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Transport exchanges as transport and forwarding management systems

Katarzyna Huk

ABSTRACT
Changes taking place in the economy affect the emergence of innovations. It is primarily technological progress that influences the creation of new solutions. Logistics is one area where innovations and improvements are needed. New solutions are primarily process improvements, the implementation of autonomous vehicles, solutions that help to supervise transport processes, and the effectiveness and costs of their implementation. The greatest benefits of technological progress are the provision of knowledge and information about the journey, the efficiency of a given car and driver, and changes in the market (e.g., information about the demand and supply for given services). This article aims to identify the possibilities of using freight exchanges in transport and forwarding management. It is based on a literature analysis and statistical data from systems dedicated to transport and forwarding, as well as surveys conducted by the author. The article uses analyses of demand, supply and prices based on data from transport exchanges. Possibilities of obtaining information for better management of a transport company were presented. Possibilities of obtaining information for better management of a transport company were presented. The article presents the relationship between the use of the transport exchange and the size of the company, fleet and the number of countries served as part of transport services. The possibilities of using transport exchanges and the possibility of replacing software dedicated to transport and forwarding by the discussed programs were indicated.

KEY WORDS
transport exchanges, transport management, transport and forwarding, IT systems

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Introduction

Technological progress significantly affects the development of the economy. It also affects enterprises on a micro-scale. Innovations and new solutions are the driving force of the developing economy. They affect individual sectors. Globalisation and the influence of the Internet are other factors influencing its development. All these factors also affect the transport and forwarding sector.

Currently, we can observe great technological progress in the industry and logistics. Automation in

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production halls or warehouses is becoming a common solution today. Two aspects of its activity can be improved in transport and forwarding: cars and transport supervision. In the first instance, prototypes of autonomous vehicles are being created, moving on autopilot and, in more advanced technologies, without the driver's intervention. Thus, a new solution would be a car that moves on the road independently and does not require human service. Such solutions require IT systems that will actually supervise and drive autonomous vehicles. These systems are being created at the current stage of economic development. However, IT systems currently available on the market offer great opportunities and solutions to improve and increase the efficiency of transport and fleet management. Such systems are transport exchanges and telematics systems that indicate the location and current costs of the transport service. This article identifies possibilities for using freight exchanges in transport and forwarding management. It is based on a literature analysis and statistical data from systems dedicated to transport and forwarding, as well as surveys conducted by the author. The possibilities and available solutions offered by transport exchanges were presented, which can be used to analyse the market and the services offered.

1. Literature review

Currently, the functioning of enterprises is based on information systems to a greater or lesser extent. Industry 4.0, including automation, will significantly impact the economy's sustainable development (Richnák & Fidlerová, 2022; Saniuk et al., 2022; Szpilko & Ejdys, 2022). The impact of the market structure and IT systems is crucial in the mobile industry (Jeanjean & Houngbonon, 2016). The future is about urban, delivery and individual transport innovations, affecting intelligent traffic (Balog & Knapčíková, 2016). According to research by the American Council of Logistics Management, transport is the leader in the use of the Internet in supply chains, with a share of 56.2 % (Lancioni et al., 2000).

The Internet has undoubtedly contributed to the development of the economy. One effect is the ability to quickly send various information, including on demand and supply (Rayport & Jaworski, 2002; Beynon-Davies, 2004). In addition, it strongly influenced information technology and new software development for various economic sectors. It gave rise to electronic marketplaces, also used in transport, e.g., electronic exchanges (Kovács & Grzybowska, 2011, p. 2).

Transport exchanges are "platforms for exchanging information on offers for the transport of products, goods, materials, etc., as well as loads between market participants" (Sosnowski & Nowakowski, 2015, p. 12). These platforms provide a great opportunity for those with free capacity on the way back to find an offer among many freight and warehouse offers (Kovács, 2011). B2B relationships use websites, instant messaging, and mobile applications that replace mailing lists, faxes, or offline databases (Witkowski et al., 2020). Freight exchanges evolved from dealing only with transport services to using optimisation up to the automation of the transport management system (Baron et al., 2017). Transport exchanges also allow long-term relationships between participants in supply chains (Witkowski, 2019). This is also reflected in the creation of agile supply chains, which are mainly based on networks, process integration and virtual activities (Grzybowska & Kovács, 2012; Christopher, 2000; Lee, 2001; Bohács, Frikker, & Kovács, 2013).

Two types of open and dedicated exchanges can be distinguished (Sosnowski & Nowakowski, 2015, p. 12). Transport exchanges are also becoming a determinant of e-logistics (Polkowski et al., 2014). Freight exchanges in the European Union are becoming more common, with growing competition between them (Jain et al., 2019; Miller, 2020; Fohring & Zelewski, 2015). It is an ideal tool in the transport orders market to increase the indicator value of the cargo holds' space use while carrying out full transport orders, i.e., the indicator of transport efficiency (Mieszaniec & Ogrodnik, 2010). This indicator is approximately 55 % in the Member States of the European Union. Exceptions are Germany with 65 % and Spain with 80 % (eea.europa.eu, 08.02.2023). Freight exchanges are also a solution to seasonality in logistics (Gmys, 2018; Pędziwiatr & Kaczmarek, 2018). The former are the most popular and form the basis for the modern operation of freight exchanges (Fuks et al., 2015). Due to the increasing freight rates in logistics, new and more effective transport solutions are constantly being sought. Transport exchanges create price competitiveness and the possibility of eliminating the so-called empty runs (Föhring & Zelewski, 2015; Kupolova, 2022). These include exchanges such as TimoCom, Trans.eu, Teleroute and others. Dedicated exchanges are used by a group of companies based on an extranet. They have limited access only to a given

team or a group of companies. The purpose of transport exchanges is to post information about offers by all companies that join and subscribe to a given exchange.

A transport exchange allows for:

- issuing transport offers,
- looking for transport offers,
- posting loads for transport,
- searching for loads to be transported,
- issuing offers for the lease of warehouse space,
- looking for offers for renting warehouse space,
- participating in tenders regarding transport and storage,
- checking contractors.

Freight exchanges have three main areas: transport, freight and storage, as shown in the figure below.

Each area has two "listing" and "searching" possibilities, meaning that each user can list and search for transport services. Thus, transport exchanges are a meeting place for people offering transport services and people looking for these services. The situation is similar to the warehousing offer. Here, similarly, the warehouse space can be listed for rent. The continuous development of the economy and competition also means the continuous development of transport exchanges. Therefore, companies keep offering new services, solutions and packages that improve and make their exchanges more attractive. Among them, the following can be distinguished:

- the ability to track the car in real-time,
- automatic calculation of the rate per km,
- automatic calculation of the fare for the entire route,
- route planning,
- indication of alternative routes depending on traffic jams and road conditions,
- indication of tolls,
- speed and tonnage limits,
- list of debtors,
- legal assistance,
- assistance in collecting debts, etc.

Exchanges can save companies time, provide access to a wide offer and make it easier to set prices and negotiate (Lewandowski, 2014; Maruszczak, 2019).

Teleroute, based on the Minitel system, was the first freight exchange established in France in 1985 (Lee, 2018). Currently, there are many transport exchanges on the market, and the most popular in Europe are TimoCom, Trans.eu, Teleroute, Cargopedia, LKWonline, 123Cargo, and Wtransnet. The main features differentiating freight exchanges are the number of offers, users, and prices. However, these exchanges also differ in specialisation. In most cases, they are focused on specific countries or regions. Specialisation and price are two conditions that determine the number of users and the number of offers available as a result. The network of the current market leader, TimoCom, has 127 000 users, translating to 750 000 offers per day (Maruszczak, 2019). In recent years, freight exchanges have evolved from the basic function of presenting cargo and unit offers to a highly developed tool with additional functions. Currently, they are real-time contractor communicators; they are also an efficient document flow channel. In addition, freight exchanges allow for the optimisation of routes and the calculation of costs. Through the tendering platform, companies can raise the best price. Moreover, in addition to traditional transport services, freight exchanges publish offers for renting warehouse space (Starkowski, 2015).

Changes in the economy generate new solutions and innovations in logistics, process automation, and solutions, such as work in the cloud (Adamczak et al.,

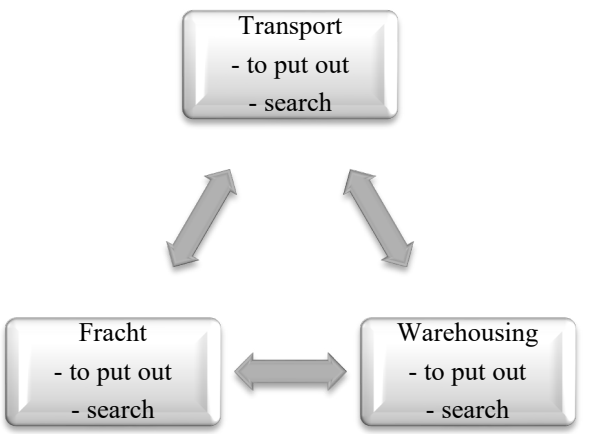

Fig. 1. Areas of freight exchanges

2022; Richnak & Fidlerova, 2022; Danko & Straka, 2022; Loucanova et al., 2022). One such solution is transport exchanges, which are new to the implementation of transport transactions. Undoubtedly, they compete with forwarding, although forwarding uses transport exchanges in its activities. Nevertheless, many companies relinquished forwarding companies because they use transport exchanges directly.

The relevant literature discusses the functioning of transport exchanges, pointing to their benefits (Witkowski et al., 2020), environmental impact through oil consumption, CO2 impact on the economy, etc. (Tiwari & Singh, 2011; Tánczos & Török, 2008; UNCTAD, 2015; Caplice, 2007). However, there is no analysis of the impact of transport exchanges on transport companies in times of economic crises, linking them with other systems dedicated to transport and forwarding. Some studies strictly show the possibilities of the basic form of exchanges and their operation, e.g., in the cloud (Grzybowska, Kovacs, & Lenart, 2013) or Agent-based Freight Exchanges (Föhring & Zelewski, 2015); however, no description exists of the possibility to use data on supply, demand and prices, which are to some extent a learned effect of the operation of exchanges. Therefore, this study will discuss the possibility of using data from transport exchanges and merging this system with other systems dedicated to transport.

2. Research methods

This study uses statistics on demand, supply and prices of transactions concluded on Trans.eu transport exchanges, presented in the Metrix system. The article also presents the author's study of the transport services market.

The Metrix system was used for the analysis, which collects data from Trans.eu transport exchanges and presents them as line diagrams. This program is based on three main data (https://metrix.trans.info, 20.05.2020):

- demand analysis,
- supply analysis,
- analysis of freight prices.

In 2020, the author conducted survey research on the use of IT systems in the transport–forwarding–logistics industry. It covered 200 enterprises, divided into two groups: transport and non-transport. The table below lists companies that participated in the survey. This division was used for a comparative analysis between transport and forwarding companies and other organisations. The sampling method was random. A questionnaire was divided into four parts: the metric, the common part, the part for transport companies, and the part for non-transport companies. It was sent to the respondents electronically and on paper. Table 1 below presents data on the respondents. This division also includes a distinction between transport and non-transport companies.

The table shows the number of companies broken down into transport and non-transport companies, i.e., 60 and 140, respectively.

The research comprised two parts: (1) the statistical frequency analysis into specific aspects of systems supporting transport management using the simple rate index and (2) the creation of the probit model.

The model was developed to explain the main factors determining whether the telematics system is or is not used by the transport and forwarding com-

Tab. 1. Classification of surveyed entities

		Other companies	Transport companies	Total
Size (no. of employees)	micro (1-9)	20	8	28
	small (10-49)	32	24	56
	medium (50-249)	48	16	64
	large (>=250)	40	12	52
	TOTAL	140	60	200
Routes (range)	local	8	4	12
	regional	8	12	20
	country-wide	24	0	24
	international	84	36	120
	global	16	8	24
	TOTAL	140	60	200

pany. For this purpose, the statistical probability probit model was created to calculate a company's probability of using a telematics system. The probit model was chosen for the analysis because of the two-level output. In this specific case, the two outputs were (1) the company uses a telematics system (the dependent variable's value equal to one) and (2) the company does not use a telematics system (the dependent variable's value equal to zero).

The following formula (1) for the probability of occurrence of the event in the probit model (Greene 2011) was used to calculate the probability:

$$p_i = prob\,[Y_i = 1|X] = \phi(x_i'\beta) = \\ = \int_{-\infty}^{x_i'\beta}(2\pi)^{-\frac{1}{2}}exp\left(-\frac{t^2}{2}\right)dt, \quad (1)$$

where:
ϕ — distribution function of the normal distribution,
$x_i'\beta$ — linear combination of independent variables:

$$x_i'\beta = \beta_0 + \beta_1 x_1 + \cdots + \beta_k x_k. \quad (2)$$

The interpretation of β coefficients obtained in the model is limited. It can only be used to indicate the relationship's direction. The marginal effect for changing the value of the x_k variable when other variables remain constant was calculated to assess the strength of the dependence. The following formula was used (Greene 2011):

$$\frac{\partial p_i}{\partial x_{ik}} = \varphi(x_i'\beta)\beta_k, \quad (3)$$

where:
φ — probability density function of a standard normal variable.
Gretl software was used to compute the model. Its output depended on three independent variables, i.e.:

- *fleet* — this variable can take the following values: 0 for no fleet, 1 for one vehicle owned, 2 for 2–5 vehicles, 3 for 6–10 vehicles, 4 for 11–20 vehicles, 5 for 21–40 vehicles, 6 for 41–100 vehicles and 7 for
a fleet of 101 and more vehicles;
- *countries* — the range of activity is measured by the number of countries where the entity operates. The values for this variable in this specific model range from 1 to 22.
- *size* — the size of the company can have four different values: 1 for micro, 2 for small, 3 for medium, and 4 for large company.

3. Research results

3.1. Functioning of transport exchanges and IT systems in transport and forwarding according to surveys

Companies were also divided by size (considering only the number of employees) and the activity area. The chart below shows the number of vehicles owned by the companies.

Most of the surveyed companies had 3 to 5 vehicles. Only 10 % of respondents indicated owning a fleet of more than ten vehicles.

Respondents were asked about the use of IT tools in their business. The table below presents the results indicating the use of these tools, broken down by transport and non-transport companies.

The vast majority of transport companies use IT tools in their daily activities. Almost half of non-transport companies use IT tools dedicated to transport management.

The analysis also looked into the types of IT systems used by the surveyed enterprises. The obtained

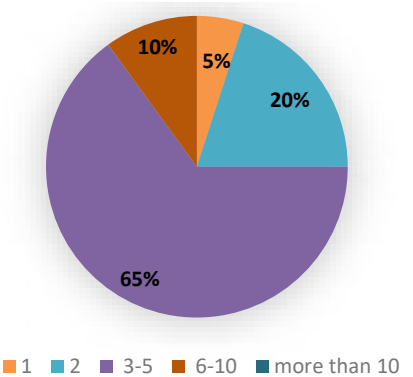

Fig. 2. Percentage of companies using the indicated number of vehicles of certain brands in their fleet

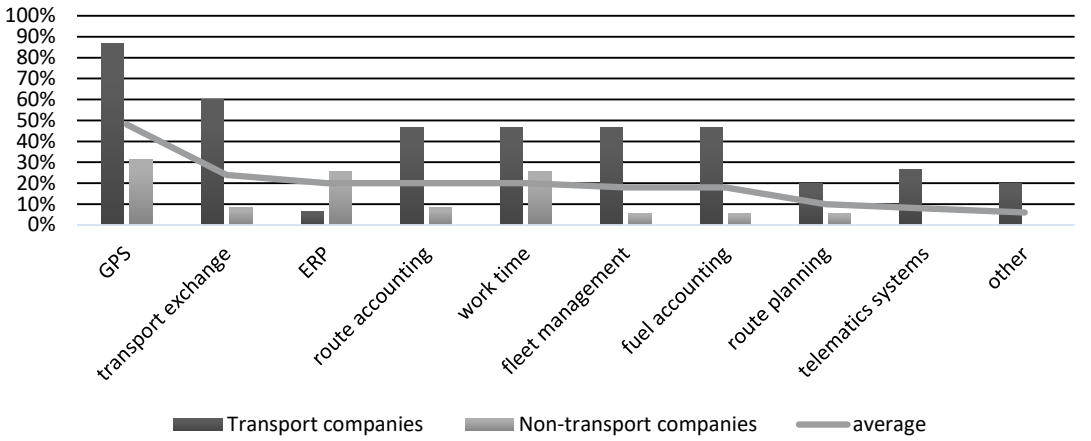

Fig. 3. Use of systems supporting transport management

Tab. 2. Use of IT solutions supporting transport management

	Transport	Non-transport
Used	92%	44.9%
Not used	8%	55.1%

Tab. 3. Problems and challenges in the transport market

Problems	Percentage
Low rates on the transport market	56 %
Problems with documentation flow	48 %
Low demand for transport services	36 %
The lack of qualified employees	28 %
Dishonesty of drivers	28 %
Problems related to the management of vehicles and drivers	16 %
High labour costs	16 %
Improperly planned routes and transports	8 %
Compliance with drivers' working hours	8 %
Problems with the identification of cars on the route and/or the actual course of the route	8 %
Problems with matching the system to GPS in cars	0 %

results are presented in the table below. The analysis was carried out considering the division into transport and non-transport companies.

