique profiles in terms of financial health and involvement in green finance. The first identified group of SMEs – passive idealists show robust financial results with restricted involvement in green finance, whereas the second group consisting of informed realists are more knowledgeable and proactive in green finance, despite facing obstacles, and exhibit favourable yet slightly less robust financial metrics. The two segments show some similarities. The level of agreement is very similar for the statement that green finance is more financially demanding than conventional forms of finance, at 53% for passive idealists and 54% for informed realists. The level of agreement is also similar for the statement that firms plan to use these instruments in the future, at 56.50% for passive idealists and 55.33% for informed realists. The two segments are also fairly unanimous that using these tools increases competitiveness, with 48.67% for passive idealists and 53.33% for informed realists.

However, the segments have different views on several claims. This relates, for example, to statements about whether they have sought expert advice on green finance. For the first segment, the passive idealists, the level of agreement with this statement is only 29.67%, while for the informed realists segment it is 49.83%. There are also significant differences in the statement on whether companies know how to apply for this form of financing. The level of agreement was 37.17% for passive idealists and 53.50% for informed realists. The last statement with a significant difference concerns whether firms received support and information on financing options for their company's green transformation process from external parties. The level of agreement is 24.83% for passive idealists and 43% for informed realists. Although the level of agreement is not as high despite the large difference, it is generally higher for the second segment for all of the three statements compared.

5.2. Green finance challenges and issues

One of the problems associated with green financing of companies is the insufficient support from the state or financial institutions and the need for more awareness of these products. These barriers emerged in the research for both segments created. These results are also supported by the research of Falcone and Sica (2019), who identified some uncertainty about the law in this area. There is a need for more knowledge about green financing options as it becomes a barrier of green financing. Berensmann and Lindenberg (2016) also pointed out the need for more awareness in this area and the ambiguity about the extent of government support. It is especially important at a municipal level where green finance policies can face some limitations (Wang, Gao 2024).

Green financing is also perceived by firms in this study as more costly compared to conventional financing methods, which is also confirmed by work of Schletz et al. (2020) who highlight the high transaction costs. The two segments identified show some knowledge in the areas of green finance, for example, regarding the benefits of using these products. In their research, Ji et al. have shown that these assets outperform conventional assets in terms of performance without taking environmental protection into account (Ji et al. 2021). There is also a certain belief among companies that the use of green financing increases their competitiveness. Flammer points out that the use of green equity leads to better operational performance in firms (Flammer 2018). Also, Hartzmark and Sussman confirm that there is a belief in the positive impact of green bonds on the overall financial performance of an organisation (Hartzmark, Sussman 2019). In the examination of the adoption of green practices, Khandelwal and Singh identified that Indian SMEs demonstrate a favourable attitude towards green manufacturing (Khandelwal, Singh 2022). However, with the existence of disparity between their willingness and preparedness to implement such practices. In contrast, European SMEs, as highlighted by Chatzistamoulou display a greater propensity to involve themselves in sustainability transformations during the digital revolution and view their engagement in public procurements as a driving force (Chatzistamoulou 2023). The relationship between digital transformation and ESG performance, including its impact on green finance and SME reporting outcomes, has become a significant area of research. There are numerous studies highlighting a positive correlation further emphasizing their importance and relevance (Chen, Wang 2024; Zhang et al. 2024).

5.3. Implications for policymakers and financial institutions

The segmentation of firms into passive idealists and informed realists offers important implications for the design of green finance strategies. Passive idealists

are firms that recognize the importance of the green transition, but lack the practical knowledge, resources, or strategic integration to act upon it. For policymakers, this suggests the need to provide simplified reporting frameworks, educational initiatives, and targeted subsidies that lower entry barriers. These firms may benefit from knowledge transfer, environmental finance literacy programs, and demonstrative pilot projects that reduce uncertainty (Hörisch et al. 2020). Financial institutions could engage this segment through standardized green loan products with clear eligibility criteria, or blended finance schemes that de-risk early investments. Such approaches are consistent with evidence that firms' environmental attitudes and financial literacy strongly influence their willingness to adopt sustainable finance instruments (Molina-García et al. 2025).

By contrast, informed realists represent firms that are knowledgeable about green finance mechanisms and are more likely to align sustainability goals with measurable performance indicators and to respond to advanced instruments such as sustainability-linked loans or green bonds. For policymakers, this means that regulation should not only incentivize adoption but also reward high-quality disclosure, carbon reduction performance, and transparent reporting standards (Kelly, Paik 2024). For financial institutions, this segment presents an opportunity to expand customized products and deepen client relationships. Research consistently shows that firms with proactive engagement in green finance enjoy reputational benefits, better capital access, and long-term financial resilience (Liu, Wu 2023).

5.4. Limitations and future research

The main limitation of this work may be shown by the question of how relevant is the assessment of the financial situation when made by the company itself. The assessment of the financial situation in this case is definitely subjective, as it is not evaluated by the financial diagnosis, but by the companies themselves, which may tend to overstate their financial results. Another limitation of the research is the focus on companies operating in the Silesian Voivodeship. Research including companies from other regions of Poland could yield different results, as Silesia has a rich mining history, and due to the transition of these regions, companies may be more inclined to the topic of green financing. Nevertheless, based on the empirical analysis, the authors may consider it both representative and significant.

Future research should address the identified limitation. First, the geographical scope should be extended to other CEE regions (Czech Republic, Slovakia) in order to validate the SME segmentation and provide comparative analysis to other regions. Second, it is crucial to integrate subjective survey data with objective financial data (e.g., from financial statements). However, this would require

a new survey with a smaller sample, as some companies might not be willing to share this data. Lastly, interesting would be conducting longitudinal studies (over time) that would monitor the effectiveness of support policies in activating the passive idealists segment and tracking the transition of firms from declarations to actual pro-environmental actions.

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Summary

The European Commission estimates that at least €1 trillion in sustainable investments will be needed over the next decade. Central and Eastern Europe countries face unique challenges to secure financing for their green transition due to their economic and political background. Among all of the players in the global economy, SMEs significantly impact the environment but face barriers in the adoption of green practices and sustainable investments. Despite the potential benefits of green investments, SMEs often lack awareness and resources to engage in sustainable initiatives effectively. The aim of the research is to investigate the awareness of SMEs of green financing tools. Our focus is set on the identification of similarities and differences between companies and the creation of segments based on different levels of knowledge of green financing and their overall financial situation. The research used a survey-based approach, focusing on SMEs in the Silesian Voivodeship (Poland), a region with a strong industrial heritage and undergoing green transformation. The data was collected from 200 Polish SMEs in the Silesian region and analysed by factor and cluster analysis. Responses were analysed to identify attitudes, levels of awareness, and readiness for green financing. The segmentation reveals distinct profiles regarding financial health and engagement with green finance. It is possible to create two segments of passive idealists and informed realists. Both acknowledged that green investments are more financially demanding. However, the informed realists displayed higher levels of engagement with green financing, including seeking and receiving expert advice and understanding application processes. Limitations include the regional focus and a reliance on subjective self-assessment by firms.

JEL codes: Q56, G32

Keywords: *green finance, SME, European Green Deal, Central Europe, SMEs segmentation*

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The impact of COVID-19 on the global renewable energy sector. An integrative review exploring the challenges and emerging opportunities

1. Introduction

COVID-19 has had detrimental effects on multiple dimensions of human life, society, and the global economy. Although it is recognized that the virus had no direct influence on the environment or the energy sector, it certainly indirectly affected these sectors. The outbreak is predicted to reduce capacity growth for global wind and solar energy by 4.9 GW and 28 percent, respectively (International Energy Agency 2020) and there have been several layoffs and changes in the energy industry. The governments worldwide needs to move promptly to establish necessary steps to limit the outbreak's negative impact on the renewable energy sector (Eroğlu 2021)

The outbreak of COVID-19 has had a huge influence on the renewable energy sector. Sharp economic downturns have slowed renewable energy supply chains, while a drop in market-based funding and government incentives for renewable energy investment has generated major concern among entrepreneurs (Karmaker et al. 2021). Global energy consumption has been reduced due to pandemic-related outages, which has had a huge influence on renewable energy programs.

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Meanwhile, government incentives have been shifted to epidemic relief efforts. The abrupt halt in production has caused substantial disruptions in the worldwide renewable energy supply chain (Ivanov, Dolgui 2021).

The impact of the pandemic on the renewable energy sector is demonstrated by the closure of numerous significant wind turbine manufacturing plants (Eroğlu 2021). Similar negative consequences can be seen in the solar business where there was a 28 percent drop in demand in 2020 (Hoang et al. 2021). As a worldwide health calamity, the COVID-19 epidemic has been a severe blow to the world economy, notably the oil industry (Chakraborty, Maity 2020). Personal automobiles and other main forms of transit were severely restricted due to containment measures (Elavarasan et al. 2021). As a result, energy production fell substantially in response to falling global demand, as indicated by lower output from nuclear reactors in Europe and the United States in the first quarter of 2020. China's tightly managed lockdowns in several of the country's hardest-hit provinces have resulted in a 15% decrease in the country's weekly energy demand (Bertram et al. 2021). Even though the regulations were initially limited to Hubei and nearby provinces, they swiftly expanded to cover most of China (Sharma et al. 2023). Looking back on 2019, many EU countries were on the edge of failing to meet their obligations owing to a lack of effective measures to assist the needed number of renewable energy projects (Stern et al. 2020). Diverse patterns of conventional and renewable energy supply across regions resulted in varying levels of energy poverty in specific geographies, resulting in divergent energy saving and consumption behaviours (Deller 2018; Castaño-Rosa et al. 2019; Zhang et al. 2019, 2021; Ampofo, Mabefem 2021). Additionally, there is a disparity in terms of energy poverty, energy consumption, and energy conservation between persons of different races and ethnicities, leading the scientific community to the subject of racial disparities in energy usage (Oppel Jr. et al. 2020).

Certain fiscal policies may obstruct project development and deployment, as well as research advancements in renewable energy technology (Gebreslassie 2020) Due to its considerable position in the existing electrical generation mix, dropping natural gas costs would naturally increase power demand, according to basic economic considerations. Energy demand and consumption are on the rise, which could provide a boost to economic growth (Fu, Shen 2020). Experts examining the impact of the COVID-19 pandemic on the global energy industry expressed conflicting opinions on the demonstrable influence on the speed and integrity of system rearrangement in response to the outbreak (Pareek et al. 2020). The transition to a low-carbon economy, as well as increased public interest in alternative energy sources, have all had an impact on these changes (Bertrand et al. 2020). As a result, power firms changed their operations in reaction to the pandemic's

effects by postponing new investment projects, tightening budgets, and eliminating wasteful spending, resulting in major short-term implications on worldwide renewable energy (Klein et al. 2018).

This study provides a fresh perspective on the problems associated with creating fundamental changes in our economy and society needed to make them more environmentally sustainable, especially in response to challenging times. The concept of managing the transition to renewable energy has taken centre stage in the policy debate on sustainable development. This paper offers an innovative approach to the role of public policies in managing this transition and covers a variety of perspectives from political science, sociology, economics, innovation studies, complex systems theory, and evolutionary thinking. Neo-classical thought regards innovation as involving market failures due to positive externalities of research and development and highlights the behavior of innovators and the users of innovators (Bergh, Bruinsma 2008). This study extends the existing theories that emphasize the need for a system-wide approach that takes into account sector interactions as well as the complex relations between the technologies, institutions, and behavior of the firms and consumers (IRENA 2020; Tung et al. 2022).

The extant literature has assessed the impact of COVID-19 on the energy sector from many perspectives (Gebreslassie 2020; Jiang et al. 2021; Tung et al. 2022) However, there is a need for a comprehensive assessment of the overall pandemic influence on the renewable energy sector. To fill this gap, we conducted an integrative review in a systematic and structured manner to meet multiple objectives. One objective was to identify research hotspots detailing the impact of COVID-19 on renewable energy while outlining the influencing mechanisms. The second objective was to propose fresh research directions based on existing findings. For the third objective, taking our cues from Fan et al. and Thomas and Tee (Fan et al. 2022; Thomas, Tee 2021), we centered our study around a theoretical framework (Fig. 1) to provide a conceptual framework for future research attempting theory development in the area needed to provide practical and theoretical implications for researchers and policymakers.

The purpose of this research is to provide an in-depth analysis of the worldwide implications and difficulties of the COVID-19 pandemic on the renewable energy industry, as well as to highlight energy-related lessons and upcoming prospects by documenting key trends and hotspots in the area. The major contributions of the study are threefold. First, the integrative review identifies five themes and explores the influence mechanism within each theme. Second, the study identifies the aspects of renewable energy that are influenced by the COVID-19 pandemic. Third, the study proposes a conceptual framework highlighting the effects and challenges of the COVID-19 pandemic on renewable energy demand

and consumption patterns, with aggregate dimensions discovered through inductive analysis to back up these findings. The three main energy challenges are: the healthcare sector primarily dealing with disease control; associated environmental impacts with challenges relating to fluctuating and uncertain energy demand and consumption, structural and pattern changes, greenhouse gas emissions, local air quality, energy transmission infrastructure, and oil production and transmission network; associated economic impact associated with activities including households, agriculture, public and commercial sector, energy import/export, sales revenue, and expenditure, social sector including human resources, labor force, population, employment, partnerships, funding schemes, and subsidies, technology R&D, and overall economic welfare and GDP. This study also makes practical propositions for researchers and policymakers.

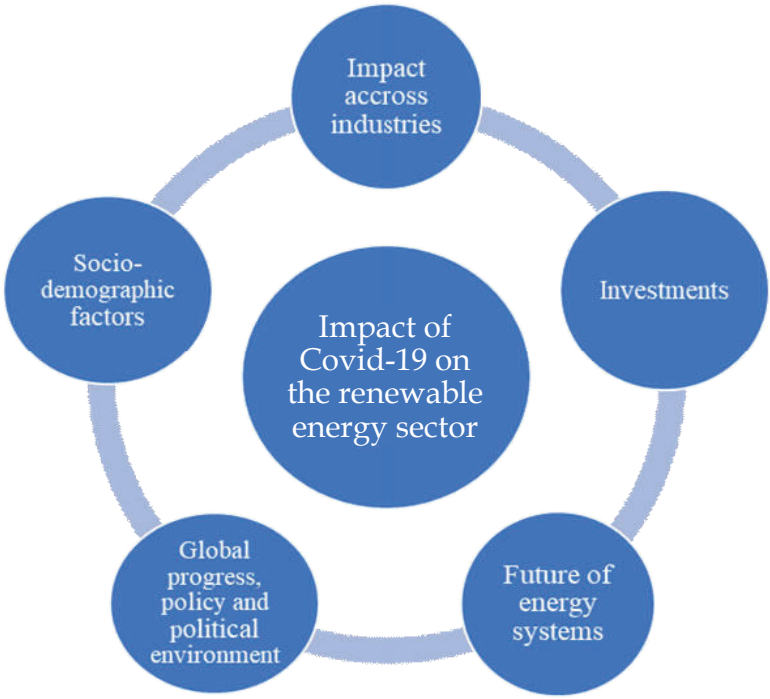

Figure 1. Theoretical framework

The paper progresses as follows: The following part describes the techniques used for this review; and the third section presents the findings; the fourth section offers the discussion along with the integrative review, fifth sections provides

future research agendas and the last section presents some conclusions and policy implications.

2. Methodology and materials

This study employed an integrated strategy combining a bibliometric review with a manual insightful review (Fig. 2). Integrative reviews aim to provide new theoretical frameworks and viewpoints by reviewing, critiquing, and synthesizing "representative" literature (Cronin, George 2020). A bibliometric review is a type of theme-based review that emphasizes facts and trends in a review subject (Paul et al. 2021). In addition, we conducted a manual in-depth review that consolidated the relevant research and synthesized the objectives, techniques, predictors, and policy suggestions. The Bibliometrix R package software was used in the study to retrieve and analyse information from documents (Aria, Cuccurullo 2017). Bibliometrics R-Tool is a piece of free software that can provide a full set of literature information analysis and scientific mapping (Rodríguez-Soler et al. 2020).

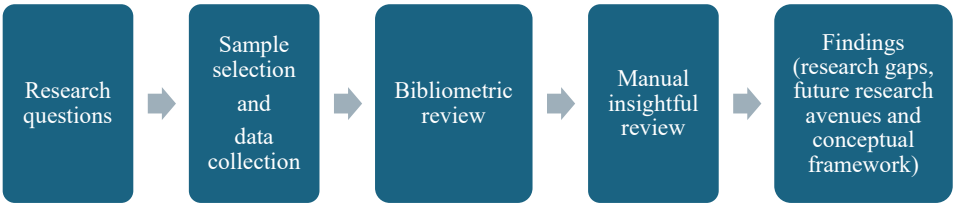

Figure 2. Methodological flowchart

The search was run in February 2022 via a Boolean operator using the keyword strings (Fig. 3). Given its consistency with social science, Web of Science (WoS) is the most extensively utilized citation database (Li et al. 2010). Following some important reviews that employed systematic research methodologies (Talan, Sharma 2019; Thomas, Tee 2021), we used the Web of Science (WoS) database to collect relevant literature. The WoS is the most extensively used database for scientometric analyses with full literature data from 1985 up to the present (Cañas-Guerrero et al. 2013; Liu et al. 2021; Lv et al. 2021). This search results in 80 research studies between 2019–2022..

The original search query results were sorted by inclusion-exclusion criteria, resulting in the inclusion of 80 publications (Fig. 3). This refinement results in

80 research articles, which are then exported as a '.txt' file with comprehensive title, author, citations, country, and so on.

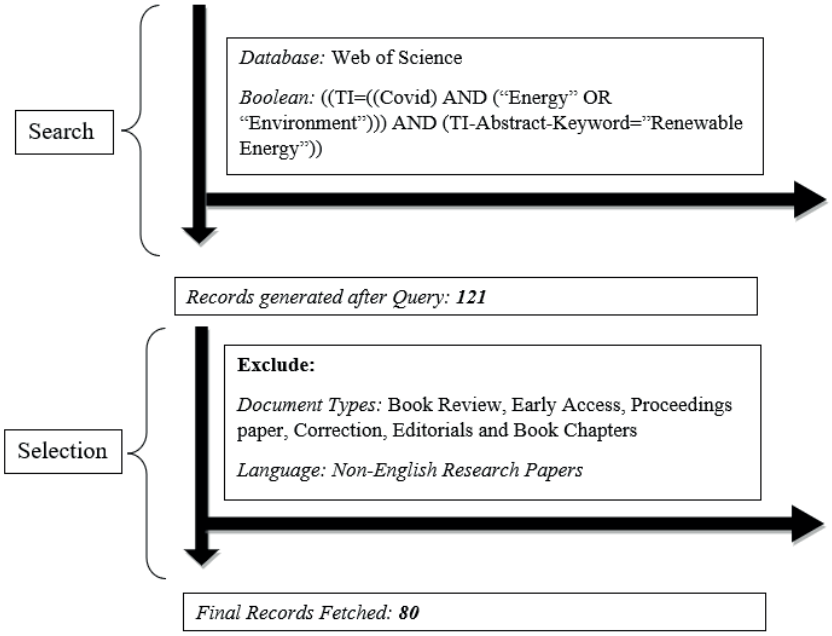

Figure 3. Search and selection process

3. Results

This section presents the social, intellectual, and conceptual structures that define the research landscape on COVID-19 and renewable energy.

3.1. Social structure

Social structure encompasses the patterns of co-authorship and country collaboration that reveal key authors, research clusters, and the geographic distribution of networks shaping the development in the field. Co-authorship visualization analysis

Co-authorship analysis is an important feature of research collaboration not only at the individual level but also at the country level (Jalal 2019). Figure 4

depicts a graphical analysis of co-authorship among the top 50 authors who have co-authored at least one publication together. The authors' links reflect their collaboration patterns, with five distinct hues signifying the authors' clusters of collaborations. The following clusters represent the most prominent and important author collaboration networks and reached the following conclusions: blue (with five authors) – that reduced energy consumption had a major impact on the operations of small electric grids, while further highlighting the challenges posed by the pandemic including the impact on the electricity generation and demand patterns, frequency deviations and load forecasting (Carmon et al. 2020; Navon et al. 2021); Orange (with three authors) opine that a resilient energy supply network with a risk-sharing model tended to stabilize the company's total profit with varying degrees of impact from the pandemic, and that renewable credit and supplier subsidy models should be considered to recover the renewable energy market (Tsao et al. 2021). The remaining three clusters show moderate collaboration with only two authors. Iqbal et al. highlight that the COVID-19 pandemic had a significantly negative effect on energy consumption and carbon dioxide emissions patterns (Iqbal et al. 2021). While Iqbal and Bilal argue that governmental offices, energy ministries, and other linked departments should provide utmost assistance for energy efficiency optimization (Iqbal, Bilal 2021). Most papers were dual-authored, thereby emphasizing the need to improve collaborations.

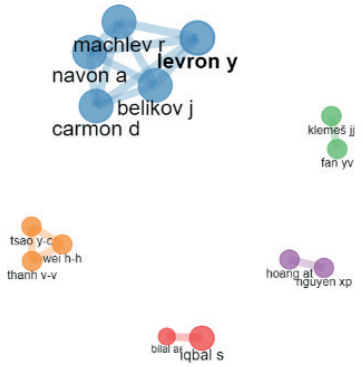

Figure 4. Co-authorship visualization analysis

3.1.1. Country collaboration map

Figure 5 illustrates another bibliographic network considering collaboration links between scholars worldwide. The deeper the blue tint, the more publications a country's researchers have. Collaborations are shown as lines, with the thickness of the lines denoting the number of publications provided by the nations

combined. A list of the countries where the scholars produced the majority of research in "COVID-19 and Renewable Energy" was compiled between 2019 and 2022. The highest rate of collaboration between scholars occurred between India and China, followed by China with Japan. It's worth noting that the country's most severely hit by COVID-19 have the highest collaboration rates, implying that they shared knowledge and assisted one another in obtaining scientifically significant findings. There were some notable collaborations between the USA with China and Thailand and Australia with the UK and Vietnam. The highest rates of networking often occur with nations that were far apart geographically and seemed to be influenced by policies and practices linked to healthcare mobility policies.

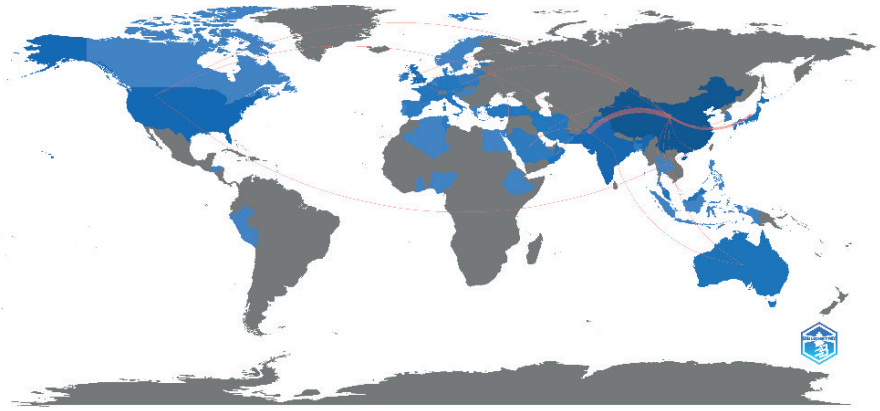

Figure 5. Co-authorship visualization analysis

3.2. Intellectual structure

The intellectual structure reflects frequently cited works and thematic linkages that collectively shape the research field.

3.2.1. Co-citation analysis of authors

As examples, Figure 6 presents two clusters showing co-citation analysis. The blue cluster shows authors like Wang, Zhang, Liu, Jiang, Li, Wu, and Huang. These authors have worked together closely. Wang has collaborated with Zhang, Chen, Liu, Xu, and Jiang. Wang has collaborated with different authors from varied fields of interest, and this has ultimately let him capture broader research areas. For instance, in one research paper Wang et al. confirmed and highlighted the versatile role of three-dimensional printing in tackling COVID-19 challenges,

leading future researchers to focus on the hurdles encountered by the additive manufacturing industry, indicating the need for further investigations to enhance three-dimensional printing technology (Wang et al. 2021). Alternatively, as part of the COVID-19 implications for BRICS Countries (Wang et al., 2021) opine on green finance as an appropriate financial strategy to reduce carbon dioxide emissions. The shape of the sphere represents how many co-citations are done by the author, the bigger the sphere is, the larger the number of co-citations of the authors. The red cluster represents the authors Hosseini, Steffen, Klemes, Elavarsan, and Birol. The combination of the pandemic epidemic and turbulent market circumstances has diverted policymakers', corporate leaders', and investors' focus away from renewable energy transitions. Hosseini and Birol explain the need to re-structure energy and climate policies over the next few years to better achieve the desired long-term trajectory towards green power generation and utilization (Birol 2020; Hosseini 2020). Additionally, the inter-cluster association is also clearly visible from the figure. For instance, Wang has collaborated with Hosseini, and Hosseini has collaborated with Zhang, and Chen as well.

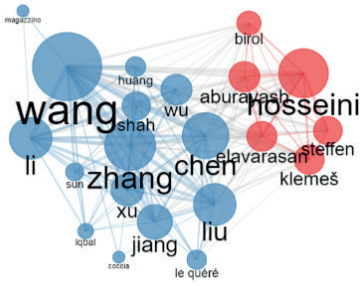

Figure 6. Co-citation authors network

3.3. Conceptual structure

This section, using the conceptual framework of the relevant scholarship, discusses the many facets of COVID-19's influence on the energy industry, including keyword co-occurrence (Fig. 7) and the strategic diagram of the thematic map. (Fig. 8), further cushioned by the inductive analysis that highlights the aggregate dimensions from the study.

Keyword co-occurrence examines the authors' main keywords by developing strategic diagrams utilizing co-occurrence network analysis and co-word analysis (Fig. 7 and 8), highlighting the major themes studied in the 80 publications covered in this study (Aria, Cuccurullo 2017). Co-word analysis provides insight into

various themes or concepts within a knowledge domain (Eck van, Waltman 2010). Keywords co-occurrence reveals the patterns and linkages between the themes of the document (Župič, Čater 2015).

Every article has at least four and up to six author keywords which play an important role in characterizing the content of papers. Figure 7 displays the co-occurrence network analysis of 50 terms that appeared at least twice in the 80 articles. The higher the frequency, the larger the nodes; the lines connecting these nodes show co-occurrence. The most commonly included keywords 'renewable energy, 'COVID-19', 'CO_2 emissions', 'SDG 7', 'sustainability', 'air pollution, and 'energy sector' have the highest total link strength for the research studying et al. the impact of COVID-19 on the renewable energy sector.

The most relevant keywords are organized into four groupings in Figure 7. First, with the corpus of knowledge concerned with COVID-19, the focus of research has been on the future of renewable energy. Second, renewable energy has borne great losses during the energy transition, and this is considered in terms of its efficiency and consumption. The third cluster includes terms like energy policy, coronavirus, sars-cov-2, power system stability, and health crisis. The fourth section is devoted to information on COVID-19, its initial outbreak in China, and the control mechanisms of lockdown.