The analysis of the IT systems used by transport companies demonstrated that vehicle location systems using GPS are the most popular, followed by freight exchanges. Other systems used by transport companies control the drivers' driving and manage other work. Non-transport companies primarily use ERP systems and those using the GPS signal to control working time.

All companies use IT systems tailored to their needs. However, the management staff faces challenges that will determine their further development. The table below shows the problems and challenges identified by the respondents.

Solutions to all the presented problems can be found in transport exchanges. They provide a wide range of solutions that help manage transport more effectively. Low rates (price) and the lack of demand for transport services were among the most significant problems. This is a problem for many transport companies, associated with failure to adjust to the current market situation. Transport exchanges, apart from the very place of concluding transactions, provide a rich database of transactions and their prices. The next part of the study will analyse demand, supply and prices for transport services based on transport exchanges.

The study employs the probit model to check the dependence of transport exchanges use on the company size, its fleet, and the number of countries in which the companies provide transport services.

According to the results of the probit model developed for this study, the size of the fleet and the number of countries in which the company operates positively affects whether it uses freight exchanges. Both effects are statistically significant. Increasing the fleet to the higher class specified in the study increased the probability of implementing a freight exchange by 8.93 percentage points. Expansion to one country increased this probability by 2.02 percentage points. No statistical significance was identified for the variable describing the size of the enterprise. Thus, company size has no bearing on whether a company uses freight exchanges.

Tab. 4. Probit model — values describing the implementation of telematics systems in transport and forwarding companies

	Coefficient	S. Deviation	P-value	Z statistic	Marginal effect
const.	-2.53113	0.667225	0.0001*	-3.794	
fleet	0.355020	0.111191	0.0014*	3.193	0.0893507
countries	0.0803853	0.0364862	0.0276*	2.203	0.0202312
size	0.331879	0.292806	0.2570	1.133	0.0835264
McFadden R^2					0.389097
Predicted correction					90.0 %

* statistical significance level of $\alpha = 0.05$

3.2. Knowledge and information in transport and forwarding management using transport exchanges

Transport exchanges are mainly a platform for exchanging information on offers for the transport and storage of goods. In addition, it is a database of the number of transactions, demand and supply, and average fares. The two largest exchanges used on the Polish market — TimoCom and Trans.eu — were analysed. Both exchanges offered databases to their clients. They mainly present data on transport services that can be filtered by destination and period. This study analysed only data from Trans.eu transport exchanges. In addition, data are limited to the COVID-19 pandemic period, which shows the market trends. The data comes from January to May 2020, when the greatest restrictions were identified, affecting the reduction of transport to other countries. At that time, the greatest increase in cases was recorded in Italy, Spain and Germany, and access and entry of transport was limited. There was also a general decline in shipments and deliveries around the world. Statistical data from the Trans.eu platform are presented in three categories:

- demand for transport services,
- supply for transportation services,
- differences in freight and transport prices.

In addition, two types of transport have been considered, which are marked on these charts (www.timocom.pl, 20.07.2023):

- FTL (in blue in the diagrams) — full truck loads, where a truck carries one load and is, therefore, fully loaded,
- LTL (in red in the charts) — less than a truckload, bulk transport, the deadline for the partial truckload. Usually, if the truck is not fully loaded, further partial loads are consolidated to make transportation profitable. Group loads are an alternative to the transport of partial loads.

The chart below presents data on the demand for transport services from Poland to Germany. These are transport offers from Poland to Germany, considering the demand for FTL and LTL (Fig. 4).

Based on the figure above, the demand for transport was stable. The first fluctuations were recorded on 13 March 2020, and there was a drastic increase in this type of service. Then, a decrease was seen in transport needs, directly related to the restrictions introduced by governments of analysed countries (i.e., closing borders or limiting the activity of certain industries). The situation began to improve in mid-May when a significant increase in demand for transport services was observed. Fig. 5 below provides data on the demand for departures from Poland to Italy using the same methodology.

As in the case of the demand for transport services from Poland to Germany, in the case of Italy, a decrease in the number of offers for the transport of cargo was recorded in January. There was a significant decrease in the willingness to transport goods in this direction, with the highest number of cases after China. The next two diagrams (Figs. 6 and 7) present the supply of transport services from Poland to Germany and Italy.

From mid-March, a decrease in supply could be observed in all directions. Decreases to zero mean holidays when no offers for transport services were issued. The decline in offers for transport services was a fear of entering countries with many cases detected. A decrease was seen in LTL and FTL transport.

The next two charts (Figs. 8 and 9) show the rates for wired services from Poland to Germany and Italy.

The diagrams above show price fluctuations, especially Italy-bound. The trend has been rather stable for Germany. In the case of Italy, however,

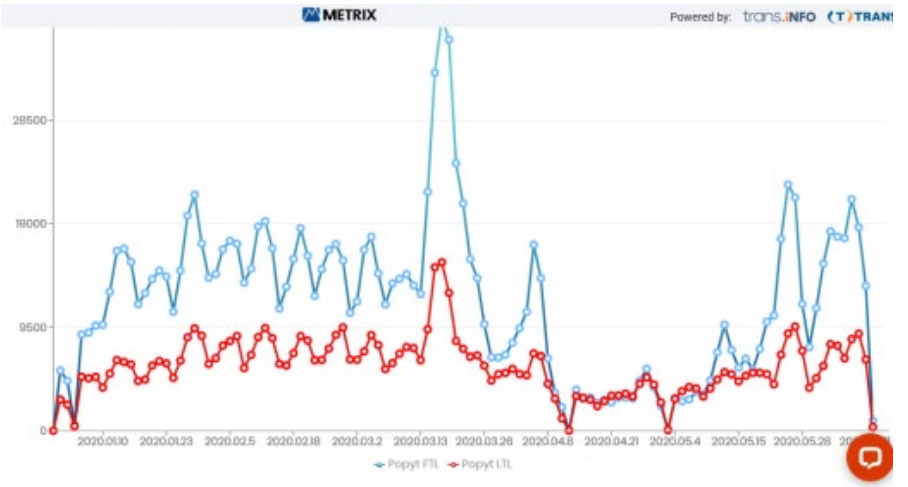

Fig. 4. Demand for transport services from Poland to Germany
Source: Metrix.

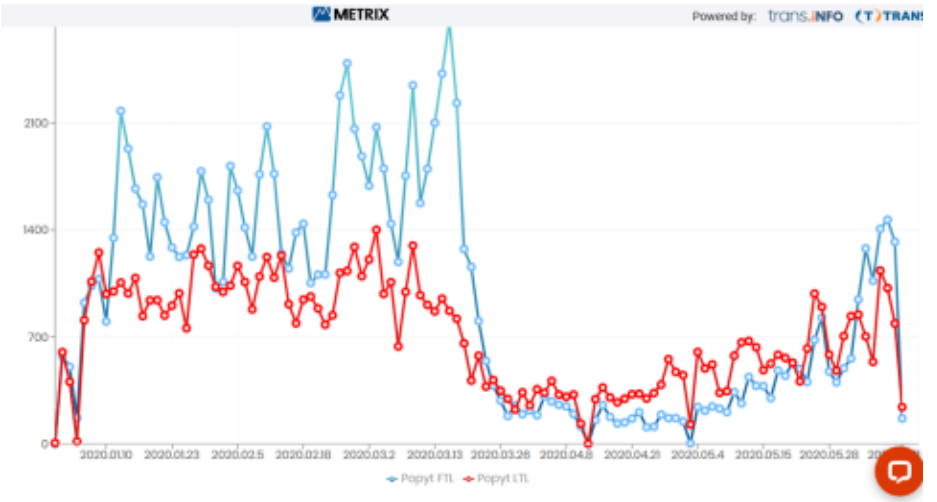

Fig. 5. Demand for transport services from Poland to Italy
Source: Metrix.

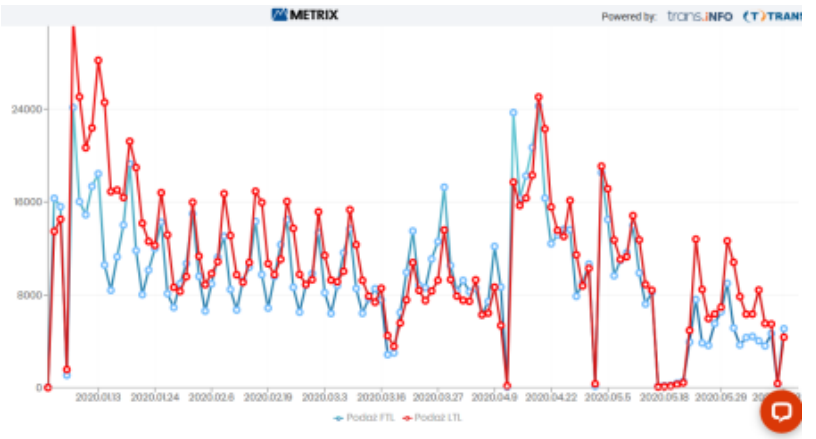

Fig. 6. Supply of transport services from Poland to Germany
Source: Metrix.

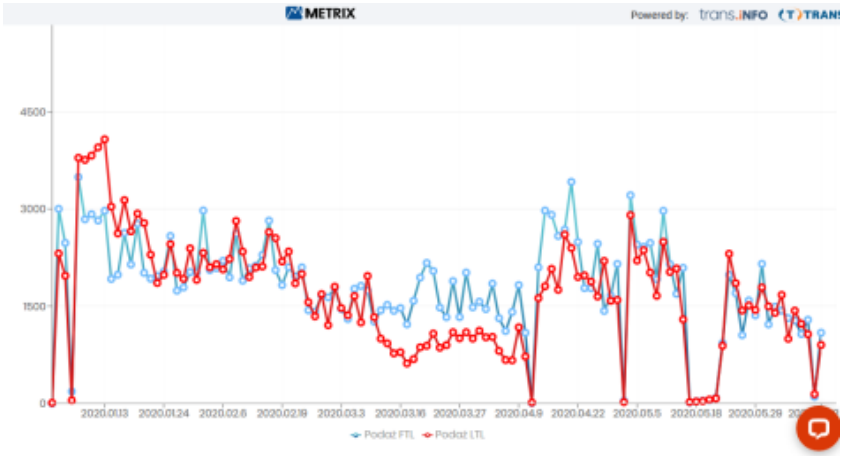

Fig. 7. Supply of transport services from Poland to Italy
Source: Metrix.

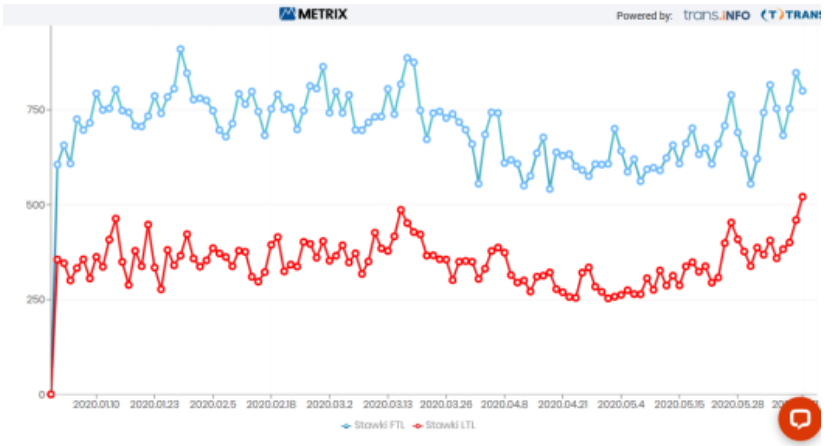

Fig. 8. Freight rates for transport services from Poland to Germany
Source: Metrix.

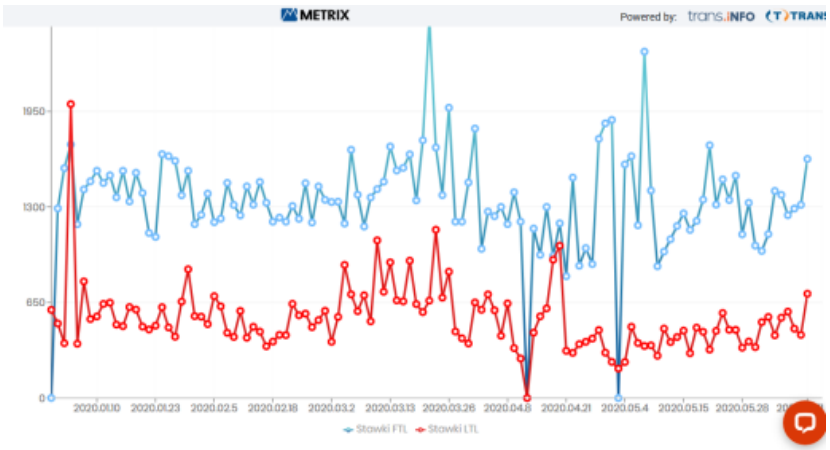

Fig. 8. Freight rates for transport services from Poland to Italy
Source: Metrix.

prices fluctuated significantly. The diagram shows factors that disturbed price stability. The information also shows that transport travelled to the analysed countries at much higher rates.

Data on demand and supply and average prices for transport services are necessary for companies that want to adjust their capabilities to the prevailing market conditions. The above diagrams were consciously presented from the period two years ago, during the pandemic. This period is the best for showing fluctuations in the transport services market as well as the opportunities and potential of the collected data. It facilitates survival in such a turbulent environment under fluctuating economic and political conditions and flexible adaptation to the prevailing market conditions. Therefore, the analysis of data on supply, demand and price can help the management of transport companies adapt to changing conditions. Analyses may indicate a gap in the supply or the choice of other profitable transport directions. Data analysis can also contribute to establishing permanent cooperation with contractors. Unfortunately, there is still a noticeable tendency to not use this data or to be unaware of its existence. However, this is the direction of changes in the field of IT systems in which transport managers should start analysing data on transport services on the market and flexibly manage their resources.