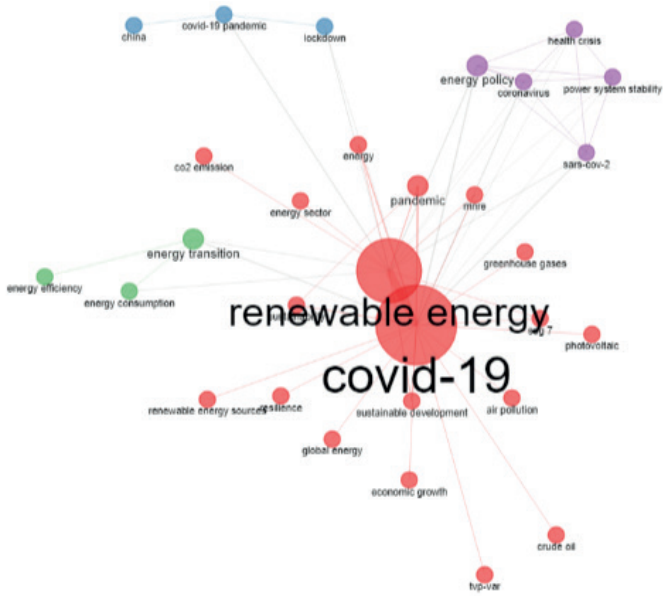

Figure 7. Keywords co-occurrence

To further investigate the influence of COVID-19 on the renewable energy industry, we develop the strategic structure (thematic map) of the relevant scholarship. We examined 50 keywords and utilized the bibliometric package with R software to create the strategic diagram. The strategic diagram categorizes the topics based on two measures: centrality and density (Cobo et al. 2015). The thematic map (Fig. 8) presents seven themes spread across the four quadrants namely motor, Niche, Emerging or Declining and Basic themes.

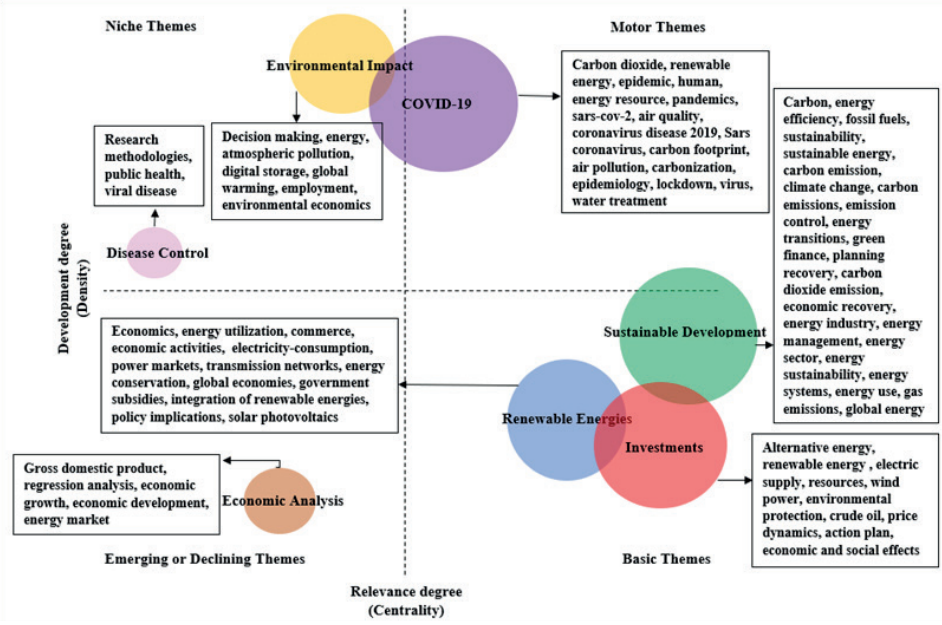

Figure 8. Thematic map

Motor themes include COVID-19 with subthemes such as carbon dioxide, renewable energy, epidemic, human energy resources, pandemics, carbon footprints, and air pollution. This industry has seen a considerable drop in emissions (58 percent of the overall reduction by sector for January–April 2020), with coal power generation's carbon dioxide emissions decreasing by 508 Mt CO2 compared to the same period in 2019. The entire reduction was projected to be 1749 Mt CO2, or 14.3%, with the COVID-19-induced lockdown from January to April 2020 accounting for the majority of the decline (Sikarwar et al. 2021). In contrast to this lockout, measures have a large short-term impact on carbon emissions. Although the reduction in carbon emissions was only transitory, it demonstrated that we

can cut carbon emissions in the long run if suitable restrictions are implemented at the city, national, continental, and global levels. Several major cities and nations with substantial carbon-emission-related operations and long-term lockdown efforts lowered carbon emissions dramatically in 2020. Numerous large cities and nations, on the other hand, that were either unaffected by COVID-19 or did not implement rigorous lockdown measures in 2019 had a limited or no influence on carbon emissions in 2020. This implies that considerable reductions in carbon emissions may be unachievable in the long run without major and long-term changes in human activities that cause a rise in carbon emissions (Ray et al. 2022). Recent studies have shown genetic material of the SARS-CoV-2 virus can be found in sludges and wastewater. When it comes to COVID-19, a significant portion of the human faeces waste generated in impoverished nations is not appropriately processed. Additionally, there is a critical shortage of skilled staff to operate and maintain the treatment works. In order to effectively manage the COVID-19 risk, the challenge is to place a greater emphasis on process control and to incorporate extra treatment stages, such as chlorination, and the use of renewable energy in the treatment process (Chen et al. 2021).

Niche themes include environmental impact and disease control, and these further incorporate energy, atmospheric pollution, and public health respectively. The quantity of medical waste created in Ahmedabad, India, surged from 550–600 kg/day to roughly 1000 kg/day during the first phase of the lockdown. COVID-19 created around 206 million tons of medical waste each day in Dhaka. As a result, medical waste (such as needles, syringes, bandages, masks, gloves, used tissue, and discarded medications) must be properly managed in order to avoid further infection and environmental pollution, which is now a global problem (Doremalen van et al. 2020; Rume, Islam 2020). Although experts and responsible authorities advise that home organic waste and plastic-based protective equipment (hazardous medical waste) be disposed of and separated appropriately, combining these wastes increases the risk of disease transmission and trash workers' exposure to the virus (Ma et al. 2020; Somani et al. 2020).

Emerging or declining themes include economic analysis which further includes subthemes such as economic development and economic growth. Apergis and Apergis suggest that COVID-19 has caused supply shocks by destroying production capacity and disrupting supply systems (Apergis E., Apergis N. 2021). Even if human capital is disrupted (due to a recession), growth can be the result of technological progress, provided manufacturing supply embodies product innovation and the latest methodologies to accommodate change. Inegbedion implemented a standard global computable general equilibrium model to describe the underutilization of labor and capital, an increase in international trade costs, and a redirection of demand away from activities that require proximity between

people (Inegbedion 2021). COVID-19 has brutalized communities by spreading infection and death indiscriminately across countries (Lucas 2020).

Basic themes include sustainable development, renewable energies, and investment, these further include subthemes such as climate change, power markets, and alternative energy respectively. Setting up a sustainable system is an effective, yet urgently needed, answer. Priority areas are identified in seven early lessons: reducing environmental harm and vulnerability to dangerous feedback; promoting urban sustainability; and improving risk analysis and management. These lessons will be useful in coping with the impending global disasters that humanity faces, such as starvation, water shortages, further pandemics, and, eventually, climate change — which will worsen all other crises (Munasinghe 2020). The deployment of sustainable systems necessitates strong and effective policies in the region, as well as the most appropriate methodologies and practices (Amir and Khan 2022). The COVID-19 epidemic is the first of its kind, and it brought global economic activity to a halt. It is projected to have a significant negative impact on businesses' cash flow. Unlike the global financial crisis, which began because of financial suffering, the COVID-19 pandemic is a health disaster with worldwide economic ramifications, accompanied by disruptions created by lockdowns and travel-related restrictions. There is a great deal of ambiguity about how it will affect various economic, social, and political structures. The availability of vaccines, as well as how rapidly consumer and business sentiments may return to pre-pandemic levels, will determine future success. During a downturn, investors pay more attention to corporate fundamentals. As a result, the ESG approach's relative outperformance stems from the fact that the likelihood of its returns being influenced by the other two safer investment methods rises during times of crisis. It denotes a shift of capital from defensive and EAFE (stocks from Europe, Australasia, and the Far East) portfolios to ESG (environmental, social, and governance) portfolios. Investors seek sanctuary in an ESG strategy which focuses on a company's long-term viability (Singh 2020).

This strategic map develops an understanding of a theme which requires immediate attention: economic analysis. COVID-19 in the context of renewable energy lacks a focus on the economic losses endured by countries which can be attributed to the reduction in renewable energy production during the pandemic. As a result of this, many countries experienced setbacks in terms of economic growth and development, with some nations in Africa, for example, suffering more losses based on the structure of their economies, the export of certain goods, the scope of trade and investment, the present state of public finances, the level of rigor, and the duration of public health measures implemented. According to the United Nations Conference on Trade and Development, the Solar PV business employs 3.9% of Africans. These employment opportunities in East, West, and

Central Africa can be filled by at least seven million people using a sustainable value chain (Amir, Khan 2022).

The sector is also facing challenges such as supply chain delays, stock market concerns, a lack of incentives, and the possibility of losing access to government subsidies. If incentives are not matched with clean energy targets, there will most likely be a large drop in clean energy expenditures, which will have a domino effect. Forecasts of a wind energy catastrophe, for example, have already begun. LM Wind Power and Siemens Gamesa in Spain have announced their decision to cease production of wind turbine blade plants. It was reported that the installation of 100 wind turbines in the Outer Moray Firth was halted due to the COVID-19 outbreak, and that other aspects of the delivery phase were also halted (Amir and Khan 2022). The identical scenario applies to the solar business. Because of the COVID-19 pandemic, renewable energy predictions for 2020 are down by 28%. According to reports, persons working in the solar energy industry have been laid off or have suffered as a result of the COVID-19 pandemic (Eroğlu 2021)

4. Discussion

The thematic map of the data structure and keyword co-occurrence form the foundation for conceptualizing the framework and are derived from commonalities revealed in the examination of the conceptual structure of the existing literature, which are reinforced by inductive analysis (Fig. 9 on the interleaf).

Figure 9 represents inductive analysis, indicating aggregate dimensions, themes, and concepts. COVID-19 has affected various industries but majorly affects power industries, transportation industries, and heating-cooling plants. Large electrical consumers, such as industries and commercial buildings, were obliged to shut down or reduce their operations due to the restrictions. This considerably alters working and living styles due to which changes in the volume, profile, and composition of power demand distribution are observed. The shift in load pattern has an additional impact on the electricity system's operation and control. Total electricity generation has decreased in tandem with demand, with coal-fired generation bearing the brunt of the loss. Although the share of renewable power has increased, curtailment rates have also increased. Furthermore, electricity prices in major areas have plummeted, with European electricity markets experiencing the world's largest price drop. The majority of investment projects have been halted, although long-term investments in the electrical sector, as well as the eventual transition to renewables, are projected to be relatively unaffected (Zhong et al. 2020).

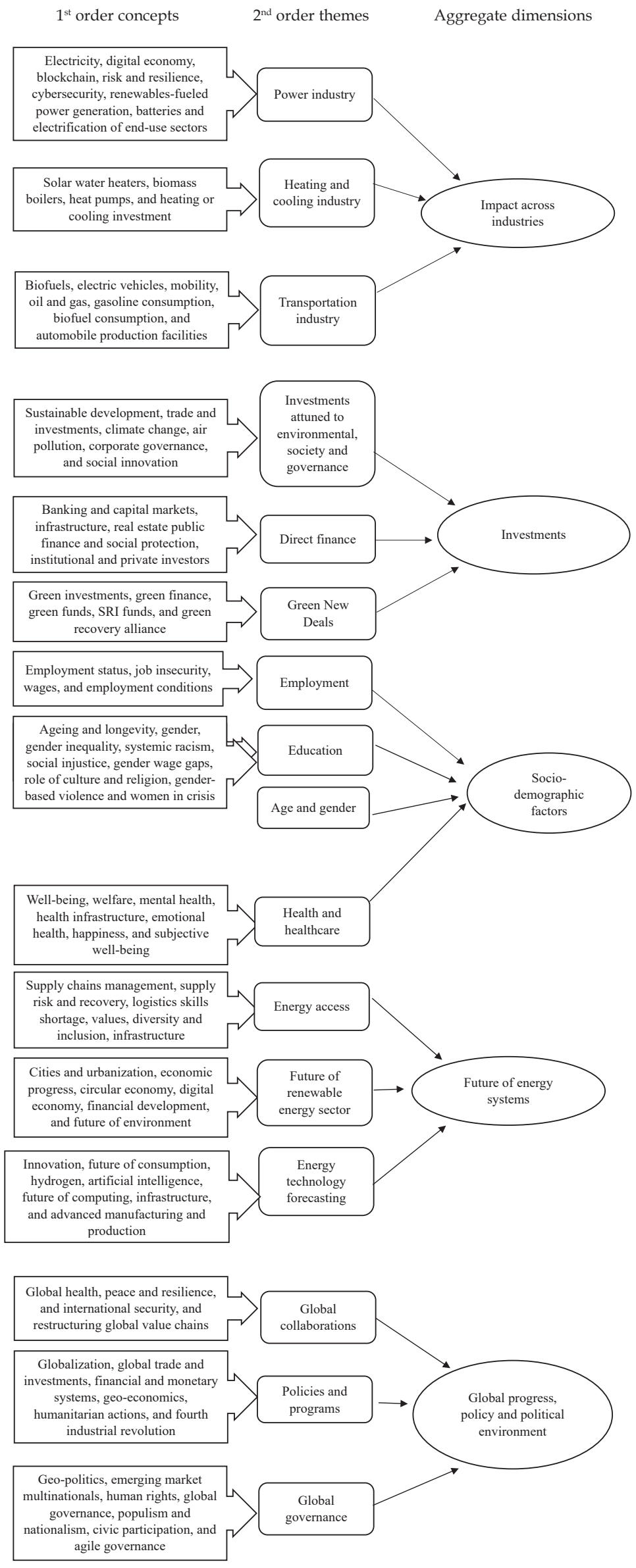

Figure 9. Data structure: concepts, themes, aggregate dimensions

COVID-19 outbreak has had a significant impact on the solar energy business, which is one of the most important renewable and sustainable energy sources. The sector's key concerns are severe employment losses, short-term difficulties for businesses, and job disruption or delay. It has been noticed that relatively large businesses can overcome challenges quickly. The effects of the pandemic disrupt the dynamics of the sector, which is heavily reliant on people's transportation. In addition, based on prior crises' recoveries, the solar energy sector is projected to rebound quickly following the pandemic. In general, governments in the industry are expected to provide significant incentives and take action to alleviate the backlog (Eroğlu, Cüce 2021). The outbreak has had a significant impact on interstate travel as well as movement within and between cities. Sobieralski examined the airline industry, discovering that major airlines' capacity had dropped by 60–80% Employees with lesser skill levels will be affected more severely (Sobieralski 2020). Airlines reacted differently to travel restrictions imposed by the government. The pandemic had a tremendous influence on the cruise liner business as well.