4. Discussion of the results

Freight exchanges have a wide range of tools and instruments for transport and forwarding management. The above research shows that the industry needs them to perform various activities. The use of the tools in individual entities depends on their fleet size (number of vehicles) and the number of serviced countries. Increasing the fleet by one vehicle may result in the need to use exchanges, amounting to almost 9 %. This shows that stock exchanges are necessary for companies operating in the transport industry. Many freight exchanges exist in the world market, so they "race" to provide the best offer or enrich their program with new modules. Currently, exchanges take over many utilities from other programs dedicated to transportation. However, they are

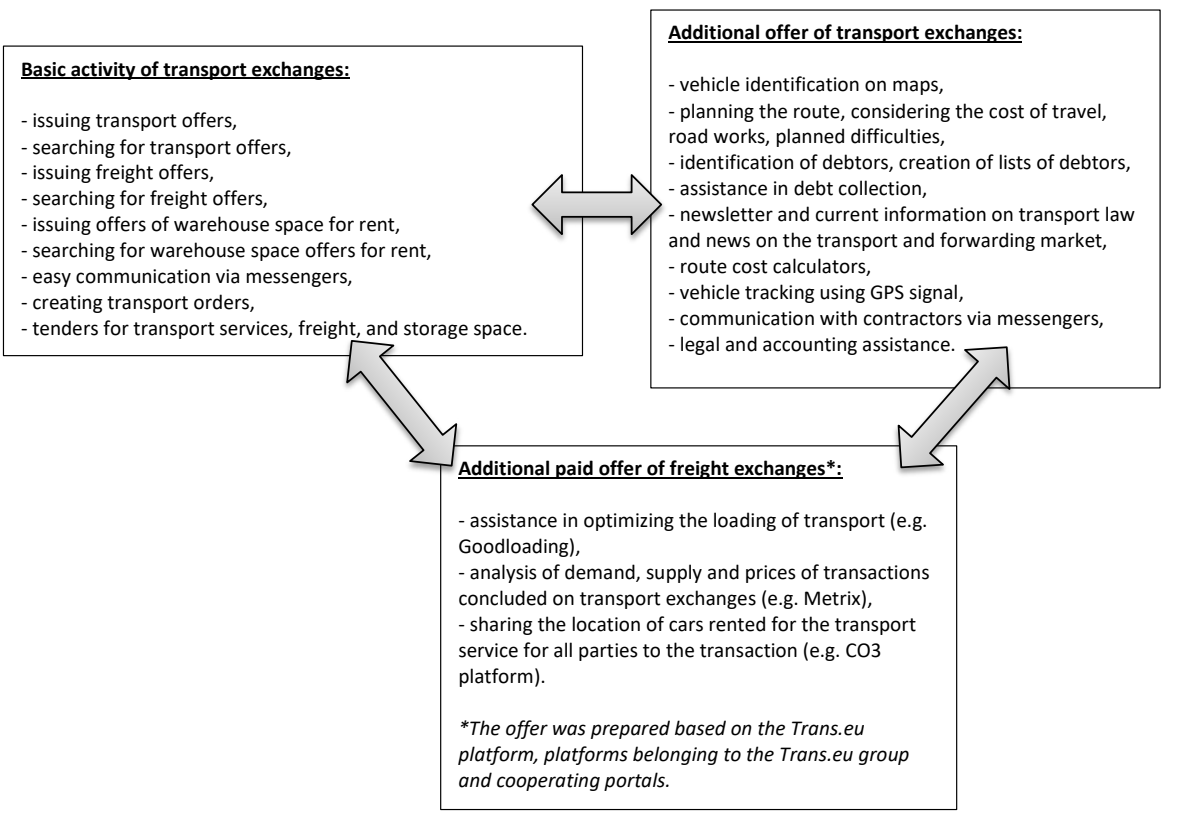

Fig. 9. Possibilities of transport exchanges
Source: elaborated by the author based on (www.timocom.pl, 20.07.2023; Trans.eu, 21.08.2023).

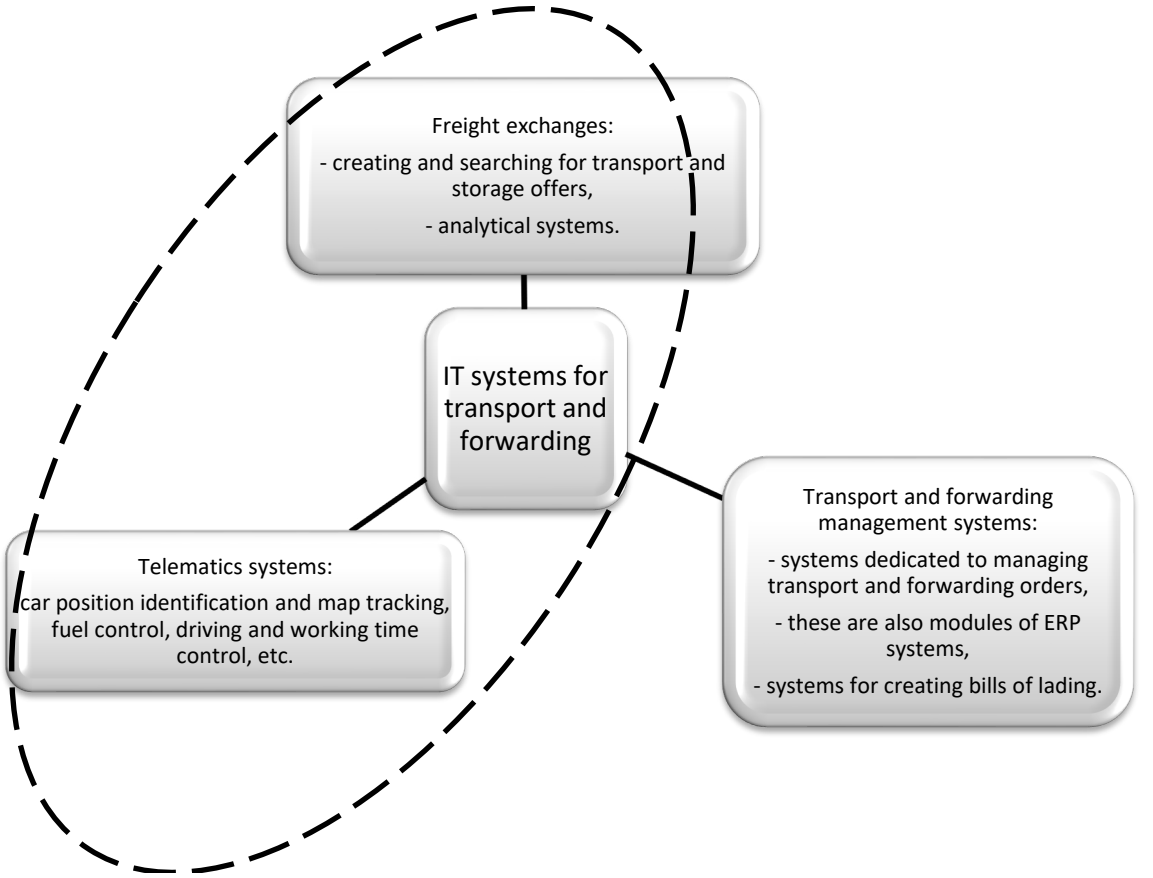

Fig. 10. Groups of information systems for transport and forwarding

not yet fully replacing these tools to become the only program used by the company. Enterprises currently need to use various types of software to obtain information and manage the transport services or their assets effectively. The diagram below (Fig. 9) shows the possibilities of operation of freight exchanges and additional modules. They have been presented using the example of the Trans.eu group, which in its offer, apart from the transport exchange, offers other programs to optimise transport services.

The presented solutions go significantly beyond the basic activity of freight exchanges. This is undoubtedly a response to changes and growing competition in the transport exchanges market. Another problem faced by transport and forwarding companies is the unification of software. Currently, new possibilities should be provided to control employees or routes, optimisation of loading, etc. This is another program that the forwarder must operate. So, as technology evolves, so does the need to engage employees who are already under a heavy workload. However, freight exchanges do not have important functions improving forwarders' work. The missing freight exchange functions are:

- management of transport orders,
- management of the transport fleet,
- management of employees-drivers (assigning routes, calculating holidays and working time, assigning vehicles, etc.),
- creating transport documentation, including contracts and bills of lading).

The following diagram (Fig. 10) presents IT systems dedicated to transport and forwarding, divided into three key groups.

Transport exchange creators introduce new modules borrowed from other IT systems aiming to improve the operation of transport and forwarding companies and strengthen their offer. They mainly borrow modules from telematics systems, such as vehicle tracking or location sharing. However, there are no modules that would support the management of transport orders and forwarding. However, the solution may be to refer to the exchanges in the transport management program and automatically redirect. The downside of the exchanges is also such modules as the one for optimising the loading area or the statistics of transport orders in separate portals, which require creating an account and another login

to a separate system. Thus, improving the operation of IT systems for transport and forwarding should begin with standardising and integrating the systems belonging to the entire group and then coordinating their operation with transport and forwarding management systems as well as telematics, where transport management systems would be superior. This is undoubtedly a problem for many transport and forwarding companies that have to use many systems and have many accounts, which is very laborious for employees jumping between systems. This also discourages using other systems, such as Metrix, which offers great opportunities to gain knowledge about the transport market. The biggest problem seems to be the lack of time and discouragement of employees from constantly using subsequent programs.

Conclusions

The world has entered an era of digitisation, globalisation, modern technologies, and the ability to use information and data. Currently, IT systems are able to acquire and store various information. The flow of information streams is also one of the main ideas of effective supply chain management. In logistics, the need for information management can be seen in all areas. This study analyses transport and forwarding in terms of demand, supply and prices. Information on these economic parameters was obtained from transport exchanges. Although the idea of transport exchanges is to exchange information about transport and warehousing services between the parties, they have additional benefits, such as massive databases on demand, supply and prices for these services. The article presents data from the period of the COVID-19 pandemic to highlight the trends that occurred in the transport services market and show the essence of using these databases. It should be noted, however, that the two most popular transport exchanges on the Polish market, Trans.eu and TimoCom, have such databases made available to their customers.

Unfortunately, few companies currently use these databases although this is one of the solutions to respond to the unstable situation on the transport services market. These databases can support the analysis of demand and supply and flexible adjustment to the existing conditions and change of strategy, e.g., in terms of price or directions served by a company.

The article also discusses the use of IT tools for transport and forwarding. It showed the possibility of replacing a part of this software with freight exchanges and indicated the potential of this software.

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Framework for assessing the environmental impacts of intermodal transportation

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ABSTRACT

This research aimed to use a sustainable approach based on the internalisation of external cost analysis of intermodal transportation of freight to assess the impacts of these activities on the environment. This research used two approaches to develop a model that illustrates the internalisation of the external cost of freight transport. The first approach was used to calculate the cost of emissions for each route considering the transportation and its' cost in the country of destination. The second approach calculated the external cost considering only the distance travelled by the vehicle. The results showed that the companies operating in the selected scenarios would have to pay an additional cost for the transportation of goods. The scenarios had different pollutants emitted during the transportation, which means that the negative impact on human health and the environment is evident. The urgency to limit carbon dioxide and other greenhouse gases in the atmosphere has increased concerns for all activity sectors. Climate change has drawn the attention of governments, companies, and academics, promoting initiatives that mitigate the impact of their activities. The model for measuring emissions was used due to the need for a comprehensive cost analysis to further assess the impact on the environment. Regarding the internalisation of the external cost emissions, the findings showed that different scenarios had a different pollutant emitted during the transportation, which means that the negative impact for human health and the environment is evident. Findings also indicate that to minimise the impact during the transportation, considering the "user-pays principle", these impacts should be discussed in more detail between stakeholders.

KEY WORDS

sustainability, intermodal transport, CO2 emissions, internalisation of external cost

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Introduction

The urgency to limit carbon dioxide and other greenhouse gases in the atmosphere has increased in all sectors. Climate change has drawn the attention of governments, companies, and academics, promoting initiatives that mitigate the impact on the climate. The concern focused on activities with a more significant rate of carbon dioxide and other greenhouse gas emissions, such as freight transport (Rossi et al., 2021). Nevertheless, for this sector, several initiatives have been considered for greening transportation,

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with intermodal transport as the main strategy for a sustainable alternative (Tamannaei et al., 2021).

Over the last few years, the possibility of industries to operate in a global market has been contributing to an increase in the transportation of goods by highways. Transportation is considered a key sector for several countries and one of the main sources of CO2 emissions (Wang et al., 2020). This economic activity leads to external costs arising from the pollutant that drives climate change and impacts society (Musso & Rothengatter, 2013).

The growth of freight transport in the global market has increased concerns regarding the negative impact on air quality and climate change. Transport is mainly driven by the combustion of fossil fuels, which results in the emission of various greenhouse gases such as carbon dioxide (CO2), nitrogen (NOx), and sulfuric oxides (SOx) (Aldakhil et al., 2018).

The current literature focuses on studies highlighting the importance of internalisation of external transport costs in companies (Tamannaei et al., 2021). The external costs of freight transport can be divided into two categories: (1) those related to internal costs, which involve traffic, accident costs, and urban road problems, and (2) those external to the sector, such as environmental problems, noise, and health problem imposed upon society.

Considering the importance of intermodality in transport as a strategy to minimise CO2 emissions and the need to assess the internalisation of the external cost of freight transportation, this research had a dual aim: first, it aimed to analyse the contribution application of intermodality to reduce the emission generated by a furniture company, and second, it assessed internalisation of the external costs of emissions in the freight transport using a furniture company as a case study.

1. Theoretical background

According to data estimated by the International Energy Agency (International Energy Agency, 2021), CO2 emissions in the transport sector represented about 24 % of all greenhouse gas emissions in 2020, and it is expected to continue growing in the coming years. In the case of urban carbon emission, this sector is also one of the primary sources, especially the activities related to passenger transportation.

The growing global demand for the transport of goods has been increasing significantly, raising concerns regarding the impact of these activities on the environment (Mhana et al., 2023). According to Kwakwa et al. (2022), the impact caused by this sector on climate change has prompted companies and governments to develop policies aiming to minimise temperature limits. Despite some initiatives, such as the use of electric vehicles instead of internal combustion engines, most goods are transported using vehicles powered by combustion engines.

The transport sector is constantly changing due to technological advances that have been contributing to more efficient solutions for freight transport in terms of time and costs (Kinsella et al., 2023). Intermodality has been gaining importance and popularity as a system for transporting goods over long distances by different transport types via ports, coastal routes, waterways, railways, roads, and airways (Bartholomeu et al., 2020).

According to Zhang et al. (2023), over the last decades, the fast-growing international market trade has been contributing to the change in the mindset of globally operating companies regarding the traditional way to transport goods, which has led to such strategies as intermodality to minimise emissions. This is especially true in the case of international freight. The authors claimed that intermodality is a key element contributing to the promotion of green transport and emission reduction. It can also shed light on implications to the efficiency of these activities for the countries that have been emerging in the intermodal competition.

Traditional models of logistics management are focused on minimising transport costs, but due to the increase in CO2 emissions in the last decades, it is imperative that new models and technologies are developed to help companies minimise and control it (Qu et al., 2016). Also, the urgency to green transport has led players from the logistics sector to increase concerns about the negative impacts of these activities on the environment and society. Impacts such as emissions, noise, and vibration, which can cause health and safety risks to human life, need to be better analysed and discussed (Petro & Konečný, 2017).

However, the current literature related to green transportation and decarbonisation of this sector does offer an intermodality strategy to minimise the impact of these activities on the environment. The situation was the main motivation for this research, i.e., bringing to light the link in the discussion between three main aspects: intermodality, environmental costs, and internalisation of these costs.

2. Research methods

This research focuses on two main data sources: the DHL Carbon Calculation, which is a platform widely used by companies and researchers to quantify CO2 emissions in transportation, considering different scenarios and transport modes, and data from a furniture company.

Fig. 1 summarises the main steps that served as instruments for considering the development of this research.

The calculation of CO2 emissions used in the DHL's Carbon Calculator can be found online and free of charge on the DHL platform (DHL, 2021). The methodology used in the platform is in line with the reports published by IPCC (Bednar-Friedl et al., 2015), which focus on the role of transportation in mitigating climate change. This work was also inspired by Lagoudis and Shakri (2015), who developed a framework to measure carbon emissions for inbound transportation, considering cargo distribution between air and sea as variables. For the creation of the scenarios, some aspects were considered, i.e., the cost of transport and the time required for transport. Then, these values were used to estimate CO2 emissions using data provided by a forwarding company. In this research, the CO2 values in the "SCENARIOS" represent the CO2 emissions from the combustion of fossil fuels used to transport the configured shipment scenario. The emission calculations are based on the guidelines outlined in the Greenhouse Gas Protocol, the Corporate Accounting and Reporting Standard, and the Corporate Value Chain Accounting and Reporting Standard.

The data was also prepared in accordance with the requirements of the European Emissions Trading System and the standards EN 16258 (European Commission, 2021) and ISO 14064 (ISO, 2021). The Carbon Calculator was used to create the scenarios, considering the waypoints between a pair of origin and destination locations based on a network dataset specific to the mode of transport and linking the waypoints to build a route. The sum of all connected waypoints shows the shortest distance travelled on that route. If an inserted location is not part of the mode-specific network data set, using a built-in algorithm, the Carbon Calculator adds a connection from that location to the nearest location that is part of the mode-specific network data of joint transport.

A set of scenarios was created to obtain a picture of CO2 emissions generated by the transport of products by a company. This research considered three routes: Matosinhos (PT) – Valls (ES), Penamaior (PT) – Erfurt (DE), and Tábua (PT) – Piacenza (IT). The DHL Carbon Calculator helped to determine the

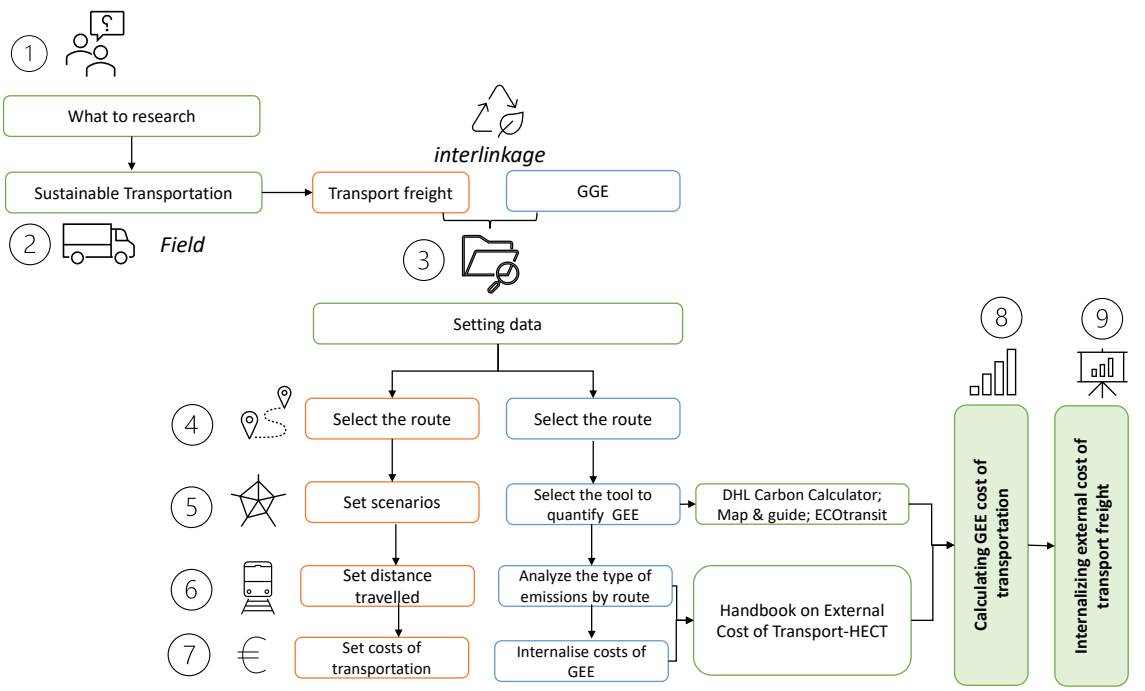

Fig. 1. Main steps used in considering the research

ideal scenario for each route, i.e., Matosinhos (PT) – Valls (ES): using the road–rail–road intermodality; Penamaior (PT) – Erfurt (DE): using the road–maritime–road intermodality; and Tábua (PT) – Piacenza (IT): using the road–maritime–road intermodality. All of them were analysed considering the relationship between the reduction in CO2 emissions, costs and time of transportation, and distance.

3. Case of a furniture company

The environment can affect the business of organisations in several ways, including the scarcity of resources, the socio-demographic context, and the presence of competitors. As a consequence, over the last decades, companies have been pushed to develop projects in the planning and construction of strategies to minimise the cost of its impacts on the environment. Transport has been seen as a longwinded part of these strategies, especially when defining routes to transport companies' goods (Schirone & Torkan, 2012).

In this research, a furniture company was used as a case study to illustrate the impact of transportation on climate footprint. Since transport intermodality can be considered a driver towards reducing CO2 emissions and offering solutions that result in low CO2 content and low costs, this research focused on suggesting a set of alternatives for transportation of the company's products in a more sustainable way.

In the last report published by the studied furniture company in 2020, relative to the previous year, the company indicated that its biggest long-term goal was to reduce its climate footprint by the year 2030 when compared to 2017, in which the footprint value was 1.2 million tons of CO2. The company is greatly concerned with sustainability and environmental impacts. For this research, a combination of different transport modes was considered, with the aim to propose the one with the lowest CO2 emissions. As presented in Table 1, for the calculation of CO2 emissions, three routes were identified from where transport will be dispatched to the destination.

The locations for the departure, transport, and reception of goods were chosen in cities where the company has stores and distribution centres. For the development and calculation of scenarios, it is necessary to consider some assumptions directly related to the adopted cost values, and these values were identified by a freight forwarder with extensive experience in the market:

- Regarding road transport, the travel cost was calculated based on kilometres travelled.
- Routes with less than or with 100 Km were estimated at a cost of EUR 100. In these cases, it was impossible to count the travel cost for the route as it is not compensatory for freight forwarders since there are fuel costs, maintenance costs, and delays in loading and unloading, which can lead to the inability to provide the next service. Thus, it is necessary to estimate a value that can cover all possible costs. For journeys over 100 km, the estimated cost will be EUR 1 per kilometre.
- For the sea route, the values were estimated according to the destination. The cost of sea freight to Spain was EUR 950. For Germany, sea freight was EUR 1250, and for Italy, the cost was EUR 1150. To the value of the sea freight, whatever the destination, the tax should be added, which is always charged for the pollution emitted by maritime transport. In this case, the value used as an estimate was EUR 25, but it is updated every month.
- For the railway mode, it was necessary to consider the cost of rail freight, which also varies according to the destination and the handling cost, which is the cost that the terminal had in handling the loads, and a fixed value of EUR 20 per movement was estimated. The cost of rail freight to Spain was approximately EUR 400, to Italy EUR 500 and to Germany EUR 600.

Table 2 details the configuration for each combined scenario, considering the starting point to the destination point. A set of scenarios was suggested for each route (Table 2), aiming to understand the difference between transport modes. Three cities in Portugal and three different countries (Germany, Spain, and Italy) were taken as a sample. These countries were chosen because the company has large distribution centres in them.

Additionally, to assess the external cost of these activities, an analysis was developed, focusing on scenario S1, which was the only one using road transport. This analysis was developed considering different steps: (1) emission calculation for the type of pollutant in each route, (2) analysis of individual costs for the type of pollutant generated during the transport for each country, (3) analysis of emission costs by category of vehicle, and (4) calculation of

Tab. 1. Proposed case study scenarios

Route	Origin	Destination
R1	Matosinhos, PT	Valls, ES
R2	Penamaior, PT	Erfurt, DE
R3	Tábua, PT	Piacenza, IT

Tab. 2. Details of chosen routes

	Routes		
Scenarios	**Matosinhos (PT) – Valls (S)**	**Penamaior (PT) – Erfurt (DE)**	**Tábua (PT) – Piacenza (IT)**
S1	Road	Road	Road
S2	Road – Rail – Road	Road – Sea – Road	Road – Sea – Road
S3	Road – Sea – Road	Road – Rail – Road	Road – Rail – Road
S4	Road – Sea – Rail – Road	Road – Sea –Rail – Road	Road – Sea – Rail – Road

emissions for route considering two methods (M1: individual cost for type of pollutant per route and M2: total cost of emissions by distance travelled).

For the calculation of the external cost of freight transport, the main source of data was the DHL Carbon calculator ECOTransit (ECOtransit, 2022), which is a tool widely used to identify the negative environmental impacts related to freight transportation and the Handbook on External Cost of Transport-HECT version 2019 (European Commission, 2019).

4. Research results

The results presented in this section summarise the novelty of this research, which has two main aspects: highlighting the need for further discussion among companies on understanding the environmental impact of transportation and the contribution of intermodality as a logistics strategy to the reduction of CO2 emissions.

The first analysis was made after defining the configuration of each route. It is important to highlight that for all scenarios, a total of 20 tons of products was considered. Since this research focused on quantifying emissions for different routes, the next sections will discuss the results achieved in each case. The costs presented in the following tables are related to the costs defined by the selected company for the value paid by the freight.

4.1. Characterisation of the proposed routes versus scenarios

4.1.1. Matosinhos (PT) — Valls (S)

For the case of the Matosinhos (Portugal, PT) — Valls (Spain, S) route, the results in Table 3 show that Scenario 1 was the most effective in terms of the number of kilometres and in terms of transport time; on the other hand, Scenario 2 is the most effective with the level of costs and CO2 emissions.

For Scenarios 3 and 4, the results showed that they were considered unsuccessful on the variables chosen for the study because the distance, costs and emissions have a higher value. Scenario 3 combines transportation by road and sea; this modality significantly contributes to the increase of each variable's value. The value increased because a sea route was used. The freight from Leixões Port in Portugal to Barcelona costs almost EUR 1000, and it takes about 48 hours, with a distance travel of approximately 2325.84 Km. In terms of CO2 emission, the results showed that the route emits about 550.69 KgCO2.

Compared to Scenario 1, PT-S_S3 would be more effective in terms of costs and CO2 emissions but not in terms of time and distance, as it takes more time and travels more kilometres. Thus, PT-S_S2 was con-

Tab. 3. Results for Matosinhos (PT) — Valls (S)

	Distance (Km)	Cost (EUR)	Time (hour)	CO2 Emissions (KgCO2)
S1	1063	1063	13	944.05
S2	1247.44	659.16	20	502.23
S3	2434.52	1163.19	50	647.19
S4	2549.33	1849.47	72	1408.13

sidered the most effective intermodality proposal for the Matosinhos (PT) — Valls (ES) route since the one that contains lower costs and a low CO2 emission level.

4.1.2. Penamaior (PT) — Erfurt (DE)

Four scenarios were analysed for the Penamaior (PT) — Erfurt (DE) route. In this case, the results showed that route PT-DE_S1 was considered the most effective in terms of the number of kilometres and time. PT-DE_S1 was positive in terms of cost-effectiveness. Finally, for the case of PT-DE_S4, the results demonstrate the scenario's effectiveness in terms of CO2 emissions. Despite not being effective in any of the variables, PT-DE_S4 presents very attractive CO2 emissions compared to Scenarios 3 and 1. In this scenario, three modes of transport were considered, namely road, sea, and rail.

The scenario with the longest route is maritime and leads to low CO2 emissions compared to, e.g., the road mode. In terms of costs, it is no longer as attractive because the combination of sea and rail modes was considered, and even the road mode showed a higher value than the other scenarios that only combine two modes of transport. Regarding the number of kilometres, PT-DE_S4 has more than other scenarios since it is necessary to create a route that can include the three modes. For the time needed for the transport, it is normal that it will be necessary for around seven days because in PT-DE_S2, the modes are slower and where there is a possibility of more delays or accidents. So, the results showed that PT-DE_S2 was considered the most successful scenario for the Penamaior (PT) — Erfurt (DE) route.

4.1.3. Tábua (PT) — Piacenza (IT)

For this route, Tábua (PT) — Piacenza (IT), the platform results showed positive evaluations for PT-IT_S1 for time and number of kilometres. PT-IT_S3 is the most cost-effective scenario, and PT-IT_S2 would be the best choice for CO2 emissions.

The PT-IT_S4 scenario is ineffective for all variables and results in Table 5 show that it takes the longest from the beginning to the destination. Regarding CO2 emissions, PT-IT_S4 ranks second behind Scenario 3, with a slight difference of 81.42 KgCO2. For this scenario, the marine mode was combined with the railway in the part of the route with more kilometres to achieve less emissions since more kilometres mean more emissions.

Finally, this was the scenario with the highest cost, as freight to Italy by sea is expensive, and the remaining costs are also high. For this route, the

Tab. 4. Results for Scenario Penamaior (PT) — Erfurt (DE)

	Distance (Km)	Cost (EUR)	Time (hour)	CO2 Emissions ($KgCO_2$)
S1	2394	2394	25	2125.65
S2	2744.30	1940.52	58	1184.53
S3	2770.14	1415.78	85	1685.15
S4	2826.01	2571.71	129	1311.35

Tab. 5. Results for Tábua (PT) — Piacenza (IT)

	Distance (Km)	Cost (EUR)	Time (unit)	CO_2 Emissions ($KgCO_2$)
S1	1915	1915	22	1700.35
S2	3187.69	1646.91	79	1006.89
S3	2201.12	801.53	54	1194.55
S4	3456.07	1964.27	77	1113.13

results showed that the intermodality scenario PT-IT_S2 emits the lowest CO2 content.

4.2. Model for internalisation of external costs of transportation: an unimodal illustration

As a vital sector worldwide, the transport sector plays an important role in the supply chain; however, as discussed before, the environmental impact generated by transportation is not the only impact of this activity, and the effects on human health are also a great concern. To illustrate both impacts, this research aimed to assess the impact of activities of each scenario presented in Table 1. To improve this analysis, a model was developed based on "user pays" and "polluter pays" principles (Auditors, 2021), as this approach maintains that polluters should bear the pollution costs, including the cost to measure, prevent, and remedy problems imposed on society.

The analysis concerned each scenario for the impact of transport on the environment and society. The emission of toxic and other substances that can impact global warming and human health was considered. Table 6 presents the main substances considered in this research.

The substances presented in Table 6 were considered in the analysis of the amount of each element emitted to the air through the combustion engines of each route proposed. It is important to highlight that for the internalisation of external costs, a set of aspects were considered: (1) emissions produced by tons for each scenario, (2) the cost for individual emissions by country for each scenario (costs were estimated based on the methodology developed by European Commission, version 2019 (European Commission, 2019)), and (3) costs for emissions by category of the vehicle used in the transportation (European Commission, 2019).

The internalisation of external costs aims to input costs to entities that are responsible for any negative or positive effects of their activities on society (Petro & Konečný, 2017). In this research, carbon calculators were used to calculate the emissions for the assessment of internalisation of external costs; instead of using the DHL carbon calculator, the ECOTransit calculator was used (ECOtransit, 2022). The ECOTransit is a tool widely used by academics and companies to identify the negative environmental impacts related to freight transportation. The tool was selected for use in this research due to the possibility of accessing data related to N2O, NOx, and PM, which is a limitation of the DHL carbon calculator.

Table 7 summarises the ECOTransit results after entering data from each route proposed in this study. The results presented in the table only considered routes that used roads to transport; for this analysis, only S1 was considered (Table 2).

To standardise the results, the outputs presented in Table 7 were considered in the calculation of the approaches Well-to-Wheel (WtW) and Tank-to-Wheel (TtW). The first (WtW) considers the energy consumption and emissions generated from the energy production for its final consumption. The

Tab. 6. Overview of transport freight emissions and their impact

Substances	Main negative impacts	Acronymous
Nitrogen oxides	Contributes to summer smog, acidification, and damages human health	N2O
Non-methane hydrocarbon	Contributes to summer smog and damages human health	NOx
Sulphur dioxide	Contributes to acidification and damages human health	SO2
Particulate matter	Damages human health	PM

Source: European Commission, 2019.