Investments attuned to the environment, society, and governance, direct finance, and Green New deals form an aggregate dimension of investment. Some investors have yet to come across socially responsible investing (SRI) funds on the market and are concerned about the absence of national support and endorsement for SRI funds. Investors are more interested in SRI funds as a result of the salience of the pandemic, adding to the idea that the general public is risk-averse in situations of disease yet cares about the environment (social benefits and sustainable development) (Xu et al. 2022). The prospect of a pandemic isn't the only issue deterring investors. Business environment, inadequate infrastructure, natural disasters, diverse and difficult geography, and climate change are some of the other factors to consider (Chaudhary et al. 2020). Many green initiatives have larger short-run multipliers (they require a large initial investment), but low operational costs, minimal climatic imprint, and hence increased long-term sustainability. The Green New Deals being proposed in many nations should prioritize such investments. Some of these are self-evident, such as solar power or building retrofits. Carbon intensity provides some insight into corporate performance during the epidemic, although ESG data appears to be less informative. We suggest that financial data be used to build new indicators that can be used to guide investors (Mukanjari, Sterner 2020).

Socio-demographics contribute towards constructing one aggregate dimension including themes such as employment, education, age, gender, health, and healthcare. This aggregate dimension is used as a backdrop to understand the influence of COVID 19 on another aggregate dimension.

The future of the energy system includes themes such as energy access, the renewable energy sector and energy technology forecasting. Meanwhile,

the future of renewable energy depends upon the seamless implementation of technologies to produce renewable energy. There is a direct connection between the level of technological maturity and the presence of economic barriers. An economic barrier is present when the cost of a particular technology is higher than the cost of competing alternative technologies, even under perfect market conditions. Although they are not directly economic in nature, the remaining sorts of obstacles are still considered to play a significant part in determining the prices of renewable energy sources which in turn hinders the implementation process. The significance of the obstacles varies according to both the technology and the market, and the order of priority shifts as a product develops along the path to commercialization. On other hand, there is a wide range of renewable energy technologies that are currently accessible, each of which is in a different stage of the development cycle. Both hydropower and biofuels are rapidly becoming significant contributors to the global energy supply. Even if their technological viability has been demonstrated and they are commercially available, other options still only cover a small portion of the markets that may be served by them. Because of this, there are a multitude of options to enhance performance while also lowering expenses (Ellabban et al. 2014).

Global progress, policy and political environment include themes such as global collaboration, policy, programmes and global governance. Renewable energy policies differ widely in terms of the technologies and energy sources they contain, as well as the policy tools used to promote them. There are required and optional targets, various incentive programs, varied suggested renewable energy sources, and other differences in policies such as renewable portfolio standards (RPSs) at the state level in the United States, as well as several regional and municipal governmental policies. These policies are samples of the numerous policy kinds that exist (Levenda et al. 2021).

In addition, the conflict between Ukraine and Russia has had significant effects on the global energy landscape (Trunina et al. 2022; Liao 2023). The constrained state of the global energy market, which has been exacerbated by a variety of supply-and-demand fluctuations, is a crucial factor exacerbating the energy crisis. Among these are the COVID-19 pandemic and geopolitical tensions in other regions (Chen et al. 2023). This combination of factors has caused a global increase in energy costs, with some regions experiencing natural gas price peaks never seen before (Osička, Černoch 2022). Russia's incursion into Ukraine in February 2022 sent shockwaves throughout Europe and exposed starkly the continent's geopolitical dependence (Kuzemko et al. 2022). The Russia-Ukraine conflict has exacerbated Europe's energy crisis by interfering with gas deliveries and heightening preexisting concerns about energy security. Given Russia's significant role as a supplier of natural gas to Europe, any disruptions to this supply chain

have significant effects on energy costs and availability (Bricout et al. 2022). The termination of long-term agreements for additional volumes of Russian gas has had a substantial impact on immediate solutions to the energy crisis (Estrada, Koutronas 2022). In the long-term, this geopolitical dynamic has eroded Europe's resistance to Russian energy pressures, culminating in a European energy crisis characterized by decreased production, limited gas reserves, elevated prices, and constrained global supplies (Kravchenko et al. 2023). However, the conflict has served as a wake-up call, highlighting the significance of renewable energy, particularly in Europe. The insufficiency of energy resources prompted European businesses to reduce their reliance on Russian oil and gas, highlighting the need to investigate alternative avenues, such as the development or acquisition of renewable energy (Liao 2023). Alternately, the development of energy ties between Europe and Ukraine is motivated by distinct political interests, and the economic dimensions of these ties are materialized by the assurance of securing additional electricity in the event of unforeseen events (Koval et al. 2023). These geopolitical upheavals have shed additional light on Europe's reliance on natural gas and emphasized the need to fasten the transition to renewable energy sources (Carfora et al. 2022). Europe has already implemented a variety of measures to reduce its reliance on gas, including the promotion of renewable energy sources such as wind and solar power and the improvement of energy efficiency. However, the crisis has highlighted the need to expedite these initiatives and promote more robust and resilient energy systems (Kravchenko et al. 2023).

Figure 10 represents a conceptual framework. This hierarchical framework positions the healthcare sector with an emphasis on disease control as the first tier, environmental impact as the second tier, economic impact, sustainable development, and investments as the third tier, and finally, the top tier is occupied by clean and affordable energy. Disease control is positioned at the lowest tier, as the first step to achieving clean energy is controlling the pandemic at the healthcare level. Many countries imposed extraordinary curfews and proclaimed states of emergency. It generated fear, worry, and a climate of stress in both developed and developing cultures. However, social anxiety and panic owing to uncertainty, economic recessions, and excessive mental stress are a result of its extreme isolation and lockdown tactics (Studdert et al. 2020). Within two weeks of full vaccination, the vaccine was proven to be 94–95 percent effective against the original strand of the COVID-19 virus. Vaccines also have a high effectiveness rate in protecting patients against the COVID-19 virus's devastating diseases. SDG-3 (good health and well-being) has aims, which emphasize the importance of understanding and resolving "communicable, non-communicable, and environmentally induced diseases," and are particularly significant for efforts to battle COVID-19 and other infectious diseases. With the paucity of screening

tests, hospital beds, medical supplies, and essentials like water and toilet paper, COVID-19 has forced many to reassess its impact on society. COVID-19 has stressed the necessity of potential preventative actions like as facemask use, social distance, frequent handwashing, school and university closures, and further travel limitations (Seshaiyer, McNeely 2020).

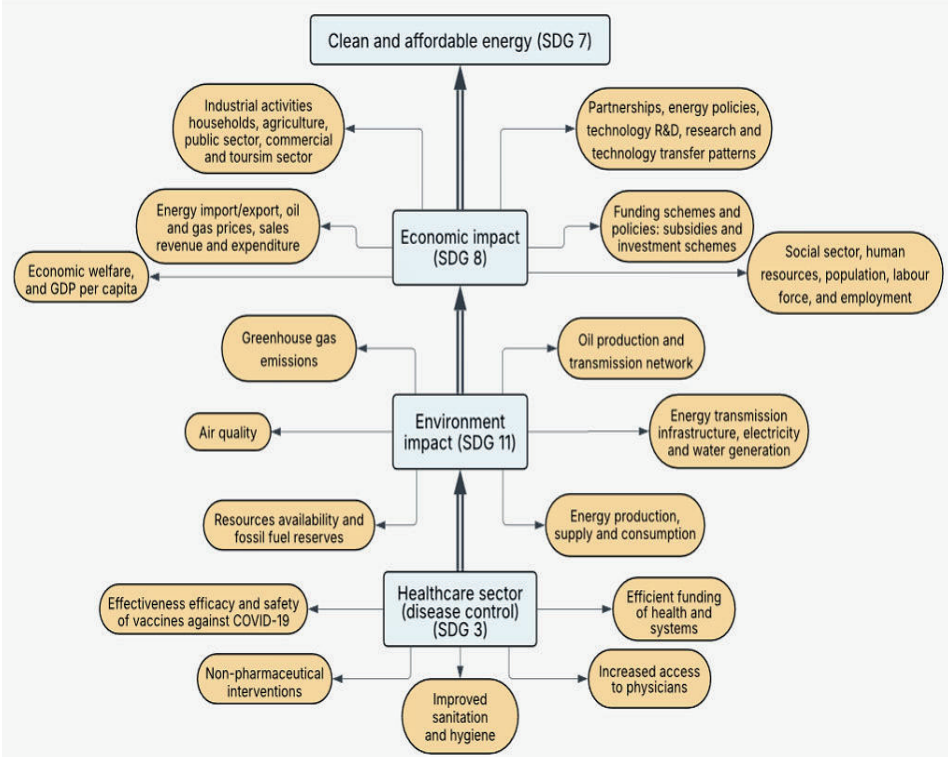

Figure 10. Conceptual framework

COVID-19 has severe effects on the environment and, in particular, the renewable energy industry. Soil and water quality are negatively impacted when individuals cleanse their hands more frequently, governments and local governments mass disinfect, and single-use plastics containing bisphenol A (BPA) are mass-produced. Products containing alcohol that are poured in water are hazardous to aquatic life, and products containing alcohol that are smeared on soil can contaminate groundwater. Detergents discharged into water create froth in bodies of water. Soap use over an extended period of time may lead to soil

contamination, degrading the soil's quality (Ankit et al. 2021). The COVID-19 outbreak is also causing havoc in the worldwide renewable energy supply chain. If incentives are not aligned with renewable energy goals, clean energy investment will almost certainly fall precipitously, causing a domino effect. The spread of COVID-19 and the suspension of a wind power station in North Dakota are two prime examples of the epidemic's effects on the renewable energy industry. Due to the COVID-19 outbreak, the installation of 100 wind turbines in the Outer Moray Firth was halted, as were some aspects of the delivery phase. The solar industry is in a comparable situation. As a result of the COVID-19 epidemic, solar energy workers have reportedly been dismissed or have suffered other negative consequences (Eroğlu, 2021) . The pandemic has also exhibited a significant lack of comprehensive disaster risk management policy at all levels of government (Pradhan et al. 2021). Recognizing changes in energy consumption patterns, establishing online portals, and developing post-pandemic methods for launching new projects are just a few of the numerous issues that have surfaced in the aftermath of COVID (Elavarasan et al. 2021).

The third tier of the framework includes economic analysis, partnership, and investment. Economies have to go through large contractions. Multiple fundamental factors have contributed to this economic downturn. These include direct reductions in the available personnel resulting from fatalities and infections, as well as the associated medical expenses. In addition, there are declines in household expenditure and corporate investment, primarily due to security measures and heightened uncertainty. The disruption of global trade and value chains as a result of lockdowns has also played a role, as have potential persistent effects that impede a return to the economy's pre-crisis state (Caracciolo et al. 2020). According to Chudik et al., the COVID-19 pandemic could result in enduring declines in global real GDP, with varying consequences across regions and countries (Chudik et al. 2021). While the impact on the United Kingdom and other developed economies could be severe, it is anticipated that China and other emerging Asian economies will be relatively unaffected. In addition, it is anticipated that the pandemic will temporarily drive long-term interest rates in advanced core countries below their levels prior to COVID-19. Emerging regions, on the other hand, are likely to encounter the opposite scenario, posing challenges for managing debt service costs.

COVID-19 has ushered in the world's biggest economic downturn since the Great Depression, resulting in 400 million job losses in the second quarter of 2020, and a 4.2 percent drop in GDP per capita in 2020. Contributing to the formulation of an economic recovery plan is extremely important in this regard, especially with a focus on the research avenues, such as performing evidence-based economic

assessments for long- and short-term recovery planning and policy initiatives to promote small and medium firms after COVID-19 (Ranjbari et al. 2021). By identifying and testing the linkages between essential aspects of behavioral and social change partnerships, global efforts are taken in terms of investment. When it comes to managing behavioral difficulties, this research has demonstrated the importance of trust, commitment, shared values, and teamwork (Duane et al. 2022).

All three tiers lead to the fulfilment of the common objective of clean and affordable energy. The energy sector was directly confronted with several technical issues, including decreased energy demand and a shift in demand patterns. It eventually had an impact on the utilities' revenue collection and caused them to postpone development initiatives. Due to COVID-19 restrictions, a significant portion of the workforce utilized digital technology to work from home, increasing the risk of cyberattacks on networks and control systems. As energy demand has decreased, the oil-exporting economies have become especially susceptible to COVID-19, suffering from price declines and labour disruptions due to closures. It is generally accepted that harvesting renewable energy is the safer and more eco-friendly option that will benefit both humanity and the environment. According to the technological evaluation, the transportation and construction industries have substantial opportunities to reduce emissions. The construction of energy storage systems and the improvement of passive cooling systems are two additional methods to reduce energy consumption. Additionally, for a community, thermal storage containers combined with renewable-based heating could make it economically feasible to spend as a group rather than individually, which would be environmentally beneficial. If the market for electric vehicles in the transportation industry expands in the post-COVID era, it will accelerate the digital revolution in a variety of disciplines, from smart infrastructure to autonomous vehicles. Massive expenditures and technological advancements are necessary for large-scale hydrogen generation and storage in order to see a change in pollution mitigation. Meanwhile, the emphasis should transition from hydrogen production based on fossil fuels to ecological hydrogen production based on renewable energy. Nonetheless, this would encourage renewable energy system growth (Elavarasan et al. 2021).

5. Future research agendas

Figure 7 is a network diagram illustrating the co-occurrence of terms in paper titles and abstracts, with the intent of identifying emerging themes related to COVID-19 in the global renewable energy literature. Each node on the map

represents a unique term and is sized based on its frequency across the eighty documents analysed. The distance of the connections between nodes represents the degree of association between the words. The nodes are color-coded and divided into clusters based on their similarity, which facilitates the identification of distinct subfields and prospective research gaps for future study.