Tab. 7. Summary emissions for an overview of emissions caused in the transport freight in tones

Matosinhos (PT) — Valls (S)						
S1	**CO2**	**CO2 e**	**NOx**	**SO2**	**N2O**	**PM**
tones	75	78	23.99	27.36	206	4.2
Penamaior (PT) — Erfurt (DE)						
S1	**CO2**	**CO2 e**	**NOx**	**SO2**	**N2O**	**PM**
tones	167	174	53.12	61.33	463	9.44
Tábua (PT) — Piacenza (IT)						
S1	**CO2**	**CO2 e**	**NOx**	**SO2**	**N2O**	**PM**
tones	135	141	43.18	48.81	376	7.68

Tab. 8. Summary of the marginal costs for transport by category of vehicle (eurocent per km)

			Metropolitan area		Urban area			Rural area	
	Full type	EURO — Emission class	Motor-way	Urban road	Other road	Motor-way	Urban road	Motor-way	Urban road
Vehicle category - articulated	Diesel	Euro 0	2.18	3.92	2.41	1.59	2.81	0.94	1.05
		Euro I	1.59	2.98	1.77	1.15	2.07	0.68	0.76
		Euro II	1.47	2.39	1.53	1.15	1.96	0.68	0.74
		Euro III	1.11	2.07	1.24	0.9	1.64	0.54	0.6
		Euro IV	0.65	1.1	0.72	0.6	1.01	0.36	0.4
		Euro V	0.32	1.2	0.45	0.26	1.08	0.16	0.223
		Euro VI	0.03	0.12	0.04	0.03	0.11	0.02	0.03

Source European Commission, 2019.

Tab. 9. Summary of the marginal costs for rail transport

	Full type	Train type	Traction	Eurocent/pkm or eurocent/tkm	Eurocent/train-km
Rail Freight transport	Diesel	Long container	Diesel	0.03	0.42
		Long bulk	Diesel	0.03	0.43
		Short container	Diesel	0.07	0.37
		Short bulk	Diesel	2.07	0.36

Source: European Commission, 2019.

second (TtW) merely reflects the emissions and energy consumption during the vehicle operation.

A truck powered by a diesel engine, loaded with 20000 kg and a full capacity of 24000 kg, was considered for the vehicle characteristics. To calculate the cost of emissions for each type of vehicle, this research considered the methodology developed by the Handbook on External Cost of Transport (HECT) (European Commission, 2019), which is well-known among academics and industries to provide an overview of the main external costs of transports in several countries. Table 8 presents a summary of the marginal costs for road (Km/Tkm) by category of vehicle and area of operation.

According to the methodology developed by HECT, there are two ways to calculate the costs of freight transport emissions. The first method can be calculated by quantifying each pollutant's emission in euros (EUR/tonne). For this case, it was necessary to summarise the cost of each pollutant by country considered in the scenario. Table 11 summarises the price of the individual cost emissions (EUR/Kg) for countries considered in this research. The data are related to the latest version of the methodology (HECT).

The second method is calculated considering the distance travelled by the vehicle (Tables 3, 4 and 5). In this case, the marginal cost was considered, and the vehicle type is classified as a EURO V, for motorway, used in a metropolitan area, and powered by diesel (Table 8).

In this research, to illustrate the internalisation of the external cost of freight transport from Portugal, both methods were used based on data presented in Tables 8, 9, and 10. The results for the first method, namely the cost for individual emissions for each route, are presented in Table 12. They were calculated considering the emissions caused during transportation and their cost in the country of destination (for all routes, Portugal was chosen as the country of origin).

The results presented in Table 10 summarise the total costs of emissions in euros for each scenario. The calculation showed that for Scenarios PT-S_S1 and PT-DE_S1, the costs of CO2 emissions are higher than NOX, SO2, and PM2.2. Only for Scenario PT-IT_S1 are the costs of NOX higher than CO2. Also, when comparing the costs of freight to the final cost of emissions by each route, it is evident that the costs of emissions are higher for PT-DE_S1 (12 %) and PT-IT_S1 (76 %). Once this research attempts to analyse the external costs of transportation in the light of the "polluter pays" principle, the results show that for the selected scenarios, companies operating in those scenarios would have to pay an additional amount of 12 % and 76 % for the transportation, and

Tab. 10. Summary of the marginal costs for maritime transport

	Vessel type			
Tank-to-Wheel emissions maritime transport	Small container vessel (28,500 gt)	Distance at sea (km)	Eurocent per pkm or tkm	EUR per vessel-km
		500	2.09	11
		3000	0.13	31
	Large bulk vessel (143,000 gt)			
		500	0.04	47
		3000	0.03	37
		15000	0.03	35
	Small bulk vessel (18,000 gt)			
		500	0.06	9
		3000	0.03	6
	Large bulk vessel (105,000 gt)			
		500	0.02	22
		3000	0.01	15
		15000	0.01	14

Source: European Commission, 2019.

Tab. 11. Summary of the individual cost of emissions by country (EUR)

	NH3	NMVOC	SO2	NOx city	Nox rural	PM2.5 metropole	PM2.5 city	PM2.5 rural	CO_2
PORTUGAL	4.3	0.5	4.1	2.8	1.7	292	94	39	12.3
SPAIN	6.4	0.7	6.8	8.5	5.1	348	112	46	11.9
GERMANY	28.1	1.8	16.5	36.8	21.6	448	144	93	39.6
ITALY	2.6	1.1	12.7	25.4	15.1	409	132	79	17.2

Source: European Commission, 2019.

Tab. 12. Method 1, a summary of the cost of freight vs costs of emissions by route (EUR)

M1	CO_2	N0x	SO2	PM2.5	Cost of freight	Total cost of emissions
R1	360.7	67.1	112.1	394.8	1063	934.8
R2	803.2	451.5	417	1057.2	2394	2729.1
R3	649.3	1096.7	619.8	1013.76	1915	3379.7

Tab. 13. Method 2, a summary of the distance travelled vs costs of emissions by scenario

M2	Distance (Km)	Cost of emissions by scenario (EUR)
PT-S_S1	1063	340.16
PT-DE _S1	2394	766.08
PT-IT_S1	1915	612.8

only Scenario PT-S_S1 presents the costs lower than the price of freight (-12 %). It is important to highlight that these costs should be paid due to the damage that may be done to society and the environment during transportation.

In this research, a second method was also considered in the assessment of the costs of emissions from road transportation, and the results are presented in Table 13.

The second method is simpler than the first as it only considers the distance travelled (in this case, only highways were considered), and the vehicle category (EURO V) resorts to the cost of the emission class of the vehicle (Table 8). It is considered a limitation since the cost of the type of pollution is not available, which is very important to consider because of the environment and people's health. Yet, when comparing both methods, the results showed that the

costs are significantly lower, which means that this method has weaknesses and does not contribute to assessing the external costs of freight transport.

5. Discussion

5.1. Internalisation of external costs considering intermodal transportation

This section applies an analysis of the internalisation of the external costs considering the intermodal transportation in an international route between Matosinhos in Portugal and Valls in Spain (Route 1). The analysis presented in this section will focus on four different intermodal scenarios.

Scenario 1. Road

The results presented in Table 14 summarise the main pollutant for the route Matosinhos — Valls when considering road transportation. It is important to highlight that the results differ from those presented in Table 7 due to the need to standardise the unit of measure, which means that for the intermodal analysis, all the presented results considered the emissions of CO2 in tons, and for NOx, SO2, and N2O in kilograms.

Regarding the costs associated with Scenario 1, Tables 15 and 16 summarise the results for the costs of emissions when transporting goods by road transport. For this scenario, both methods show that the costs of emissions are higher than the costs of freights paid by the company. It is more significant for Method 2 since the method considered different types of pollutants.

Scenario 2. Road–Rail–Road

Based on the methodology proposed in this research, Table 17 summarises the results for each type of pollutant emitted during transportation when considering three stages: (1) the load departs from Matosinhos (PT) to Alfarelos (PT) by truck, (2) then goes to Alfarelos to Constanti (S) by rail, and finally, (3) from Constanti to Valls (S) by road. This scenario was considered due to the capability to connect road and rail transportation. According to Merchan et al. (2016), rail freight transportation has a better performance when compared with road transportation. The authors maintained that intermodal rail–road solutions can contribute to minimising the environmental impacts of several pollutants in different categories.

The research results presented in Table 17 showed that despite of the distance travelled, in this scenario, Stage 2 is has the lower emission level when compared with the distance travelled by road.

Tab. 14. Total emissions for Scenario 1

Results for Scenario Matosinhos (PT) - Valls (S)_S1										
Road	Matosinhos→Valls S1	Distance (Km)	Cost (EUR)	Time (hour)	GHG CO_{2E} (WTW)	$C0_2$ (WTW) (tons)	N0x (Kg)	SO2 (kg)	N2O (kg)	PM (kg)
		1065	1063	13	1.57	1.52	0.48	0.55	4.25	***0.085***

Tab. 15. Summary of the cost of freight vs costs of emissions S1

Method 1						
	CO_2 (EUR)	N0x (EUR)	SO2 (EUR)	PM2.5 (EUR)	Cost of freight (EUR)	Total cost of emissions (EUR)
Matosinhos→Valls	7.5517	1.344	2.255	7.99	**1063**	**19.1407**

Tab. 16. Summary of the distance travelled vs. costs of emissions by scenario S1

Method 2				
Matosinhos→Valls	Distance (Km)	Cost of emissions by scenario (EUR)	Total cost of emissions (EUR)	Cost of freight (EUR)
	1065	340.8	**1065**	**1063**

Tab. 17. Total emissions for Scenario 2

Results for Scenario Matosinhos (PT)—Alfarelos (PT)_S2										
Road	Matosinhos→Alfarelos S2	Distance (Km)	Cost (EUR)	Time (hour)	GHG CO2 (WTW)	C02 WTW) (tons)	N0x (Kg)	SO2 (kg)	N2O (kg)	PM (kg)
		139.16	139.16	3	0.2	0.19	0.062	0.072	0.55	***0.011***
Results for Scenario Alfarelos (PT) – Constanti (S)_S2										
Rail	Alfarelos→Constanti S2	Distance (Km)	Cost (EUR)	Time (hour)	GHG CO_{2e} (WTW)	C02 (WTW) (tons)	N0x (Kg)	SO2 (kg)	N2O (kg)	PM (kg)
		1085.45	420	15	0.32	0.31	0.088	0.66	1.51	0.088
Results for Constanti (S) – Valls (S)_S2										
Road	Constanti→Valls S2	Distance (Km)	Cost (EUR)	Time (unit)	GHG CO_{2e} (WTW)	C02 (WTW) (tons)	N0x (Kg)	SO2 (kg)	N2O (kg)	PM (kg)
		22.82	100	0.5	0.0032	0.0032	0.0094	0.012	0.034	0.00096

Tab. 18. Emissions for Scenario S2

Method 1						
	CO_2 (EUR)	N0x (EUR)	SO2 (EUR)	PM2.5 (EUR)	Cost of freight (EUR)	Total cost of emissions (EUR)
Matosinhos→Alfarelos	0.962	0.1736	0.2952	1.034	**139.16**	**2.46**
Alfarelos→Constanti	1.5392	0.03256	4.488	9.856	**420**	**15.91**
Constanti→Valls	0.015392	0.0799	0.0816	0.10752	**100**	**0.10**

Tab. 19. Summary of the distance travelled vs costs of emissions by scenario S2

Method 2				
	Distance (Km)	Cost of emission by scenario (EUR)	Total cost of emissions (EUR)	Cost of freight (EUR)
Matosinhos→Alfarelos	139.16	44.5312	**44.52**	**139.16**
Alfarelos→Constanti	1085.45	401.6165	**401.61**	**420**
Constanti→Valls	22.82	7.3024	**7.304**	**100**

For Scenario 2, the costs were computed considering both methods. For the first method, the results in Table 18 show that the route Alfarelos (PT) to Constanti (S) by rail has higher costs in terms of pollutants. For this route, the individual costs of emissions were calculated considering the costs for Spain (Table 9). This means that, in this scenario, despite the use of intermodality, the costs of emissions also increase when the company uses rail transportation.

The results presented in Table 19 represent the second method. Despite being more straightforward, since the method does not consider different pollutants emitted during the transportation, the results are in accordance with Table 18. Yet, in this analysis, the costs of emissions are significantly higher than the freight for Matosinhos — Alfarelos (Portugal); for the route to Spain the costs are lower.

Scenario 3. Road–Sea–Road

With regard to Scenario 3, the analysis focused on transporting 20 tons of product by three transport modes: (1) Matosinhos (PT) — Leixões (PT) by road, (2) Leixões (PT) — Barcelona (PT) by sea, and last

mile Barcelona (PT) — Valls (S) by road. The results for each route and total pollutants emitted are presented in Table 20.

According to Santos et al. (2022), sea shipping is of significant importance in freight transportation worldwide due to the positive economic and environmental benefits of this transport mode. Compared to road transport in terms of cost and time transit, the authors argue that sea transportation has no significant market share in Europe. In this context, the results presented in S3 have considered sea shipping as an important mode to be considered. As presented in Table 20, the results showed that for Scenario 3, most transportation is carried out by sea, meaning that the total amount of emissions is significant.

Regarding the external costs for this scenario, the two proposed transport modes (road and sea) are presented in Tables 21 and 22. The analysis compared the costs of freight that should be paid by the company for each route and the total cost of emissions proposed in this research.

For Method 1 (Table 21), the route Leixões (PT) — Barcelona (S) has a higher cost of freight, but the cost of emissions is lower. It shows the benefit of sea shipping when transporting goods. The costs of emissions are significantly lower when compared with S1 (Table 15), and the distance travelled is very close to the sea route. Method 2 is presented in Table 22. The results are also aligned with the previous method, although for the last route (Barcelona — Valls), the results show that total costs of emissions are higher than proposed using Method 1. However, this method did not consider different types of pollutants.

Scenario 4. Road–Sea–Rail–Road

This section presents the results for Scenario 4 considering all three modes of transport: road, sea, and rail. The main idea of presenting the combination of these modes is to highlight the possibility of combining them using the intermodality approach. The results presented in Table 23 summarise the total emissions for each route, with the sea and rail emitting the most pollutants. The results presented in Table 23 highlight an important aspect that the emissions between rail and road are rather different for

Tab. 20. Total emissions for Scenario 3

Results for Scenario Matosinhos (PT) — Valls (S)_S3										
Road	**Matosinhos→Leixões S3**	**Distance (Km)**	**Cost (EUR)**	**Time (hour)**	**GHG CO_{2e} (WTW)**	**$C0_2$ emissions (WTW) (tons)**	**N0x (Kg)**	**SO2 ((kg)**	**N2O (kg)**	**PM (kg)**
		11	100	1	0.0051	0.0049	0.0016	0.0018	0.0015	***0.00029***
Results for Scenario Leixões (PT) — Barcelona (S) Results_S3										
Sea	**Leixões→Barcelona S3**	**Distance (Km)**	**Cost (EUR)**	**Time (hour)**	**GHG CO_2 (WTW)**	**$C0_2$ emissions (WTW) (tons)**	**N0x (Kg)**	**SO2 ((kg)**	**N2O (kg)**	**PM (kg)**
		1850	975	48	0.506	0.5	0.47	6.58	7.71	0.88
Results for Barcelona (S) — Valls (S)_S3										
Road	**Barcelona→Valls S3**	**Distance (Km)**	**Cost (EUR)**	**Time (unit)**	**GHG CO_2 (WTW)**	**$C0_2$ (WTW) (tons)**	**N0x (Kg)**	**SO2 ((kg)**	**N2O (kg)**	**PM (kg)**
		100.7	100	1.5	0.16	0.16	0.047	0.058	0.18	0.0048

Tab. 21. Emissions for Scenario 3

Method 1						
	CO_2 (EUR)	**N0x (EUR)**	**SO2 (EUR)**	**PM2.5 (EUR)**	**Cost of freight (EUR)**	**Total cost of emissions (EUR)**
Matosinhos→Leixões	0.025	0.004	0.007	0.02	**100**	**0.1**
Leixões→Barcelona	2.43	3.99	44.74	98.56	**975**	**149.7**
Barcelona→Valls	0.770	0.400	0.394	0.53	**100**	**2.1**

Tab. 22. Summary of the distance travelled vs costs of emissions by scenario S3

Method 2				
	Distance (Km)	Cost of emissions by scenario (EUR)	Total cost of emissions (EUR)	Cost of freight (EUR)
Matosinhos→Leixões	11	3.52	**3.52**	**100**
Leixões→Barcelona	1850	55.5	**55.5**	**975**
Barcelona→Valls	100.7	32.224	**32.2**	**100**

Tab. 23. Total emissions for Scenario 4

Results for Scenario Matosinhos (PT) — Setubal (PT)_S4										
Road	**Matosinhos - PT→ Setubal - PT S4**	**Distance (Km)**	**Cost (EUR)**	**Time (hour)**	**GHG CO_{2e} (WTW)**	**C02 emissions (WTW) (tons)**	**N0x (Kg)**	**SO2 ((kg)**	**N2O (kg)**	**PM (kg)**
		361	354.47	5	0.53	0.5	0.16	0.19	1.42	***0.029***
Results for Scenario Setubal (PT) — Sagunto (S)_S4										
Sea	**Setubal PT → Sagunto - S S4**	**Distance (Km)**	**Cost (EUR)**	**Time (hour)**	**GHG CO_2 (WTW)**	**C02 emissions (WTW) (tons)**	**N0x (Kg)**	**SO2 ((kg)**	**N2O (kg)**	**PM (kg)**
		1317	975	48	0.364	0.359	0.34	4.67	5.49	0.62
Results for Scenario Sagunto (S) — Barcelona (S)_S4										
Rail	**Sagunto -S → Barcelona - S S4**	**Distance (Km)**	**Cost (EUR)**	**Time (unit)**	**GHG CO_2 (WTW)**	**C02 emissions (WTW) (tons)**	**N0x (Kg)**	**SO2 ((kg)**	**N2O (kg)**	**PM (kg)**
		310	420	10	0.1	0.103	0.083	1.05	1.29	0.14
Results for Barcelona (S) — Valls (S)_S4										
Road	**Barcelona→Valls S S4**	**Distance (Km)**	**Cost (EUR)**	**Time (unit)**	**GHG CO_2 (WTW)**	**C02 emissions (WTW) (tons)**	**N0x (Kg)**	**SO2 ((kg)**	**N2O (kg)**	**PM (kg)**
		147	100	1.5	0.079	0.077	0.045	0.429	0.61	0.057

Tab. 24. Emissions for Scenario 4

Method 1						
	CO_2 (EUR)	N0x (EUR)	SO2 (EUR)	PM2.5 (EUR)	Cost of freight (EUR)	Total cost of emissions (EUR)
Matosinhos - PT→ Setubal - PT	2.5493	0.448	0.779	2.726	**354.47**	**6.50**
Setubal PT → Sagunto-S	1.75084	0.952	19.147	58.28	**975**	**80.12**
Sagunto-S → Barcelona-S	0.481	0.2324	4.305	7.524	**420**	**12.54**
Barcelona→Valls	0.37999	0.126	5.4483	5.358	**100**	**11.31**

Tab.25. Summary of the distance travelled vs costs of emissions by scenario S4

Method 2				
	Distance (Km)	Cost of emissions by scenario (EUR)	Total cost of emissions (EUR)	Cost of freight (EUR)
Matosinhos - PT→ Setubal-PT	361	115.52	**115.52**	**354.47**
Setubal PT → Sagunto-S	1317	39.51	**39.51**	**975**
Sagunto -S → Barcelona-S	310	114.7	**114.7**	**420**
Barcelona →Valls	147	4.41	**4.41**	**100**

those routes, and the distance travelled is very close. This supports the claim of environmental benefits when choosing sea shipping as a mode of transport.

In this scenario, different modes of transport were used, and Tables 24 and 25 summarise the total costs of emissions for each method. For the case of Method 1 (Table 24), for all considered routes, the costs of emissions are lower than the costs of freight, yet the results showed that sea transportation was considered as the mode with a higher cost of emission. This can be explained by the distance travelled, which means that for this scenario, if pollutants and their costs are considered, the possibility of using rail and road as the main alternatives for transporting goods may be considered.

Using Method 1 (Table 25), the route Matosinhos (PT) to Setubal (PT) had higher costs, followed by Setubal — Sagunto — Barcelona.

The results presented in this section aimed to assess and discuss the external costs of transportation, focusing on the environmental and social impact. The presented case summarises the impact caused during the transportation from Portugal to different countries. For most of them, companies should pay a price higher than the cost of transportation.

Since the demand for freight transport has been increasing worldwide, there is a need to develop initiatives to support transport companies in the process of decarbonisation. Nevertheless, several initiatives are ongoing. It is also important to highlight that companies cannot support the additional total external cost of emissions by themselves. Thus, this research brings together two approaches: the intermodality and calculation of the external cost of transportation as key elements to be considered by stakeholders, governments, and academics to draw attention to the negative impacts of transportation.

Conclusions

As an essential economic activity, freight transport experienced significant growth over the decades. However, questions should be asked regarding the impact of these activities on the environment and society. From this perspective, it is urgent to develop initiatives to support companies operating in this area, overcome these barriers, and operate in a greener and more sustainable way.

The work presented in the article aimed to bring together two main approaches that need to be better discussed to support logistics companies and stakeholders in the decarbonisation of the sector, i.e., intermodal transportation and the internalisation of the external transport costs. The proposed model is linked with the current literature that calls attention to the need to use intermodality in transportation as a key element to minimise the impact on the environment, as well as the importance of economically quantifying transportation costs.

The literature showed that intermodal transport is an option that supports companies in delivering goods and reducing their carbon footprint. This work used a case study to illustrate the role of intermodality in reducing CO2 emissions and contributing to sustainable transportation. Three routes were selected, and a furniture company was used as a case study to study four different scenarios.

The scenarios were analysed using the DHL Carbon Calculator platform to calculate the kilometres and the emitted CO2 content. The results determined the ideal scenario for each route. The evaluation of the remaining variables also allowed for the choice of the best scenario. For example, the cost of transport increases with the growth in the number of kilometres and if several types of transport modes

are combined. The evaluation of the remaining variables also allowed for conclusions regarding the choice of the best scenario.

It is important to highlight that the emissions are directly related to the load weight and the mileage travelled. This research draws attention to the importance of using the concept of intermodality as a particular and relevant strategy in supporting companies in the transition to a means of sustainable transport.

In this research, the model proposed to measure emissions was used due to the need for a comprehensive cost analysis to further assess the impact on the environment. Based on the results, a set of key policy measures were identified:

- Regarding the internalisation of the external cost emissions, the findings showed that for the selected scenarios, there is a different pollutant emitted during transportation, which means that the negative impact on human health and the environment is evident.
- Findings also indicate that considering the "user pays principle", these impacts should be paid. The results also indicate the total costs of emissions by route, which is higher than the value paid for the freight.
- The findings also suggest a better discussion and application of the presented method. It would be an important tool to disseminate the environmental and social concerns between freight transport companies.

For future works, some adjustments in the methods can be made, including an analysis of different routes. Regardless of the potential contribution of this research, some limitations need to be highlighted, such as the difficulty in assessing availability and schedules in the transport used and the need for a detailed economic cost analysis for different scenarios considering intermodality. Despite being a simple approach, the achieved results could offer an important lesson for companies, logistics operators, and local governments in developing strategies to support companies in the transition from unimodal to intermodal transportation.

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Investigating challenges and responses in supply chain management amid unforeseen events

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ABSTRACT

The emergence of increasingly complex global supply networks and the rising risk of unpredictable events may have far-reaching consequences for various industries and the global economy. The impact unpredictable events have on supply chains remains a relatively underexplored area that requires further research and analysis. Current studies primarily concentrate on singular events, particularly the COVID-19 pandemic and its effects on supply chains. This research aims to identify the main challenges in supply chain management resulting from unforeseen events and the actions taken in supply chains in response to them. The research is based on individual in-depth interviews conducted with a purposive sample of experts in supply chain management using a partially structured interview questionnaire. The research results were analysed using Nvivo v. 17.1, software for qualitative data analysis. A hybrid approach was employed for data coding. The research indicates several problems and the main remedial actions in supply chains in response to unforeseen events. Unforeseen events in the supply chain affect almost all supply chain operations: procurement, planning (including inventory planning and maintenance of company resources and production lines), logistics management (including transportation), and order management. The research indicated that cooperation, integration, and information exchange within the supply chain are crucial for effective responses to unforeseen events. Furthermore, the research highlighted the positive impact of unforeseen events on supply chain innovation. Moreover, there is an observed prevalence of intuitive management, particularly when responding to unexpected events. The research findings can serve as a basis for further discussions and studies on the potential impact and consequences of future unexpected events on supply chain resilience.

KEY WORDS

supply chain, unforeseen events, disruptions resilience, just-in-case, cooperation, information exchange, trust, demand, supply, framework agreements

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Introduction

Liberalisation of foreign trade, favourable conditions for foreign direct investments, and the dynamic development of transportation and information and communication technologies have significantly facilitated the creation of international supply chains. However, today's supply chains encounter numerous challenges, including uncertainty, rising operational costs, complexity, and susceptibility to disruptions (Núñez-Merino et al., 2020; Gatenholm & Halldorsson, 2022). Stone and Rahimifard (2018) emphasised

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that supply chains are increasingly confronted with growing variability and dependence on various factors, such as exchange rates, energy costs, and resource availability. The environment is also characterised by unpredictability, the overlap of different problems, the absence of straightforward cause-and-effect relationships, and ambiguity, all of which increase decision-making risks. These characteristics epitomise the VUCA environment (volatility, uncertainty, complexity, ambiguity) (Bennett & Lemoine, 2014). Today's environment can also be aptly described using the acronym BANI — brittle, anxious, nonlinear, and incomprehensible — (Cascio, 2020), portraying business conditions as unstable, chaotic, or entirely unpredictable.

Particularly difficult to predict are the consequences of so-called "black swan" events, which are unpredictable, large-scale occurrences with profound consequences when they occur (Makridakis & Taleb, 2009). An example of such an event is the COVID-19 pandemic, which began in 2019 and caused a shock to the global economy and an unprecedented impact on supply chains (Antipova, 2020; Weber, 2021). Most events, such as earthquakes, tsunamis, or wars, usually remain limited to specific countries or regions and have relatively short durations. The COVID-19 pandemic lasted for many months, and its end was difficult to predict. It affected over 210 countries and impacted supply chains in most industries, both on the demand and supply sides (Ali & Alharbi, 2020). Another instance of an unpredictable event is the Ukraine conflict, which substantially impacted global supply chains, particularly in energy, food, fertilisers, and raw materials, exacerbating the adverse effects caused by the pandemic.

Determining whether the COVID-19 pandemic and the Ukraine conflict can be accurately classified as "black swan" events is challenging, as pandemics and conflicts occur worldwide. However, they were undoubtedly unforeseen disruptions for which supply chains were unprepared, and the impact scale was vast, taking the world by surprise. According to Siegenfeld et al. (2020), COVID-19 proved to be a "black swan" event as nations were unaware of its impact on supply chains and how industries could operate during a pandemic outbreak.

With the emergence of increasingly complex and global supply networks, the risk of unpredictable events also rises, potentially resulting in far-reaching consequences for various industries and the global economy. The impact of unpredictable events on supply chains remains a relatively underexplored area and requires further research and analysis. The literature makes many references to the influence of disruptions on supply chains (Wilson, 2007; Oke & Gopalakrishnan, 2009; Hopp et al., 2012; Parast et al., 2019; Rajesh, 2021; Katsaliaki et al., 2022; Azam et al., 2023). Certain studies explore the consequences of unforeseen events on supply chains (Pettit et al., 2010; Ong et al., 2015). However, current studies primarily concentrate on singular events, particularly the COVID-19 pandemic, and its effects on supply chains (Remko, 2020; Kumar et al., 2020; Chowdhury et al., 2021; Ketudat & Jeenanunta, 2021; Singh et al., 2021; Raj et al., 2022; Pujawan & Bah, 2023).

Research lacks pinpointing the main challenges in supply chain management resulting from unforeseen events and responsive actions within supply chains. Thus, the research question is: What are the primary areas of supply chain management affected by unforeseen events which are unpredictable, of considerable scale, and have significant consequences, and what general actions are undertaken within supply chains in response to these events?

The study draws upon insights from in-depth individual interviews (IDIs) with experts in supply chain management. The research findings were rigorously analysed using NVivo v. 17.1, a qualitative data analysis software.

The article presents the issue of unforeseen events' impact on the resilience of the supply chains, using the COVID-19 pandemic and the Russia–Ukraine war as examples. It describes the methodology and results of the conducted qualitative research and recognises the main problems in supply chain management that result from unforeseen events and actions taken in response. The article closes with conclusions and recommendations for further research.

1. Research background

1.1. Unforeseen events and supply chain resilience

Unforeseen events (unexpected events, emergencies, or uncertainties) are disruptions that are challenging to predict and forecast and that significantly impact supply chains. Such events encompass war, epidemic, terrorism or ecological disaster. The recent surge in unforeseen events and their profound influence on supply chain operations has increased con-

cerns about risk and resilience. Supply chain resilience is defined as the ability of a supply chain to prepare for and respond to disruptions (Hussain et al., 2023). The term "resilience" is derived from the Latin word "resiliens", meaning "to bounce back" or "to rebound", and it refers to the ability to quickly recover or restore equilibrium following a period of instability. Disruptions within the supply chain pose a threat to the normal execution of business operations in the affected enterprises within the supply chain (Konecka, 2015). Resilience plays a pivotal role in effectively mitigating risks and enables swift and efficient restoration of regular operations, sometimes resulting in improved outcomes even after a disruption (Yu et al., 2022).

The concept of supply chain resilience combines the principles of supply chain risk management (SCRM) and business continuity management (BCM) (Wieteska, 2019). Supply chain risk management focuses on anticipating threats, assessing risks, and employing various methods to reduce the likelihood of disruptions in the supply chain's operations and minimise the consequences of unplanned events (Hafiani et al., 2021). While supply chain risk management aims to identify and gain control over risks to limit their impact, supply chain resilience is an adaptive capability designed for addressing unexpected events and responding to them. Supply chain resilience can be assessed across three phases: readiness for the potential disruptions/risks, their response to such events, and the restoration to the pre-risk operating state (Ali et al., 2022).

Several factors influence supply chain resilience, including the coordination and streamlining of processes throughout supply chain links, collaboration, agility, and awareness of the risks present in the supply chain (Christopher & Peck, 2004). Supply chain risk management and the unpredictability of disruptions are interconnected issues, yet SCRM alone is insufficient for dealing with unexpected events (Olivares-Aguila & Vital-Soto, 2021).

Business continuity management (BCM) encompasses a set of principles, standards, and tools designed to underpin the safeguarding of an organisation's critical functions and processes essential for maintaining operational continuity in the face of disruptions (Suresh et al., 2020). BCM's objective is to enhance the supply chain resilience against potential threats and enable it to sustain operations even under highly unfavourable events. In contrast to the conventional risk management approach, BCM typically concentrates on events characterised by high propagation of disruptions and low likelihood of occurrence, leaving decision-makers with very little time to react and take appropriate actions. Business continuity management predominantly relies on risk analysis and crisis management, particularly in scenarios involving the loss of critical resources (Wieteska, 2019).

1.2. Impact of unforeseen events on supply chains

1.2.1. Example of the COVID-19 pandemic

The first case of SARS-CoV-2 infection likely appeared in early November 2019 in China. The first infections outside China were reported in January 2020 in Thailand and subsequently spread to the USA and Europe. As of the end of April 2023, the WHO reported nearly 763 million confirmed cases of COVID-19, with nearly seven million fatalities (WHO, 2023).

The global crisis caused by COVID-19 profoundly impacted nearly every sector of the global economy (Sebaa & Slimane, 2022). The crisis led to a negative demand shock due to consumer concerns and a supply shock caused by border closures, business disruptions, and disruptions in supply chains. A notable surge in demand occurred for essential products and services, particularly food. Additionally, the demand for medical products, including masks, gloves, face shields, and medical equipment, such as ventilators, experienced a significant increase. In the initial phase of the pandemic, most major economies around the world implemented nationwide lockdowns. Restrictions in many cities, along with limited availability of workforce, raw materials, and consumables, resulted in the shutdown or suspension of production capacity in nearly all sectors of the economy (Sridhar et al., 2022).