The six major sectors highlighted are human resource management (HRM), finance/economics, education and research, marketing, micro-level (operations), and macro-level (destination). These thematic areas highlight topics that present research opportunities. Understanding how the pandemic has affected renewable energy and post-COVID practices, particularly in terms of development, is a focus of HRM. In the realms of finance and economics, the phase of recovery following the pandemic elicits questions regarding the adoption of renewable energy, investor confidence, financial mechanisms, and government interventions. Education and research provide opportunities for shaping research agendas in the post-pandemic environment by integrating educational technologies, investigating experiential learning approaches, and broadening the scope of the discipline via a curriculum adapted to the post-COVID era.

6. Policy implications and concluding remarks

The global COVID-19 epidemic has had a significant impact on individuals, communities, and nations. It is evident from the preceding discussion that economic activities in each country have had a significant impact on the transition to renewable energy. Policy actions taken in the energy sector during the COVID-19 epidemic have had an impact on renewable energy production and use. The impacts of the COVID-19 pandemic on the energy industry have been thoroughly studied in the literature, however the implications on renewable energy generation remain unexplored (Dong et al. 2022). Policies that can withstand severe disruptions and protect investments in renewable energy from potential dangers are highly desirable. The government may accelerate the renewable energy by abandoning conventional forms of energy production. Government officials must define authorized pandemic responses in order to establish short-term policy goals that promote both the recovery effort and the growth of renewable energy sources (Hoang et al. 2021). The structural ramifications of the changing energy system, as well as the potential collateral impacts of such policy changes, should be given special consideration (Pahle et al. 2018).

The ongoing conflict between Ukraine and Russia and the uncertainty around natural gas supplies have significant implications for the future development of

the European energy transition. Ukraine has historically served as a key transit route for Russian gas supplies to Europe, and any disruption to this supply chain can have far-reaching consequences. One of the main consequences of the Ukraine-Russia conflict is that it has highlighted the need for Europe to diversify its energy sources and reduce its dependence on Russian gas (Bricout et al. 2022; Carfora et al. 2022). The Ukraine-Russia conflict serves as a reminder that Europe must reduce its reliance on fossil fuels and accelerate the transition to greener, more sustainable energy sources. It highlights the importance of developing a more diverse and resilient energy system that is less vulnerable to geopolitical risks and supply chain disruptions. The policy responses to the crisis thus far have had varying effects on these objectives. On the one hand, there is significant potential for the acceleration of Europe's renewable energy supply. This could contribute to the reduction of greenhouse gas emissions and the improvement of air quality, which would have positive environmental and health effects. On the other hand, there are complications for fossil fuel phase-out. The crisis has had a significant impact on oil and gas prices, which has made it more difficult for some countries to transition away from fossil fuels. In addition, some governments have provided financial support to fossil fuel companies, which may slow down the transition toward clean energy. In terms of energy equity and social justice, the crisis has had significant implications both within and beyond Europe. The economic impacts of the crisis have hit vulnerable populations the hardest, and there is a risk that the transition toward clean energy could exacerbate existing inequalities. For example, if energy prices rise because of investments in renewable energy, low-income households may be disproportionately affected.

Considering the pandemic scenario, research should be conducted to create the most efficient solar cells at the lowest cost, mass produce them, and deploy them. Potentially, solar energy production and energy storage could be combined by using novel electrocatalysts and renewable energy, synthesizing chemicals and fuels more efficiently, or generating electricity from a variety of fuels more efficiently using improved fuel cells. Since electrifying vehicles can cut fossil fuel usage (despite crude oil's historically low price), more powerful, less expensive, and safer Li-ion batteries are needed (Jin 2020).

The well-being and prosperity of current and future generations can be assured through successful regulation of the use of natural resources. To address every aspect of the problem, effective environmental policies, including carbon-neutral policies, would necessitate the use of one (or a combination) of the available instruments, such as direct regulation (of water quality or vehicle emissions), public spending, and technology programs, as well as information provision and policies to address barriers to behavior change. Furthermore, public-private collaborations in renewable energy producing projects are critical for job

development and economic recovery. State funding agencies and government programs should be expedited to provide financial relief measures to enhance the supporting factors behind renewable energy generation and restoring the energy distribution network.

As all the studies, our study also has a few limitations. The availability and quality of data is affected as the database used in the study is WoS and this led us to omit papers that may be found in other sources such as Scopus. This limited data extraction may have compromised the comprehensiveness of the study and introduced potential biases or uncertainties into the findings. The study also suffers from limitations in terms of publications, resulting in the exclusion of pertinent information from unpublished or non-English sources. This could affect the overall representativeness and generalizability.

This study uses predetermined timeframes (includes studies until March 2022), therefore the swiftly evolving nature of the subject matter may result in the omission of recent developments or studies that were not yet published during the review period. Moreover, the methodology of the review may have certain limitations, namely the exclusion of certain keywords during data extraction.

Declaration of competing interest

None

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Summary

The shift from traditional fossil fuel energy to cleaner, renewable energy has the potential to help achieve long-term sustainability goals. The COVID-19 pandemic has had a significant impact on the renewable energy sector. This study aims to provide an integrative review of the global impacts and challenges of the COVID-19 pandemic on the renewable energy sector and highlight the energy-related lessons and emerging opportunities by capturing the main trends in the field. First, the integrative review identifies five themes. Second, the study identifies the aspects of renewable energy that are influenced by the COVID-19 pandemic. Third, the study proposes a conceptual framework highlighting the impacts and challenges of the COVID-19 pandemic on renewable energy demand and consumption patterns, and these results are further supported by the aggregate dimensions identified through inductive analysis. The three main energy challenges are: the healthcare sector primarily dealing with disease control; associated environmental impacts with challenges relating to fluctuating and uncertain energy demand and consumption, structural and pattern changes, greenhouse gas emissions, local air quality, energy transmission infrastructure, and oil production and transmission network; associated economic impact dealing with industrial activities including households, agriculture, public and commercial sector, energy import/ export, sales revenue and expenditure, social sector factors, funding schemes, and subsidies, technology R&D, and overall economic welfare. The study also makes theoretical and practical propositions for researchers and policymakers.

JEL codes: I18, Q42, Q5

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High-Volume Return Premium on the Warsaw Stock Exchange: evidence, drivers, and strategy design

1. Introduction

Research on financial markets has long focused on understanding the dynamics of stock prices and the factors that drive their fluctuations. Prices reflect investors' expectations regarding firms' future performance, and these expectations evolve as new information arrives. While the Efficient Market Hypothesis (EMH) suggests that trading volume merely reflects the process of price discovery without influencing future returns, a growing body of empirical evidence challenges this view. In particular, several studies indicate that trading volume may contain independent information about investor sentiment, disagreement, or attention, which can translate into predictable return patterns.

One of the most influential findings in this context is the High-Volume Return Premium (HVRP) documented by Gervais et al. (Gervais et al. 2001). They demonstrated that stocks experiencing unusually high relative trading volumes tend to have abnormally positive returns in subsequent days, while unusually low volumes predict weaker performance. This phenomenon highlights the informational role of volume and suggests that market participants do not immediately and fully incorporate trading shocks into prices. Subsequent research has extended this evidence across different markets, but results for emerging European markets remain scarce and inconclusive.

This study investigates whether the HVRP effect exists on the Warsaw Stock Exchange (WSE) and whether it can be systematically exploited through realistic,

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long-only investment strategies. Building on prior work, we test whether extreme trading volume predicts short-term returns and explore how this relationship varies with firm characteristics and trading conditions. Specifically, the paper examines how the strength and persistence of the HVRP depend on firm size, stock price level, and the duration of the holding period. It also compares results obtained under alternative reference windows used to define extreme volume and benchmarks strategy performance against the WIG index. Finally, the study analyses the time variation in trading intensity – measured as the frequency of high-volume events − to assess whether volume shocks reflect broader shifts in market sentiment or liquidity.

The contribution of this paper is threefold. First, it provides the most comprehensive test of the HVRP in Poland to date, extending beyond earlier evidence limited to event-study or monthly asset-pricing approaches (Gurgul, Wójtowicz 2009; Wójtowicz 2017). Second, it introduces an implementable strategy design tailored to local market frictions, focusing on long-only rules and daily signals. Third, it highlights the role of firm-specific heterogeneity and trading intensity in shaping the persistence of the volume premium, thereby offering new insights into behavioural explanations of price anomalies in emerging markets.

By documenting the presence and characteristics of the HVRP on the WSE, this research contributes to both the academic literature and practical investment perspectives. For scholars, it extends the debate on whether behavioural and informational mechanisms identified in developed markets translate to less mature environments. For practitioners, it demonstrates that volume-based strategies can provide a source of systematic excess returns, though their effectiveness depends strongly on market segmentation and trading conditions.

The results show that the HVRP is a short-lived phenomenon, strongest over one-day horizons, and influenced by both firm-level and market-wide factors. Mid-sized and low-priced firms generate the highest raw returns, while large firms deliver superior risk-adjusted performance. The findings demonstrate that volume-based anomalies persist in an emerging market setting, offering new insights into behavioural price formation and practical implications for investors constrained by short-selling limitations.

The remainder of the paper is structured as follows. Section 2 reviews the relevant literature on the informational role of trading volume. Section 3 describes the dataset and methodology used to construct and evaluate the strategies. Section 4 presents the empirical results, including the analysis of firm size, stock price level, holding periods, reference windows, and comparisons with the WIG index. Section 5 concludes the paper, summarising key findings and their implications for both theory and practice.

2. Literature overview

Trading volume is one of the key variables in financial markets, offering valuable insights into investor behaviour, market sentiment, and liquidity. It supports the interpretation of price dynamics, volatility patterns, and even asset valuation. Beyond its descriptive utility, volume has significant predictive potential, especially when analysed in relation to price movements and volatility.

One of the foundational studies on the role of trading volume in market dynamics was by Copeland, who introduced the Sequential Information Arrival Hypothesis (SIAH) (Copeland 1976). According to this hypothesis, information reaches market participants sequentially: first to informed investors, whose actions signal this information to others (uninformed or noise traders). This process creates observable lead-lag relationships between prices, trading volume, and volatility. Blume et al. and Suominen developed this perspective further, suggesting that uninformed traders often interpret volume as a signal of private information, meaning that shifts in trading activity may directly influence prices rather than merely accompany them (Blume et al. 1994, Suominen 2001).

A broad empirical literature has examined how trading activity relates to future returns, volatility, and investor sentiment. Lee and Swaminathan showed that volume helps predict price continuation and reversal patterns in U.S. equities (Lee, Swaminathan 2000). Llorente et al. linked trading activity to information asymmetry and return dynamics (Llorente et al. 2002). More recently, studies such as Atmaz and Basak, Bajzik, Floros and Salvador, Sukpitak and Hengpunya documented how volume interacts with volatility, disagreement, and investor attention across different markets (Atmaz, Basak 2018; Bajzik 2021; Floros, Salvador 2016; Sukpitak, Hengpunya 2016).

Gervais et al. conducted a seminal study that differs from traditional approaches using trading volume as a proxy for liquidity or investor disagreement (Gervais et al. 2021). Instead, they focused on relative trading volume – defined as the ratio of trading activity in a given period compared to a reference period of the previous 50 trading days. They showed that relative changes in trading volume, rather than volume levels themselves, contain valuable predictive power for future stock returns, laying a foundation for strategies that exploit temporary shifts in investor attention and trading intensity. Based on data from the New York Stock Exchange, they demonstrated that extremely high relative trading volume is systematically followed by significantly higher stock returns, while extremely low relative volume precedes unusually low returns. This phenomenon, termed the High-Volume Return Premium (HVRP), is robust to other commonly considered explanatory variables such as liquidity, price level, or dividend and earnings announcements.

The HVRP has been linked to several behavioural and informational mechanisms. A key explanation offered by Gervais et al. builds on Miller's visibility hypothesis (Gervais et al. 2001; Miller 1977). It posits that when investors have heterogeneous beliefs and face short-selling constraints, stockholders tend to overvalue the assets they already hold and are reluctant to sell, creating supply frictions. A sudden surge in trading volume, interpreted as a positive volume shock, draws investor attention to the stock, increasing recognition and demand. The imbalance between constrained supply and increased demand results in a temporary price increase, leading to excess future returns.

Another theoretical support for the HVRP is Merton's investor recognition hypothesis, further extended by Zheng and Shen (Merton 1987; Zheng, Shen 2020). According to this view, higher trading volume signals greater visibility and awareness of a stock among market participants. As more investors become aware of the stock and include it in their portfolios, the stock experiences a recognition-driven repricing, contributing to the observed return premium. These frameworks emphasize the role of investor attention, information diffusion, and market frictions in explaining why abnormal returns often follow unusually high trading activity.

The HVRP has been tested across many markets, often with mixed results. In China, studies such as Wang et al., Wang and Cheng and Zhou found evidence of the premium, though its magnitude varied with market conditions (Wang et al. 2017; Wang, Cheng 2004; Zhou 2010). Huang et al. analysed several Asian markets, while Tang et al. and Gordon and Wu documented the effect in Australia, showing it is particularly strong for large-cap firms (Gordon, Wu 2018; Huang et al. 2011; Tang et al. 2013). Israeli et al. provided a novel angle by linking volume shocks not only to pricing but also to real corporate investment, suggesting that HVRP-like dynamics may reduce firms' cost of capital (Israeli et al. 2022). On a cross-country scale, Kaniel et al. analysed 41 stock markets and found that the premium is consistently present in developed economies, while evidence for emerging markets was inconclusive due to limited data availability (Kaniel et al. 2012).