The pandemic also disrupted transportation connections and impeded the flow of goods between suppliers, manufacturers, and customers (Kumar et al., 2020; Kuźmicz, 2022). Uncertainty in demand and supply, including price and volume volatility, shortages of materials for production, and delays in goods deliveries, seriously disrupted the availability and delivery of a wide range of raw materials, materials, semi-finished goods, and finished products. As Xu et al. (2020) highlighted, the COVID-19 pandemic caused disruptions in most global supply chains, especially in the pharmaceutical, food, electronics, and automotive industries. According to a Fortune

Report (2020), 94% of Fortune 1000 companies experienced supply chain disruptions due to the pandemic.

The pandemic has also prompted questions regarding the costs and benefits of operating global supply chains. COVID-19, by significantly slowing down the global economy, has triggered irreversible changes, which in turn have created new challenges for global supply chains (Jackson et al., 2021). Global supply chains, which have demonstrated a high level of resilience to various disruptions in recent decades, now confront novel and unprecedented challenges (Blessley & Mudambi, 2022). According to Raj et al. (2022), the repercussions of the SARS-CoV-2 virus significantly impacted various facets of international logistics enterprises, with the primary focus on production processes, material management, transportation, and distribution. Meanwhile, studies conducted by Chowdhury et al. (2021) indicate the impact of the COVID-19 pandemic across different areas of supply chains, including demand management, supply management, production management, transportation and logistics management, relationship management, overall supply chain impact (affecting operations up and down the supply chain), financial management, and sustainable development management. The main disruptions identified include (Chowdhury et al., 2021; Remko, 2020):

- surges in demand for essential goods, shortages of these products, delivery delays, and decreased demand for other products;
- supply shocks, materials and components shortages, forecasting difficulties, supply disruptions, a lack of preparedness for disruptions, and limited use of existing contingency plans and crisis management;
- disruptions and delays in production, reduced production capacity, labour shortages;
- transportation and distribution delays, restrictions on international trade/transportation, loss or lack of physical goods distribution, changes in distribution methods (e.g., shifting from offline to online channels or introducing mixed distribution channels);
- limited social contacts, uncertainties in information flow, lack of supplier engagement, or opportunistic behaviour;
- domino effect, i.e., the impact of problems occurring in one part of the supply chain on other operations, supply chain disruptions, facility closures, including production plants;
- decreased financial performance of supply chains (e.g., losses, reduced financial stability), decreased financial flows, and asset freeze;
- reduced focus on social and environmental issues, limited practices and sustainable development initiatives within supply chains, threats to the health and safety of workers, less interest in the development of green and low-emission energy sources, and an increase in waste and materials suitable for recycling.

1.2.2. Example of the Russia–Ukraine conflict

The war in Ukraine is another event that was challenging to foresee. The repercussions of this event, including economic sanctions (primarily affecting the financial sector, real estate, and the import and export of various products and services) imposed on Russia, the withdrawal of numerous companies from both the Russian and Ukrainian markets, the reduction or limitation of energy supplies from Russia, fuelling global inflation, and transportation restrictions (including those resulting from sanctions imposed on Belarus supporting the Russian regime) have had a notable impact on global supply chains, further intensified the negative effects caused by the pandemic. For instance, economic forecasts suggest that economic sanctions could potentially lead to a reduction of up to 50% in Russian imports from Europe and the United States (Liadze et al., 2023).

The armed conflict in Ukraine has predominantly impacted the supplies of energy, food, fertilisers, and raw materials. Russia is one of the world's largest crude oil producers and energy exporters. The European market was significantly dependent on Russian energy sources, including coal, crude oil, and natural gas, with approximately one-quarter of crude oil imports and almost half of natural gas imports to the EU originating from Russia (some countries, like Germany and Italy, were even more reliant on Russian energy supplies). Disrupted supply chains have led to a substantial surge in energy prices, affecting the functioning of supply chains across various industries.

Ukraine and Russia were responsible for approximately 30% of the world's wheat and barley exports, 15% of corn, and a remarkable 65% of sunflower oil (White et al., 2022). Prior to the conflict, around 6

million tons of agricultural goods were exported monthly from Ukrainian Black Sea ports (Dyson et al., 2023). Presently, the scarcity of these products is impacting food security, especially in poorer countries in the Middle East, North Africa, and Western and Central Asia (Jagtap et al., 2022). Additionally, Ukraine and Russia represented roughly one-third of the world's ammonia and potassium exports, resulting in price increases for agricultural fertilisers. Both countries also played significant roles as suppliers of titanium, nickel, palladium, platinum, steel, and other essential metals, the shortages of which affected the automobile, smartphone, and aircraft manufacturing industries (Liadze et al., 2023). The challenges faced by these industries also led to increased defence spending in many countries and growing demands from the defence industry.

The war in Ukraine has triggered shifts in demand. In countries like Poland, which received the largest number of war refugees from Ukraine, the onset of the conflict led to an upsurge in demand for essential products. Also, shortages were observed for other products, such as sleeping bags, flashlights and power generators. On the other hand, the heightened global inflation has made customers more inclined to save, resulting in decreased demand for many products.

1.3. Actions taken in the supply chain in response to unforeseen events

1.3.1. Shortening the supply chains

The crisis triggered by such unforeseen events as the COVID-19 pandemic and the war in Ukraine emphasised the importance of supply chain resilience (Rajesh, 2021; Pujawan & Bah, 2023). Many companies, with their lean production and complex global supply networks, faced challenges and had to respond to disruptions. Among the shifts in supply chain management, a prevalent response has been the endeavour to shorten supply chains as a response to seek production sources closer to the market and reduce the operational risk of losing critical resources or control over them (Nandi et al., 2021; Chen et al., 2022).

Insourcing, backshoring, and nearshoring strategies emerged because of rethinking supply chain and production approaches. Insourcing involves utilising an organisation's internal resources to perform tasks that were previously outsourced to external parties (Cabral et al., 2014). Backshoring entails bringing back production and services, primarily offshored for cost reduction, to the country of origin (Foerstl et al., 2016). Despite higher labour costs, backshoring offers increased quality control and supply chain flexibility. In contrast, nearshoring involves relocating production and services to geographically closer locations, such as countries much closer to the market (Foerstl et al., 2016). Nearshoring reduces transportation costs and time while minimising cultural barriers.

Another response to the possibility of unforeseen events is friendshoring, which entails collaborating with countries that align with norms and values governing global operations (Paché, 2022). As organisations seek ways to mitigate supply chain risks, further production relocations are expected in the coming years. For example, countries like the United States, Japan, and Europe are decreasing their dependence on the Chinese manufacturing sector (Kearney Report, 2021).

However, it is important to note that these strategies can also carry inherent risks. Sheffi (2020) underscored that relying solely on domestic production to meet domestic demand may not be viable if production is halted due to pandemic restrictions or other disruptions, potentially leading to the collapse of the domestic economy.

1.3.2. Supply source diversification and regionalisation

On the other hand, as indicated by Lopes et al. (2022), companies are diversifying their sources of supply and markets to mitigate disruptions. This often entails increasing the number of links in supply chains. In response to supplier challenges, companies adopt the strategy of "dual sourcing", which involves sourcing from multiple suppliers (Namdar, 2018). This allows them to have alternative primary component suppliers, often from different countries, to ensure a steady supply of the required components. According to Sheffi (2020), diversification is a practical solution only for large, highly internationalised companies with extensive supply chain networks, and it may not be as suitable for small and medium-sized enterprises due to increased administrative costs and a shift in the management model.

Verheijen (2022) identifies regionalisation as one of the strategies for reducing supply chain risks. This strategy involves multinational corporations creating multiple distinct supply chains, such as one in Europe, one in China, one in North America, and one in Southeast Asia. This approach enables the considera-

tion of sourcing from nearby and local suppliers, reduces dependence on a single supplier, and broadens the geographic scope of raw material sourcing.

1.3.3. Just-in-Case inventory management

Certainly, in uncertain times, the approach to inventory management is also evolving. Companies are primarily increasing safety stock (Remko, 2020). Companies' approaches are shifting from the concept of just-in-time inventory management to the just-in-case approach. This means that organisations diversify suppliers, even at the cost of higher prices for purchased goods and maintain a certain level of inventory to safeguard against unexpected production stoppages due to disruptions in the supply of components. This shift emphasises a balance between efficiency and resilience.

1.3.4. Openness to innovation and greater flexibility

Unforeseen events give rise to various disruptions in supply chains, but they can also yield positive effects on resilience-building initiatives and risk management in global supply chains (Ozdemir et al., 2022). As Rozhkov et al. (2022) demonstrated, the multitude of factors influencing disruptions in global supply chains allows for greater flexibility in seeking new preventive solutions for future disruptions. An openness to innovation and proactive risk management efforts fosters the development of supply chain resilience. Innovation and knowledge, according to Orlando et al. (2022), are regarded as driving forces in establishing supply chain resilience to disruptions, directly impacting the ability to counteract disruptions.

While events such as COVID-19 and the armed conflict in Ukraine have revealed that the risks associated with supply chain fragmentation and globalisation were inadequately estimated and largely ignored (Maternowska, 2021), they have also accelerated the development and adaptation of various technologies and practices that may ultimately enhance the stability and resilience of supply chains in the face of future disruptions. These changes aim to achieve greater supply chain flexibility and agility, enabling the production of smaller quantities of products in shorter cycles, often with a focus on mass customisation (Perret et al., 2022). Oliveira-Dias et al. (2022) also underscore the need to shorten product development cycles in a dynamic environment. According to the authors, this is partially achievable due to the reduced significance of constraints like the geographical distance that separates supply chain partners. The pandemic has revealed that personal contact can be replaced by online meetings. Technological platforms facilitate easier access to necessary resources or services and the offering of unique resources to other organisations, such as know-how and non-material resources, that are difficult or impossible to replicate (Faro, 2022).

Concepts like Open Supply Chain Management (OSCM) are seen as a new paradigm in the evolution of supply chain management, where companies can leverage integrated physical and conceptual resources to promote efficiency and flexibility in key supply chain processes. These processes encompass procurement and delivery, production, distribution, and marketing. The OSCM concept incorporates trends, such as crowdsourcing, open innovation, Industry 4.0, cloud manufacturing, the Internet of Things (IoT), Big Data, and Digital Twin, which have emerged in recent decades and offer opportunities for building more resilient supply chains (Xiong et al., 2021; Rahmanzadeh at al., 2022). Pisz (2021) highlights the significant increase in innovation and progress in the digitisation processes of enterprises as a positive outcome of the pandemic on supply chains. Digitalisation and fast, reliable global connectivity enhance the flexibility and efficiency of supply chains, directly influencing how companies must address disrupted supply, fluctuating demand, excess inventory, and the exploration of long-term, global opportunities and distant markets for both sourcing and selling.

1.3.5. Improved connectivity, greater visibility and transparency

According to Modgil et al. (2022), recent events have accelerated many developmental trends in supply chains, focusing on enhancing connectivity between different supply chain links. Greater visibility and transparency across the entire supply chain have become even more critical. For example, during COVID-19, Rohlig Suus Logistics based its supply chain risk management and resilience-building efforts on actions related to monitoring and analysing the market situation and identifying new opportunities. In response to supply chain continuity challenges, Rohlig Suus implemented a Control Tower (CT) service for proactive supply chain management.

The Control Tower function allowed for the monitoring of the entire flow of goods and improved communication with customers, providing them with notifications of potential threats, such as delivery delays or other ongoing issues that could affect order fulfilment. The accuracy and timeliness of the acquired information empowered supply chain managers to make swift and well-informed decisions during crisis situations (Gumel, 2021).

1.3.6. Development of sustainability and viability

A positive aspect may also involve the development of Sustainable Supply Chains (SSCM). Shifting suppliers to local factories or those relocating from the Far East to Europe reduces transportation routes for raw materials, components, semi-finished products, and finished goods from production sites to consumption locations. This, in turn, directly leads to reduced CO2 emissions and positively impacts supply chain costs (Milewska, 2022).

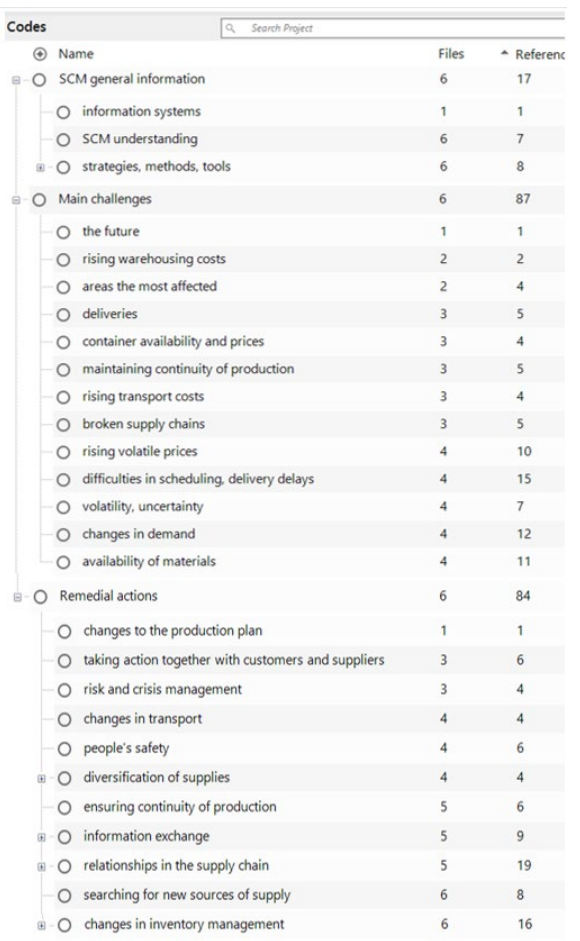
The ability of a supply chain to endure and adapt in a changing environment through redesign of its structure and re-evaluation of logistics processes from a long-term perspective is known as viability (Ivanov, 2020). Viability is considered a fundamental property of supply chains, encompassing three perspectives: agility, resilience, and sustainable development.

The core principles of the Viable Supply Chain (VSC) model are built on the development of adaptive mechanisms. Viable supply chains respond with agility to events and demonstrate the ability to survive short-term and long-term disruptions and global shocks related to social and economic transformations. The Viable Supply Chain model can assist companies in making decisions regarding the repair and reconstruction of supply chains after global, long-term crises (Joshi & Sharma, 2022).

2. Research methodology

The objective of this article is to identify the key issues in supply chain management that arise from unforeseen events and to examine the response actions. The research is grounded in qualitative method (individual in-depth interviews). This approach is employed to gain a comprehensive understanding of new or previously unexplored phenomena in all their diversity and complexity (Maison, 2019). The interviews were conducted from 1 May 2022 to 9 June 2022, with a purposive sample of six experts who possessed at least several years of experience in supply chain management and represented different industries. The respondents were affiliated with companies with over 49 employees in the FMCG, sanitary-heating, automotive, agriculture machinery, and furniture sectors (Table 1).