In the context of the Warsaw Stock Exchange (WSE), research remains relatively scarce. Gurgul and Wójtowicz used an event-study methodology and confirmed that unusually high trading volume was followed by positive short-term abnormal returns (Gurgul, Wójtowicz 2009). Wójtowicz expanded the analysis with an asset-pricing framework, showing that the HVRP is robust at the monthly horizon and not explained by common risk factors such as size, value, momentum, or liquidity (Wójtowicz 2017). However, both studies focused on documenting the anomaly itself rather than its practical exploitability. Evidence from other Central European markets, such as the Vienna Stock Exchange (VSE), indicates that the HVRP may exist but is more fragile and sensitive to weighting methodology and significant only for equally-weighted returns. (Wójtowicz 2017).

Despite these contributions, emerging markets such as Poland remain understudied. Structural factors – such as lower liquidity, greater retail investor dominance, and different regulatory environments – may significantly alter the volume-return relationship. While preliminary evidence from Gurgul and Wójtowicz supports the HVRP existence in Poland, no study has yet explored how this effect varies across firm sizes, sectors, or market conditions (Gurgul, Wójtowicz 2009; Wójtowicz 2017). This gap limits the practical applicability of HVRP-based strategies for local investors and raises important questions about the generalizability of behavioural asset pricing theories – such as SIAH and the investor recognition hypothesis – in less efficient and less mature markets. This study addresses these gaps by providing new empirical evidence on the nature of the HVRP on the Warsaw Stock Exchange. Special attention is paid to short-term trading behaviour, firm-level heterogeneity, and the influence of market segmentation.

3. Dataset and methodology

The main objective of this study is to examine whether trading volume can serve as a predictor of future stock returns and to test for the existence of the High-Volume Return Premium (HVRP) on the Warsaw Stock Exchange (WSE). The dataset, sourced from the EquityRT database, covers daily prices, trading volumes, and market capitalisations for all stocks listed on both the main WSE market and NewConnect between January 2002 and April 2023. All figures are expressed in U.S. dollars and adjusted for corporate actions such as stock splits and dividends. The one-month U.S. Treasury bill rate is used as a proxy for the risk-free rate.

To evaluate the impact of unusually high trading activity on future returns, we construct an investment strategy based on trading volume. For each stock and trading day, we calculate the relative trading volume (RVOL) as the ratio of the current day's trading volume to the maximum volume observed over the preceding 20 trading days. A relative volume greater than one indicates that the stock is experiencing a surge in investor attention compared with recent history. Such stocks are classified as high-volume on that day.

Importantly, only stocks with complete data for the entire reference window, specifically, those that exhibited trading activity on each day within that period, are included in the analysis. This filtering step ensures that infrequently traded stocks, for which the definition of relative volume may be distorted and unreliable, are excluded. As a result, the analysis focuses on liquid, actively traded stocks, thereby reducing noise and enhancing the robustness of the results. To further ensure data quality, additional filters are applied: all stocks with a nominal share price below USD 0.25 on a given day are excluded to avoid issues related to penny stocks. Additionally, we remove all stocks of firms with a market capitalisation lower than USD 1 million.

Following the framework of Gervais et al., the strategy consists of buying high-volume stocks and holding them for either one day or five days before selling (Gervais et al. 2001). Since portfolios are formed daily, a 5-day holding period implies five overlapping portfolios – those formed one, two, up to five days earlier. The daily portfolio return is thus defined as the average return of all active positions held on that day. In addition to the baseline specification, we examine several extensions of the strategy to assess robustness and parameter sensitivity. Specifically, we test two alternative reference windows (20 and 50 trading days) used to define abnormal volume, and two holding periods (one day and five days). We also construct both equally-weighted and capitalisation-weighted portfolios to analyse whether results depend on firm size and liquidity concentration.

To benchmark performance, we compare the returns of the HVRP-based strategies against the WIG index, evaluating excess returns, Sharpe ratios, Jensen's alpha, and Treynor ratios. Finally, we analyse the monthly intensity of volume signals – measured as the number of occurrences of extreme trading volume per month – to investigate whether the frequency of such signals correlates with broader market dynamics.

The investment strategy described above, which selects stocks based on short-term changes in trading activity and holds them briefly, aligns with the broader HVRP framework but also introduces several key methodological distinctions compared to dominant approaches in academic research. First and foremost, our approach relies on a short reference window (20 trading days) to compute relative trading volume. This enables the strategy to detect extreme short-term increases in investor attention, which may reflect news events, speculation, or sudden shifts in sentiment. Unlike Gervais et al., who formed portfolios every 50 days using static reference windows, our method updates daily (Gervais et al. 2001).

Second, our strategy employs very short holding periods (one or five days) and constructs daily portfolios based on rolling signals. This setup aims to capture short-lived return patterns following abnormal trading activity, which may be driven by behavioural overreactions or liquidity effects. Most prior studies, including Zhou and Wang et al., analyse effects over several weeks or months, assuming slower price adjustments (Wang et al. 2017; Zhou 2010).

Third, our filtering approach excludes stocks lacking continuous trading data over the reference window. This eliminates illiquid or infrequently traded stocks, ensuring that the relative volume measure is well-defined and not distorted by artificial volume jumps due to sporadic trading. This is particularly important in emerging markets, where thinly traded stocks can introduce considerable noise. In contrast, many studies (such as Gordon, Wu 2018) include a broader universe of stocks, often applying liquidity filters post hoc. Only a few papers (such as Wójtowicz 2017) explicitly emphasize liquidity constraints in markets like Warsaw and Vienna.

Additionally, a key distinguishing feature of the methodology employed in this paper is its exclusive reliance on long positions. The investment strategy consists solely of taking long positions in high-volume stocks, without a corresponding short position in low-volume stocks. This contrasts with many previous studies (e.g., Gervais et al. 2001; Kaniel et al. 2012), where the HVRP is typically examined using a long–short strategy and measured as the return spread between high- and low-volume portfolios. The decision to focus exclusively on long positions is particularly relevant in the context of the Warsaw Stock Exchange — an emerging market characterized by significant constraints on short selling. In practice, establishing short positions in low-volume stocks (typically highly illiquid and of limited investor interest) is extremely difficult due to regulatory restrictions and a general lack of borrowable shares. Therefore, a long-only strategy more accurately reflects the practical limitations faced by investors in such markets and enhances the real-world applicability of the study's findings.

4. Empirical results

In this section, we present and evaluate the key empirical findings of our study. The primary objective is to assess how sudden increases in trading volume affect future returns and whether this phenomenon, the High-Volume Return Premium (HVRP), can be utilized to construct profitable trading strategies. The second objective is to assess how various factors, including company size (market capitalisation) and stock price level, affect the performance of volume-based trading strategies.

We conduct this analysis using both equally-weighted and capitalisation-weighted portfolios to capture potential differences in outcomes stemming from the High-Volume Return Premium (HVRP) across small-cap and large-cap stocks.

Although the analysed portfolios are rebalanced on a daily basis, we evaluate their performance using monthly returns. This approach allows, among other things, for meaningful comparisons with findings from studies on other asset pricing anomalies, which are typically examined using monthly data.

4.1. Firm size

Firm size, proxied by market capitalisation, often plays a crucial role in shaping investor attention and, as a result, the effectiveness of volume-based trading strategies. The higher visibility and greater liquidity of large firms may amplify the return effects of trading volume shocks. Previous research has shown that the High-Volume Return Premium may not be uniform across firms of different sizes.

For example, Tang et al. found that in the Australian stock market, the HVRP was significantly stronger for large-cap firms, particularly those in the top deciles of capitalisation, while it was largely absent for small-cap firms (Tang et al. 2013). Conversely, Wójtowicz reported that on Poland's NewConnect market, which is characterized by smaller and less liquid firms, the HVRP was only statistically significant under equally-weighted portfolios (Wójtowicz 2017). This suggests that the capitalisation structure of the market influences whether volume anomalies can be profitably exploited, with small firms potentially requiring different assumptions or portfolio construction methods due to their higher volatility and trading frictions. Despite these findings, there remains limited research on how trading volume interacts with firm size in emerging markets. For instance, Kaniel et al. concluded that while the HVRP is robust in developed economies, it is less evident in emerging markets, potentially due to smaller sample sizes, limited data, or institutional constraints (Kaniel et al. 2012). Importantly, they emphasized that capitalisation effects should not be overlooked when interpreting cross-country anomalies in trading behaviour.

To analyse how firm size impacts the HVRP on the WSE, we consider two complementary approaches. In the first, we examine the HVRP for firms whose market capitalisation exceeds one of three thresholds: 1, 10, and 50 million USD. In the second, we analyse the HVRP separately within market capitalisation quintiles. Each quintile represents 20% of firms, sorted from smallest (quintile 1) to largest (quintile 5). This dual approach allows us to investigate whether the HVRP varies systematically with firm size and whether capitalisation acts as a moderating factor in the relationship between abnormal trading volume and subsequent returns. By exploring this dimension, we aim to provide more granular insights into the nature of volume-based signals on the WSE and assess whether investors should tailor their strategies according to firm size. This analysis also contributes to addressing a notable gap in the literature regarding the applicability of HVRP theories in emerging markets compared to developed ones.

Table 1

The impact of firm size on the High-Volume Return Premium

Minimum market capitalisation (million USD)	Average return [%]	Standard deviation [%]	Sharpe ratio	Average monthly trades
Panel A: equally-weighted portfolios				
1	5.53	12.10	0.45	319
10	5.80	11.08	0.52	292
50	5.77	12.00	0.48	263

Table 1 cont.

Panel B: capitalisation-weighted portfolios				
1	4.35	10.37	0.41	319
10	4.33	10.35	0.41	292
50	4.14	10.62	0.38	263

Note: This table presents the results of the High-Volume Return Premium (HVRP) strategy on the Warsaw Stock Exchange for the period from January 2002 to April 2023. The analysis examines how the performance of the strategy varies depending on the minimum market capitalisation threshold applied when selecting stocks for the portfolio. Each row corresponds to a portfolio that includes only firms with a market capitalisation above the specified threshold (in million USD). For each portfolio, the table reports the average monthly return, the standard deviation of monthly returns, the monthly Sharpe ratio, and the average number of trades executed per month based on the strategy. Panel A presents results for equally-weighted portfolios, panel B shows results for capitalisation-weighted portfolios. All average monthly returns are statistically significant at the 1% level, as confirmed by the Newey–West test

The results in Table 1 show that equally-weighted portfolios exhibit relatively high and significant average monthly returns across all thresholds. Notably, increasing the minimum capitalisation from 1 million USD to 10 million USD leads to an improvement in the Sharpe ratio from 0.45 to 0.52. This enhancement is driven by both a moderate rise in average returns (from 5.53% to 5.80%) and a reduction in return volatility (from 12.10% to 11.08%). However, when the threshold is raised further to 50 million USD, the Sharpe ratio declines slightly to 0.48. This suggests that while excluding the very smallest and potentially most volatile or illiquid firms can enhance performance, excluding too many small and mid-sized firms may reduce portfolio diversification and overall return potential.

Capitalisation-weighted portfolios present a different pattern. These portfolios show consistently lower average returns compared to their equally-weighted counterparts, and the returns decline gradually as the minimum capitalisation increases. The monthly Sharpe ratio remains stable at 0.41 between the 1 million USD and 10 million USD thresholds but decreases to 0.38 at the 50 million USD level. This indicates that the exclusion of smaller companies has a limited effect on the risk profile of capitalisation-weighted strategies but may reduce expected returns and, consequently, risk-adjusted performance.

The results demonstrate the importance of minimum size filters in the analysis of the HVRP. Equally-weighted portfolios benefit significantly from the inclusion of smaller firms, although removing the very smallest firms can improve risk-adjusted returns. Conversely, capitalisation-weighted portfolios – naturally biased toward larger firms – are less sensitive to such exclusions, though their performance also deteriorates when a substantial portion of the smaller-cap

universe is omitted. Overall, a moderate minimum capitalisation threshold (e.g., 10 million USD) appears to strike an optimal balance between return and risk, particularly for equally-weighted strategies.

Table 2

The High-Volume Return Premium in capitalisation quintiles

Size quintile	Average return [%]	Standard deviation [%]	Sharpe ratio	Average monthly trades
Panel A: equally-weighted portfolios				
1 (small)	7.23	25.09	0.28	72
2	8.18	22.74	0.36	64
3	9.19	19.81	0.46	65
4	7.75	16.80	0.46	64
5 (big)	7.25	13.89	0.52	73
Panel B: capitalisation-weighted portfolios				
1 (small)	7.04	24.85	0.28	72
2	8.04	22.28	0.36	64
3	9.02	18.91	0.47	65
4	7.41	16.24	0.45	64
5 (big)	6.09	12.91	0.47	73

Note: This table presents the results of the High-Volume Return Premium (HVRP) strategy on the Warsaw Stock Exchange over the period from January 2002 to April 2023, with stocks grouped into quintiles based on market capitalisation. Firms are sorted into five equally-sized groups, ranging from the smallest companies (1st quintile) to the largest companies (5th quintile). The HVRP strategy is applied independently within each capitalisation group. For each quintile portfolio, the table reports the average monthly return, the standard deviation of monthly returns, the Sharpe ratio, and the average number of trades executed per month. Panel A displays results for equally-weighted portfolios, panel B shows results for capitalisation-weighted portfolios. All average monthly returns are statistically significant at the 1% level, as confirmed by the Newey–West test

Differences in the HVRP between groups become much clearer, especially when the analysis is conducted by dividing companies into capitalization quintiles, making it easier to identify the best-performing segments (see Table 2). Interestingly, the highest average returns are not achieved by companies at the extremes of capitalisation (either the smallest or the largest), but rather by those in the middle quintiles. These mid-sized companies deliver monthly returns exceeding 9%, outperforming their smaller and larger counterparts.

Besides changes in average returns, we observe a monotonic pattern in standard deviation: portfolio volatility decreases with increasing capitalisation. The interaction between these two patterns leads to a monotonic increase in the Sharpe ratio, which increases steadily from quintile 1 (0.28) to quintile 5 (0.52), indicating improved risk-adjusted performance in larger-cap stocks.

In capitalisation-weighted portfolios, the pattern is broadly similar. Returns of the relative volume-based strategy again peak in the mid-cap quintiles, particularly the third quintile (9.02%), and Sharpe ratios increase from 0.28 (smallest firms) to 0.47 (largest firms). However, the highest Sharpe ratio is not limited to the largest companies – quintile 3 also shows strong risk-adjusted performance (0.47), mirroring the equally-weighted results.

The number of trades across the capitalisation quintiles is similar. This indicates that the number of companies experiencing a surge in trading volume (i.e., those with high relative volume values) is evenly distributed across firms of different sizes. No particular size group dominates in this regard.

These findings indicate that the HVRP performs best, in terms of raw returns, among mid-sized companies (quintiles 2 and 3), while the highest risk-adjusted returns (Sharpe ratios) are observed in the largest-cap stocks (quintile 5). Smaller firms generate high returns but are accompanied by significantly higher volatility, leading to lower Sharpe ratios. The results underscore the importance of firm size in determining both the effectiveness and efficiency of investment strategies. While mid-cap stocks may offer the most attractive return potential, large-cap stocks deliver more stable and consistent performance when adjusted for risk. These dynamics should be considered when constructing portfolios, particularly in balancing return objectives with turnover constraints and implementation costs.

4.2. Stock price level

In this section, we investigate whether the level of stock prices influences the HVRP. Lower-priced stocks – while not necessarily small in market capitalisation, but often associated with lower liquidity or higher volatility – tend to behave differently from higher-priced ones and may be more prone to speculative trading. Han and Zhang, analysing the Chinese stock market, emphasised that low-priced and high-turnover stocks often reflect noise trading and sentiment-driven fluctuations, rather than informed trading (Han, Zhang 2024). This observation aligns with the broader literature indicating that low-priced stocks are more likely to attract speculative retail investors and may deviate from fundamentals more frequently than higher-priced stocks.

As in the case of capitalisation, we consider two approaches: one based on minimum price thresholds, and another based on price quintiles. To exclude lower-priced stocks, we apply the following price thresholds: 0.25 USD, 1.00 USD, and 4.80 USD. These thresholds were chosen based on quantiles from the distribution of stock prices on the Warsaw Stock Exchange (WSE). The results of this analysis are summarised in tables 3 and 4.

The results demonstrate a clear decline in both raw and risk-adjusted returns as the minimum stock price increases. The highest average monthly return (5.53%) and Sharpe ratio (0.45) are observed when the threshold is set at 0.25 USD, indicating that low-priced stocks significantly contribute to the performance of the HVRP. However, increasing the threshold to 1 USD reduces both return and Sharpe ratio, and setting it at 4.80 USD leads to a substantial drop in average return (3.47%) and the lowest risk-adjusted performance (Sharpe ratio of 0.26). This suggests that excluding lower-priced stocks may result in the loss of high-return opportunities, even if those stocks are more volatile or less liquid. A similar trend is observed in capitalisation-weighted portfolios.

Table 3

The impact of stock price level on the High-Volume Return Premium

Minimum stock price (USD)	Average return [%]	Standard deviation [%]	Sharpe ratio	Average monthly trades
Panel A: Equally-weighted portfolios				
0.25	5.53	12.10	0.45	319
1.00	4.79	11.80	0.40	237
4.80	3.47	12.80	0.26	111
Panel B: Capitalisation-weighted portfolios				
0.25	4.35	10.37	0.41	319
1.00	4.19	11.22	0.37	237
4.80	3.41	11.99	0.28	111

Note: This table presents the results of the High-Volume Return Premium (HVRP) strategy on the Warsaw Stock Exchange from January 2002 to April 2023, analysing the effect of imposing minimum stock price thresholds. Each row corresponds to a portfolio that includes only stocks priced above the specified minimum level (in USD). For each portfolio, the table reports the average monthly return, the standard deviation of monthly returns, the Sharpe ratio, and the average number of trades executed per month. Panel A presents results for equally-weighted portfolios; panel B shows results for capitalisation-weighted portfolios. All average monthly returns are statistically significant at the 1% level, as confirmed by the Newey–West test

Table 4

The High-Volume Return Premium in stock price quintiles

Price quintile	Average return [%]	Standard deviation [%]	Sharpe ratio	Average monthly trades
Panel A: Equally-weighted portfolios				
1 (low-priced)	17.98	37.27	0.48	46
2	9.37	24.85	0.37	63
3	8.71	18.63	0.46	76
4	7.81	17.28	0.45	77
5 (high-priced)	4.29	16.47	0.26	83
Panel B: Capitalisation-weighted portfolios				
1 (low-priced)	15.64	35.20	0.44	46
2	8.97	21.67	0.41	63
3	8.19	18.11	0.45	76
4	7.58	15.23	0.49	77
5 (high-priced)	3.98	13.45	0.29	83

Note: This table presents the results of the HVRP strategy applied to stocks listed on the Warsaw Stock Exchange from January 2002 to April 2023. Stocks are sorted into five quintiles based on nominal price, from the lowest (1st quintile) to the highest (5th quintile). The strategy is implemented independently within each quintile. The table shows the average monthly return, the standard deviation, the Sharpe ratio, and average monthly trades. Panel A shows equally-weighted portfolios; panel B presents capitalisation-weighted portfolios. All average monthly returns are statistically significant at the 1% level, as confirmed by the Newey–West test.

These findings indicate that imposing a minimum stock price threshold may inadvertently reduce the HVRP and the effectiveness of a volume-based investment strategy. While excluding very low-priced stocks may be motivated by concerns about liquidity, transaction costs, or speculative behaviour, doing so significantly lowers both the return potential and the risk-adjusted performance of portfolios, especially in equally-weighted constructions. The consistent decline in Sharpe ratios across both weighting schemes as the price filter becomes more restrictive suggests that lower-priced stocks play an important role in enhancing the efficiency of the HVRP. As such, investors should carefully consider the trade-off between perceived quality or liquidity and the loss of return opportunities when applying stock price filters.

Similarly to capitalisation, constructing portfolios based on stock price quintiles provides valuable new insights. Not only did this approach clarify differences between groups, but it also revealed a distinct pattern in the HVRP.

The results show a clear inverse relationship between stock price and the HVRP. The lowest-priced quintile delivers the highest average return (17.98%) and the highest Sharpe ratio (0.48), despite also exhibiting the highest volatility. Performance declines consistently across higher price quintiles, with the most expensive stocks yielding the lowest return (4.29%) and Sharpe ratio (0.26). Interestingly, the number of trades increases steadily from the lowest to the highest price quintile, suggesting greater signal activity and trade frequency among higher-priced stocks – despite their weaker performance. A similar trend is observed in capitalisation-weighted portfolios.

Overall, the strategy based on high-volume stocks performs most effectively among low-priced stocks, generating substantially higher returns and Sharpe ratios compared to higher-priced stocks. While volatility is also higher in the lower-price segment, the premium more than compensates for the added risk. The findings suggest that nominally cheaper stocks may exhibit more pronounced inefficiencies or mispricing that the strategy successfully exploits. Conversely, the declining performance in high-priced quintiles – despite increased trading activity – indicates that price level is a meaningful cross-sectional factor in determining the profitability of volume-based return signals.

4.3. Holding period

In this part of the analysis, we examine how the duration of the holding period affects the HVRP. Specifically, we construct two categories of strategies: one with a 1-day holding period, where positions are closed the day after signal generation, and another with a 5-day holding period, where positions are held for a full trading week. The aim of introducing a longer holding window is to capture potentially more persistent investment behaviour and to test whether the effects of abnormal trading volume on returns extend beyond the very short term. By doing so, we assess whether the HVRP effect remains significant over several days or if it is limited to immediate, short-lived price movements, as suggested in earlier studies. For example, Gervais et al. (2001) examined daily returns in the immediate aftermath of unusually high relative trading volume and documented significantly higher returns over short horizons, especially within one day. This suggests that the market reaction to volume shocks is rapid and often short-lived. Similarly, Gurgul and Wójtowicz confirmed a short-term effect, with statistically significant positive abnormal returns appearing primarily within the few days after very intense trading activity (Gurgul, Wójtowicz 2009).

Table 5

The High-Volume Return Premium for various holding periods

Holding period	Average return [%]	Standard deviation [%]	Sharpe ratio
Panel A: Equally-weighted portfolios			
one day	5.53	12.10	0.45
five days	2.87	9.81	0.29
Panel B: Capitalisation-weighted portfolios			
one day	4.35	10.37	0.41
five days	2.71	9.28	0.28

Note: This table presents the results of the HVRP strategy on the Warsaw Stock Exchange from January 2002 to April 2023, evaluated for two different holding periods: one day and five days. Panel A shows results for equally-weighted portfolios, while panel B presents results for capitalisation-weighted portfolios

The results in Table 5 clearly indicate that the 1-day holding period delivers superior performance significantly outperforming the 5-day variant in both absolute and risk-adjusted terms. Although the longer holding period reduces volatility (from 12.10% to 9.81%), the decrease in return is proportionally greater, resulting in a marked decline in the Sharpe ratio. The same pattern holds for capitalisation-weighted portfolios: the 5-day holding period results in lower returns (2.71%) and reduced risk-adjusted performance (Sharpe ratio of 0.28).

These findings suggest that the effectiveness of the strategy declines with longer holding periods, implying that the HVRP is most pronounced in the very short term. The majority of the return premium appears to be captured shortly after the occurrence of unusually high trading activity, indicating that the HVRP is short-lived and likely driven by temporary mispricing or behavioural overreactions. Extending the holding period dilutes this effect and leads to lower efficiency. For both equally-weighted and capitalisation-weighted portfolios, the 1-day holding period consistently outperforms the 5-day variant, both in terms of raw returns and Sharpe ratios.

4.4. Trading intensity

In this section, we examine whether the monthly intensity of transactions implied by extremely high trading activity can provide investors with valuable insights – either by signalling favourable trading opportunities or by reflecting underlying changes in overall market conditions. Specifically, we analyse how

the monthly number of transactions behaves relative to the state of the market and whether it contains predictive content. To do this, we consider the number of transactions per month generated by the high-volume return strategy, applying a minimum stock price of 0.25 USD, a minimum capitalisation of 1 million USD, and a 1-day holding period.

Figure 1 shows a rapid increase in the number of companies experiencing high-volume trading days between 2002 and 2010. This surge likely reflects the broader development of the Warsaw Stock Exchange (WSE). Notably, 2007 was a milestone year, with 81 new listings, including companies from 12 foreign countries. In the same year, the WSE also launched the NewConnect market for small and medium-sized enterprises.

After 2011, the average number of transactions per month stabilises. However, around April 2020, a notable spike in extreme trading activity occurs. A similar peak is observed at the end of 2022. These fluctuations are most likely linked to major global events that significantly impacted the WSE. In particular, the onset of the COVID-19 pandemic and the beginning of the Russian invasion of Ukraine appear to have triggered heightened trading intensity across many companies. The period from 2020 to 2024 is also characterized by greater volatility in the monthly number of transactions under the volume-based strategy, especially when compared to the relatively stable phase between 2017 and 2020.

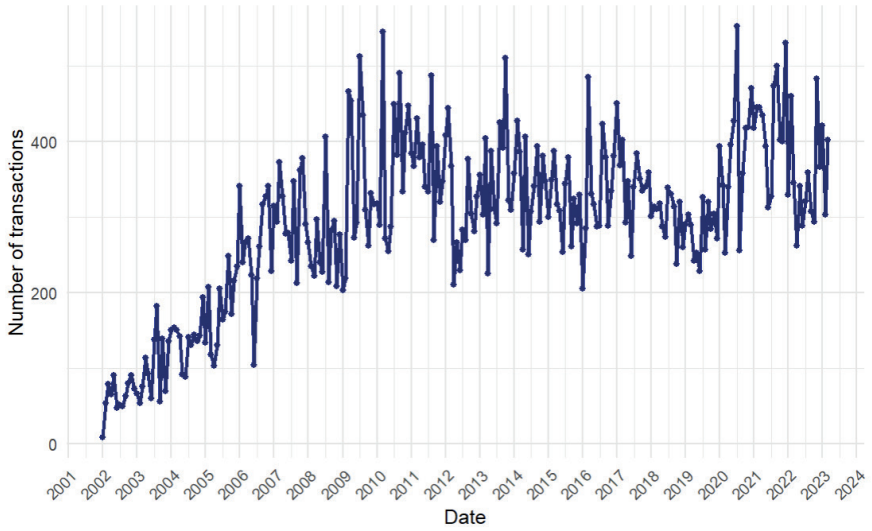


Figure 1. Monthly number of trades
generated by the High-Volume Return Premium strategy

These findings suggest that the intensity of trading activity, as captured by the number of companies experiencing abnormal volume, is not constant over time and appears to be influenced by macroeconomic shocks. The sharp increases observed during global crises highlight its potential as a proxy for market sentiment and systemic stress. Therefore, the monthly intensity of transactions may indeed serve as a useful indicator for investors – not only by signalling heightened trading opportunities but also by reflecting broader shifts in market conditions.

4.5. Benchmark comparison

In this section, we compare the performance of the HVRP strategies against the WIG index – the main index of the WSE representing the performance of almost all stocks listed on the main market of the WSE. First of all, in Table 6, we summarise basic performance indicators of the WIG index.

Table 6

Performance of the WIG index

Average return [%]	Standard deviation [%]	Sharpe ratio	*t*-statistics
0.81	8.85	0.09	0.83

Note: This table reports the performance statistics of the WIG index over the period from January 2002 to April 2023. The table shows the average monthly return, the standard deviation of monthly returns, the Sharpe ratio, and the corresponding *t*-statistic for mean excess return.

The WIG index delivered an average monthly return of 0.81% over the sample period, with a standard deviation of 8.85%, resulting in a Sharpe ratio of just 0.09. The corresponding *t*-statistic suggests that the excess return is not statistically significant at conventional confidence levels. Compared to the HVRP strategies analysed in Table 1 and 3, the WIG index shows substantially lower risk-adjusted returns, highlighting the potential value added by applying volume-based signals in portfolio construction on the WSE.

Further evidence supporting this observation is provided by the analysis of excess return characteristics, as well as Jensen's alpha and the Treynor ratio calculated for selected HVRP-based strategies.

The results in Table 7 indicate that HVRP-based strategies generate strong and statistically significant excess returns, particularly in equally-weighted portfolios. Across all equally-weighted portfolios, Jensen's alphas range

from 7.25% to 7.31% and are statistically significant at the 1% level, providing robust evidence of outperformance relative to market risk as measured by the CAPM. The corresponding Treynor ratios, between 8.35% and 8.77%, suggest that these strategies deliver high returns per unit of systematic risk.

Capitalisation-weighted portfolios also show positive and significant alphas, although at lower levels: between 4.63% and 5.09%. Treynor ratios for these portfolios are also lower (5.85% to 7.71%), indicating slightly reduced efficiency in converting market risk into excess return as portfolio construction shifts toward larger, more liquid firms.

Table 7

Risk-adjusted performance metrics of HVRP-based strategies

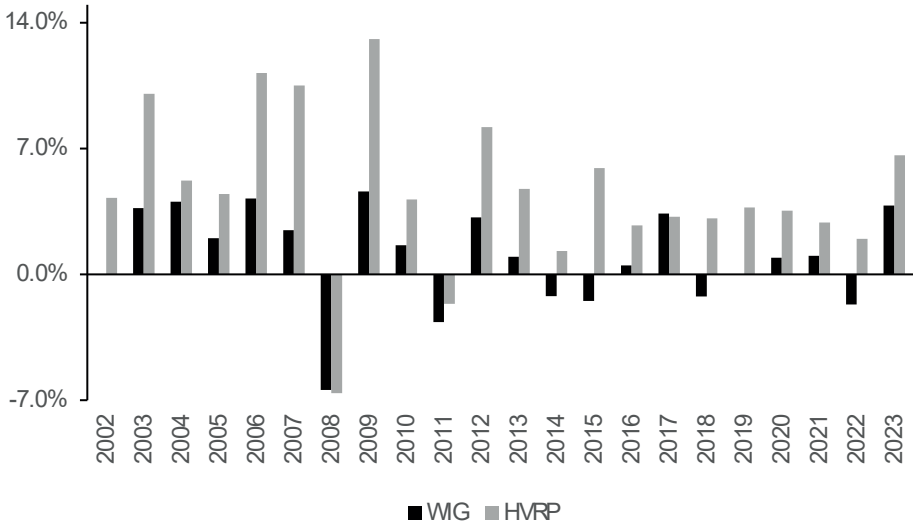
Minimum market capitalisation (million USD)	Average return [%]	Standard deviation [%]	Jensen's alpha	Treynor ratio
Panel A: equally-weighted portfolios				
1	4.72	15.45	7.25%	8.77%
10	4.99	15.42	7.26%	8.64%
50	4.96	14.94	7.31%	8.35%
Panel B: capitalisation-weighted portfolios				
1	3.54	14.43	5.09%	7.71%
10	3.52	14.24	5.03%	6.65%
50	3.33	13.98	4.63%	5.85%

Note: This table presents the risk-adjusted performance of strategies based on the HVRP on the WSE between January 2002 and April 2023. Each row corresponds to a portfolio that includes only firms with market capitalisations above the specified threshold (in million USD). The reported metrics include the average monthly excess return, the standard deviation of monthly excess returns, Jensen's alpha (estimated based on the CAPM), and the Treynor ratio. Panel A shows results for equally-weighted portfolios, while panel B reports outcomes for capitalisation-weighted portfolios

Overall, the consistently significant Jensen's alphas underscore the robustness of the HVRP effect. The results suggest that the strategy is more effective when applied to smaller firms and with equal weighting, possibly due to stronger behavioural or liquidity-driven mispricing among small-cap stocks following volume shocks. Nevertheless, it is worth noting that the results for large firms also remain very strong, with HVRP-based strategies delivering statistically significant excess returns even in capitalisation-weighted portfolios, which are more heavily tilted toward larger and more liquid companies.

To gain further insight into the dynamics of the HVRP strategy relative to the market, it is useful to examine how their average monthly returns evolved over time. Presenting the results year by year allows us to compare the behaviour of both the WIG index and the strategy under varying market conditions – during periods of growth, stability, and crisis. This perspective sheds light on whether the HVRP effect remains consistent across different phases of the market cycle or whether its strength is conditional on broader market environments.

The comparison of average monthly returns of the WIG index and the HVRP-based strategy across 2002–2023 presented in Figure 2 reveals several important patterns. First, the HVRP strategy consistently outperforms the benchmark in the vast majority of years. Particularly strong excess returns are observed in expansionary periods, when volume signals seem to have captured momentum and investor attention effects especially well. Similar, although somewhat smaller, advantages appear in post-crisis and moderately growing years such as 2012 (8.2% vs. 3.2%) and 2023 (6.6% vs. 3.8%).



Note: The HVRP-based strategy is constructed with a minimum stock price of 0.25 USD, a minimum market capitalisation of 1 million USD, a 1-day holding period, and capitalisation-weighted returns

Figure 2. Average monthly returns of the WIG index and the HVRP-based strategy by year

In downturns, the results are more mixed. During the global financial crisis of 2008, both the WIG index and the HVRP strategy posted negative average returns, with the latter performing slightly worse (–6.6% vs. –6.4%). By contrast, in 2011, marked by the euro area debt crisis, the HVRP strategy reduced losses relative to the benchmark (–1.6% vs. –2.7%). It is worth noting that the HVRP strategy considered only relative volume spikes, without conditioning on the concurrent direction of price changes. As a result, the strategy could include stocks that were heavily sold off during crises, such as in 2008. Incorporating price dynamics alongside volume signals might have helped to filter out distressed stocks and potentially improve performance in downturns. These differences suggest that the effectiveness of volume-based signals during crises may depend on the nature of the shock and its impact on liquidity and trading behaviour.

In stable or less dynamic market phases, the HVRP-based strategy still generally generated higher returns than the index, although the difference was smaller. This indicates that even in relatively calm markets, relative volume contains exploitable information that translates into a modest but consistent return premium.

Table 8 presents the average monthly returns of the HVRP-based strategy and the WIG index over the period 2002–2023, together with the average number of transactions (number of occurrences of extreme relative volume values). Several notable patterns emerge from these data. First, the HVRP strategy generally outperforms the WIG index in all months, reflecting the ability of volume-based signals to generate positive excess returns. Particularly strong and statistically significant performance is observed from February to April and in September. In these months, both average returns and the frequency of extreme volume events are relatively high, which appears to enhance the profitability of the strategy.

Table 8

Average monthly returns of the WIG index and the HVRP-based strategy by month

Month	WIG [%]	HVRP [%]	Average monthly trades	Permutation test p-value
Jan	-0.5	2.8	333	0.019
Feb	-0.9	5.5	325	0.000
Mar	1.0	5.9	352	0.002
Apr	4.1	7.9	302	0.013
May	-0.6	2.4	288	0.063

Table 8 cont.

Jun	-0.8	0.3	268	0.234
Jul	4.4	7.4	322	0.070
Aug	0.0	4.9	334	0.013
Sep	-1.2	4.7	329	0.001
Oct	1.5	4.5	322	0.090
Nov	0.8	4.1	328	0.081
Dec	3.0	4.6	340	0.194

Note: The HVRP-based strategy is constructed with a minimum stock price of 0.25 USD, a minimum market capitalisation of 1 million USD, a 1-day holding period, and capitalisation-weighted returns. The last column reports p-values from one-sided permutation tests with the alternative hypothesis that HVRP-based strategy outperforms the WIG index

The weakest performance of the volume-based strategy occurs in June (0.3%), although even in this case the return remains higher than that of the market as a whole (–0.8%). Importantly, the difference of the results for June is insignificant (p = 0.234), and this month also records one of the lowest average numbers of extreme volume-based transactions, suggesting that the strategy's effectiveness relies heavily on the frequency of volume spikes. Similarly, May and July show weaker significance despite positive excess returns, while results in October and November fall into a borderline range. By contrast, results for January and August confirm significant excess returns despite moderate trading activity, underlining the robustness of the premium across different seasonal conditions.

The results in Table 8 suggest that the profitability of volume-based strategies is not uniform across the year but instead varies systematically with the intensity of market activity and seasonality in trading behaviour.

4.6. Length of the reference period

Another important design choice in the construction of the HVRP strategy concerns the length of the reference period used to calculate abnormal trading volume. In the original framework of Gervais et al., a 50-day reference window was applied, but subsequent studies have suggested that shorter horizons may provide timelier signals, albeit at the cost of higher noise (Gervais et al. 2001). In particular, shorter periods may better capture rapid changes in trading intensity and investor attention, while longer periods smooth out fluctuations but run the risk of diluting the informational content of abnormal volume.

Table 9

The impact of the length of the reference period on the High-Volume Return Premium

Reference period	Average return [%]	Standard deviation [%]	Sharpe ratio	Average monthly trades
Panel A: Equally-weighted portfolios				
20	5.53	12.10	0.45	319
30	5.38	13.85	0.38	210
50	5.25	15.96	0.32	121
Panel B: Capitalisation-weighted portfolios				
20	4.35	10.37	0.41	319
30	4.63	11.69	0.39	210
50	5.18	14.35	0.35	121

Note: This table reports the results of the High-Volume Return Premium (HVRP) strategy on the Warsaw Stock Exchange from January 2002 to April 2023, analysing the effect of different lengths of the reference period. Each row corresponds to a portfolio constructed on extreme relative trading volume, defined using data from the specified number of previous trading days. For each portfolio, the table reports the average monthly return, the standard deviation of monthly returns, the Sharpe ratio, and the average number of trades executed per month. Panel A shows results for equally-weighted portfolios, while panel B presents capitalisation-weighted portfolios. All average monthly returns are statistically significant at the 1% level, as confirmed by the Newey–West test

The findings in Table 9 indicate that shorter reference periods generally enhance the efficiency of the strategy. For equally-weighted portfolios, the 20-day window delivers the highest average monthly return (5.53%) and Sharpe ratio (0.45), while performance gradually declines with longer horizons, reaching 5.25% and 0.32 respectively at 50 days. In capitalisation-weighted portfolios, the pattern is broadly consistent but somewhat weaker. Returns are lowest for the 20-day horizon (4.35%) but increase with longer reference periods, reaching 5.18% for the 50-day window. However, standard deviations increase, leading to the decrease in Sharpe ratios, from 0.41 for 20 days to 0.35 at 50 days, indicating that risk-adjusted performance remains superior with shorter horizons.

Extending the reference period implies that the strategy increasingly relies on more extreme relative volume values. This is reflected in the steadily declining number of average monthly trades as the reference window lengthens, suggesting that volume signals become rarer but stronger. Such extreme shocks in trading activity are more likely to be associated with large swings in investor sentiment or attention, which in turn generate return patterns of greater amplitude. This mechanism likely explains why the standard deviation of returns rises with longer reference periods, even though the number of trading opportunities decreases.

5. Conclusions

This study set out to re-examine the existence of the High-Volume Return Premium (HVRP) on the Warsaw Stock Exchange (WSE) and to identify practical strategies for exploiting this anomaly. To this end, several portfolio strategies were constructed and evaluated based on their average returns, risk characteristics, and overall performance.

The analysis confirmed the presence of the HVRP in the short term, with strategies consistently generating significantly positive excess returns. Notably, this effect was observed across firms of various sizes, including both small- and large-cap stocks – contrary to many known anomalies that are typically confined to the small-cap segment.

The study also explored how firm-specific characteristics (such as market capitalisation, stock price level, and holding period) affect the performance of HVRP-based strategies. Shorter holding periods, especially one-day strategies, yielded the highest returns and Sharpe ratios, emphasising the short-lived nature of the HVRP in the Polish market. However, the performance of the strategy varied across market regimes, indicating the importance of market timing, liquidity conditions, and behavioural factors in determining effectiveness.

Further insights emerged from the analysis of firm size and stock price levels. The highest returns were observed for mid-cap companies, while among price groups, the lowest-priced stocks delivered the strongest HVRP effects, albeit with higher volatility. This suggests that investor attention and speculative trading may be more intense in the lower price segment, leading to short-lived price pressures following abnormal trading activity. In contrast, large-cap and high-priced stocks exhibited more moderate yet more stable excess returns, consistent with their higher liquidity and greater institutional participation. Moreover, strategies based on dynamic, cross-sectional measures (such as daily volume quantiles) consistently outperformed those using static thresholds (e.g., fixed capitalisation cut-offs), likely due to their better adaptability to changing market structures.

Nevertheless, this research has certain limitations. Although the HVRP appears statistically significant, its real-world applicability may be constrained by liquidity conditions and execution risk, particularly for strategies involving smaller firms or sudden surges in trading activity. Additionally, the analysed strategies involve high trading frequency, and this study did not account for transaction costs, bid-ask spreads, or slippage – all of which could materially reduce actual profitability.

In conclusion, the High-Volume Return Premium appears to be a robust and exploitable anomaly on the WSE, particularly over short investment horizons and when using adaptive, cross-sectional portfolio construction methods.

However, successful implementation in practice would require careful consideration of trading frictions, liquidity constraints, and market conditions. Transaction costs, bid–ask spreads, and market impact could substantially erode realised returns, especially for smaller and less liquid stocks. Future research could extend this analysis by explicitly incorporating trading costs and assessing the net profitability of HVRP-based strategies under realistic implementation constraints.

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Summary

This paper investigates the High-Volume Return Premium (HVRP) on the Warsaw Stock Exchange from 2002 to 2023. Building on prior research, it tests whether an unusually high trading volume predicts short-term return anomalies. Using daily data and long-only strategies based on relative trading volume, the study confirms the existence of the HVRP, with the strongest effects observed over one-day horizons, particularly for mid-cap and low-priced stocks. The premium weakens with longer holding periods and lower trading activity. These findings indicate that trading volume carries predictive information in an emerging market context and that volume-based signals can generate exploitable short-term return patterns. However, practical constraints such as transaction costs may limit the real-world profitability of such strategies.

JEL codes: G11, G12, G14

Keywords: *trading volume, emerging markets, trading strategy*

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