On average, each interview lasted approximately 60 minutes. The research findings were analysed using Nvivo v. 17.1, qualitative data analysis software. The data underwent a coding process that utilised a hybrid approach, combining both deductive and inductive approaches. Deductive coding involves applying a predetermined set of labels (codes) based on literature or theory, while inductive coding involves assigning labels to the data based on recurring patterns, themes, and issues observed in the data. In the hybrid approach, the predefined code structure was complemented based on the analysis of the collected data. In total, 28 codes were applied and


Codes — Search Project

Name	Files	Referenc
SCM general information	6	17
information systems	1	1
SCM understanding	6	7
strategies, methods, tools	6	8
Main challenges	6	87
the future	1	1
rising warehousing costs	2	2
areas the most affected	2	4
deliveries	3	5
container availability and prices	3	4
maintaining continuity of production	3	5
rising transport costs	3	4
broken supply chains	3	5
rising volatile prices	4	10
difficulties in scheduling, delivery delays	4	15
volatility, uncertainty	4	7
changes in demand	4	12
availability of materials	4	11
Remedial actions	6	84
changes to the production plan	1	1
taking action together with customers and suppliers	3	6
risk and crisis management	3	4
changes in transport	4	4
people's safety	4	6
diversification of supplies	4	4
ensuring continuity of production	5	6
information exchange	5	9
relationships in the supply chain	5	19
searching for new sources of supply	6	8
changes in inventory management	6	16

Fig. 1. Data coding in the NVivo software

Tab. 1. Description of experts

Expert information	Company	Main areas of activity	Company's description
Expert 1 Brand Manager for CE region; 5–10 years of experience	A	FMCG, production of soap, cosmetics and detergents, washing and cleaning agents	One of the largest companies in the world selling 40 product categories in over 180 countries around the world. It operates 60 factories worldwide and employs nearly 180,000 employees
Expert 2 Head of the supply department; 25–30 years of experience	B	Production of home and institutional furniture	One of the largest manufacturers of metal furniture in Europe with over 30 years of experience. It currently employs over 600 people and produces approximately 280,000 products annually, with a total sales value of around PLN 200 million, 70% of which is exported worldwide
Expert 3 Branch Manager; 25–30 years of experience	C	Sale of cars and car parts	An importer and distributor of spare parts for passenger cars, vans and trucks in Central and Eastern Europe. It has 338 branches in Europe (Czech Republic, Slovakia, Ukraine, Lithuania, Latvia, Hungary, Croatia, Romania, and Bulgaria) and offers over a million different spare parts for passenger cars and trucks
Expert 4 Sales Department Manager; 15–20 years of experience	D	Engineering services, semiconductor and renewable energy production	Leading manufacturer of battery systems for public transport, AGV, and ESS for energy and telecommunication. It sells its products and services around the world, including Europe, North America, and Asia
Expert 5 Manager in Purchasing and Logistics Department; 5–10 years of experience	E	Production of agricultural, construction and mining machines	A Polish manufacturer of trailers, agricultural, grassland, municipal and recycling machines, as well as disc wheels. It has nine production plants and its own steel wholesaler. It has a dealer network in all European Union countries and cooperates with partners in Asia, Africa, North America, South America and Australia. It has 3000 employees
Expert 6 Head of Purchasing Department; 25–30 years of experience	F	Production of plastic products (water and heating systems)	An experienced manufacturer of modern KAN-therm installation systems recognised worldwide. It employs over 1100 people. Has a branch network in Poland and subsidiaries in Germany, Hungary, Ukraine, the UAE, India, China, and the CIS countries. The products are exported to 68 countries around the world. The distribution chain covers Europe and a significant part of Asia, Africa and America

organised into two primary thematic categories: (1) challenges in supply chain management when unforeseen events occur and (2) actions taken to address the challenges (Fig. 1).

3. Findings

3.1. Main challenges in supply chain management resulting from the occurrence of unforeseen events

The qualitative research participants cited several examples of recent events that have had an impact on supply chain management, including factors like inflation, the war in Ukraine, the COVID-19 pandemic, and disruptions in the Suez Canal, such as the blockage caused by the container ship Ever Given in March 2021. One participant noted, "Rising inflation, the war in Ukraine, the pandemic, and a blocked canal are things that few people would have expected a few years ago".

The respondents observed that areas in the supply chain directly affected by such events include transportation management, demand, and supply, while production and inventory management are indirectly impacted. Experts emphasised that many of these issues were primarily a result of "the pursuit of cost reduction without consideration of risk and the extension of supply chains to seek low prices far beyond the country's borders".

3.1.1. Disruptions, delays and allocations in supply

The occurrence of unforeseen events primarily results in disruptions, delays, unavailability, or limited availability of certain goods, materials, and raw materials. One expert explained, "In our company, the most significant issue is the highly dynamic changes in component availability in the market.

Depending on the products, lead times have sometimes extended by up to six months for advanced technologies".

Availability issues mainly stemmed from periodic factory and port closures during the pandemic. An expert shared, "Ports in China are constantly opening and closing, even with a few infection cases. It's a huge ordeal for us. For instance, when an American company that manufactures a component in Europe sends it to China, produces it there, and then sends it back to Europe, the supply chain becomes long (...). It's important for us to run a trial production of this [product], but unfortunately, it is not as smooth as it used to be. These are the effects of COVID-19 and the lockdown in Shanghai".

The limited availability of goods, materials, and raw materials led manufacturers to introduce allocations, creating challenges in supply planning and inventory management. One respondent noted, "We have lead times, but they are often postponed or changed, and the quantity received is not as ordered. It's much more complicated than it used to be". Another added, "Before, our supply chains were intact, and we could plan deliveries freely from week to week, from month to month, with deliveries at any time. Today, it's all on the go. We spend the entire Monday and three hours of each subsequent day trying to save production continuity and putting out fires". This problem affected every supply chain to a greater or lesser extent. According to the respondents, there were hardly any products, materials, or components that did not encounter problems in the last two years.

3.1.2. Price increases

The limited availability of goods led to price increases, with one expert stating, "Increased demand for products manufactured in Asia led to reduced availability of components in the market, resulting in higher prices". Respondents suggested that these price hikes could also be attributed to deliberate manufacturers' policies. One expert explained, "Raw materials availability is poor, and there are allocations for most raw materials. Due to high demand, manufacturers of less common plastics, for instance, introduce allocations, meaning monthly quantities are much smaller than market demand. This is partly a strategy to raise prices. Why operate four additional production lines when you can increase the prices fourfold and sell the same quantities at higher prices?". Furthermore, it was noted that large, global organisations involved in crude oil processing for plastics achieved historic profits. As a result of these challenges, companies were compelled to search for new supply sources, often at higher procurement costs. One expert shared, "There were instances where, a week before an expected delivery, it turns out that a particular product couldn't be shipped, and we had to hastily find alternatives. Even if the price in Poland was five times higher, we had no choice but to accept it".

3.1.3. Lower availability and higher transportation cost

Another challenge is transportation planning due to restrictions on movement or safety concerns (e.g., during wartime) and, as a result, reduced availability of transportation infrastructure and even multiple increases in all modes of transport costs. One expert stated, "When it comes to transportation management, since the start of COVID-19, we have seen a decrease in the number of available drivers and transport costs have surged. Container prices have skyrocketed tenfold. [The problem is also] reduced tracking or planning of deliveries because a container from China can take various routes. [...] It is not uncommon for a later shipment to arrive earlier than an earlier planned one". The expert further added, "There were also instances when we wanted to ship by air, and there were no planes [available] because everyone wanted to ship by air. (...) The significant difference was that everyone wanted to get the products from China right now". Additionally, there were fluctuations in freight prices. One expert noted, "These fluctuations occurred every half a month, every week, and every two weeks. Forwarders were reluctant to provide specific freight amounts, making it somewhat of a mystery regarding what the final costs would be".

The disruptions extended to other modes of transportation as well, with one expert mentioning, "We used trains for certain materials from Asia, but at the moment, due to the war, train transport became unavailable. Broken supply chains meant that we had to accept huge costs to bring in a few pallets of goods by air". In maritime transportation, issues included a shortage of available containers and loading equipment, slow container rotation, container rolling (which extended the loading and sailing time of containers compared to the previously established schedules), blank sailing (where vessels deviated from set schedules and skipped certain ports), and extended waiting times for goods in ports and during customs processing. One expert shared, "There were situations

where the goods were ready, but they had to be transported to the nearby warehouse, and we had to wait for a week or even two before they were loaded onto the ship". Another added, "In some cases, ships had to undergo quarantine and wait on the water for two weeks after COVID-19 tests were conducted before entering the port". The issues were exacerbated by carrier alliances, with another expert noting, "Problems like the lack of available containers and loading equipment were compounded by carrier alliances, who frequently raised prices and revised them every two weeks".

3.1.4. Difficulties in inventory management

Another challenge is the rising costs associated with maintaining inventory, coupled with capital freezing due to increased warehousing requirements. Respondents shared that companies adopted strategies to manage these issues, "At this moment, we grab onto everything, particularly higher inventory levels. We try to convince our suppliers to maintain larger stocks if possible. We also rent additional warehouses and increase our inventory levels to ensure a longer security period compared to before". The necessity of building up inventory levels to address these challenges was further emphasised. An expert noted, "We have minimum stock levels for every raw material, and this stock is automatically increased because if a product comprises, let's say, ten or a hundred components, and one is missing, we cannot start production. Due to various reasons, like COVID-19, war, and other things".

However, despite efforts to increase inventory, many companies still struggle to meet customer demands. One expert described the situation, saying, "We are trying to catch up with the rabbit. Currently, we are fulfilling customer orders that were placed several months ago. There is such high demand and limited raw materials supply that, despite increasing production by thirty per cent, we are unable to produce the required quantity and meet our customers' needs for certain products".

3.1.5. Demand fluctuations

Unforeseen events also lead to significant fluctuations in demand. Both the outbreak of the pandemic and the war in Ukraine led to a tremendous surge in demand for essential goods. The research respondents pointed out that customers themselves were responsible for shortages of products in stores as they made panic purchases in bulk, "There was a huge surge in purchasing hygiene products. People were hoarding baby diapers, toilet paper, etc. because they feared shortages in stores, which was completely untrue in our situation". In the case of industries like construction, the increase in demand during the pandemic was related to the rising demand for properties and securing themselves against potential shortages and further anticipated increases in the prices of raw materials and materials. One respondent explained, "Our industry is closely tied to the construction industry. There was a time when our customers were buying pipes and connectors in large quantities; there was a general belief that everything would run out". On the other hand, the outbreak of armed conflict in Ukraine accelerated inflation and led to a collapse in the mortgage market and a decline in demand for real estate.

The increased but temporary demand also caused problems for some manufacturers who experienced the cancellation of previously placed orders. This was also influenced by fluctuations in raw material prices. As mentioned by an expert, "Everyone placed large orders. When everyone orders a surplus of goods, there will be a lot of unsold inventory in the market. Customers will cancel their orders, and when production capacities are reserved in factories and components are already ordered, each producer will lower the price. When we produce a product with more expensive steel, but the price of steel is continuously dropping, soon we will have to sell it at the new price, even if it means selling below production costs. It can be a dangerous situation".

A positive aspect revealed in the research is the change in some customers' habits and their choice of new, previously unchosen products. A respondent noted, "People had the opportunity to try out some products that used to stay on the shelf, and they found them acceptable. Even though they hadn't used them before, they later discovered that these products were fine".

3.1.6. Growing uncertainty and ambiguity

According to experts, today's businesses confront an array of challenges that are more intricate. These challenges encompass the constant increase in customer demands coupled with a decrease in customer loyalty, shifts in the power dynamics within the supply chain, and social and environmental issues. The

escalating influence of technological innovations compounds these challenges. One expert observed, "In my work, I notice that every eight minutes, some supplier declares bankruptcy […]. Customers are becoming more demanding and less loyal. Forecasting and planning supply chain processes are becoming increasingly difficult, and the growing number of suppliers at different levels and changes in the supply chain's power structure is leading to fewer yet more dominant suppliers and clients. Social and environmental challenges are further contributing to the chaos in the supply chain. I believe that the rapidly growing role of technological innovations also significantly influences these dynamics".

The use of the crisis as a justification for disruptions exacerbates planning difficulties, even if it isn't the root cause, with another expert noting, "Today, everyone can cite force majeure, leading to varying consequences".

3.1.7. Diminished significance of conventional supply chain management methods and tools

According to the respondents, the primary objective of supply chain management is to seek opportunities for improving customer satisfaction, cost reduction, and enhancing performance achieved by the supply chain, and this objective does not change when events occur unforeseen "Supply chain management is, regardless of time and circumstances, about seeking the greatest cost reduction ensuring that we meet customer needs at a level that satisfies them. I would describe it as a living organism that is continually evolving". The experts emphasised that managing the flow of materials and services between businesses is the most critical aspect of supply chain management. This encompasses the planning, execution, and control of supply chain flows, as well as the identification of areas where issues may arise and the ability to respond promptly to disruptions in the supply chains. Managing information and financial flows also plays a significant role.

The research experts indicated that their companies use supply chain process management methods and tools such as Just in Time, Vendor Managed Inventory, Product Lifecycle Management, Lean Management, and Total Quality Management. However, the significance of these well-known supply chain process management methods was emphasised to have diminished during the COVID-19 pandemic. One expert mentioned, "When we consider the impact of COVID-19, I suspect that any mistakes [in supply chain management] today mean much less. It's just about having that product. Essentially, price is already secondary, so each of these tools loses some value. We simply need to use all possible means to have the product available and the inventory as large as possible".

3.2. Identification of actions taken in the supply chain in response to unforeseen events

3.2.1. Increased safety stocks

The respondents in the study frequently mentioned increasing safety stock as a response to disruptions caused by unforeseen events affecting the supply chain. Safety stocks served as a safeguard against unexpected changes in product demand or delays in the delivery of raw materials and production materials. As indicated by the respondents, for example, during the COVID-19 pandemic, the safety stock levels were raised and remained at a higher level for an extended period. Companies attempted to boost their inventory wherever possible, creating a buffer: "Companies built warehouse stocks to cover a year's production, especially for components with long lead times". Safety stocks were adjusted based on market conditions, and ongoing monitoring of product and raw material availability was necessary.

The creation of larger safety stocks contributed to the reduced availability of materials and raw materials in the market, leading to an increase in their prices. However, businesses were willing to bear the high costs of building and maintaining these inventories to ensure continuity of production and sales. The respondents observed, "The planning department had to adjust its indicators for inventory management, and companies accepted additional costs such as renting extra warehouses and doubling the value of inventory to increase safety stocks. Such practices became commonplace".

Safety stocks were increased both in companies and among their suppliers. Suppliers stocked up raw materials with larger safety stocks than before, incurring additional costs. Nevertheless, this enabled them to deliver products, and companies could maintain a smooth flow in the supply chain. In experts' opinion, "At this point, one grabs everything, especially the appropriate stock levels". Companies worked on persuading their suppliers to also keep larger stocks: "It is necessary to plan long-term demand for compo-

nents, purchase larger quantities of components, and store them in our company or in the warehouses of our suppliers"; "[Suppliers] were ordering raw materials, creating larger safety stocks, much higher than before, which, of course, came at a cost. However, thanks to this, they were able to deliver the product to us, and after some time, we were able to ensure a smooth supply chain, even in the case of semi-finished products that did not come from us but from suppliers. These semi-finished products were then made in China and stored in Europe".

3.2.2. Framework agreements with suppliers

Enterprises also began to sign framework agreements with suppliers more frequently than before, giving them greater influence over prices and delivery volumes. According to the respondents, "If the material is available, there is no need to conclude framework contracts. It's a convenience in a way, but it didn't have the added value it has today. Today, these agreements allow us to negotiate better prices and certainly help suppliers plan their production or supply of raw materials better, whether to us or the supplier".

Therefore, the question arose about the passing on of costs to the producing company. One expert stated, "I believe these costs were certainly passed on to us, but in the situation of maintaining continuity of supply, it was not a problem. At least we could sell something to the client; without these agreements, we would not have been able to sell anything. I think this cost is fixed in the framework contracts with the suppliers".

3.2.3. Choice of alternative modes of transport

Companies also explore alternative transport methods, choosing to change their mode of transport, opting for pricier yet faster solutions, and prioritising deliveries. For instance, respondents note, "When there were delays in smaller ports, sometimes lasting up to two weeks, we sought the fastest route. In situations where we received an order from the factory for ten containers of goods that were ready, we significantly adjusted our approach. We prioritised two to four of these containers, which were required immediately, and arranged for them to be shipped via the intermediate port in Hamburg. Ships from Asia sail thirty days, and from India, where we import the most, sail even forty days. In such scenarios, we had to explore alternatives. We considered intermodal transportation as an option. Eventually, we chose to transport by sea, followed by land transportation via trucks, bypassing the rail system due to inconsistencies in scheduling. This approach proved successful at the time, but we primarily utilised it for priority situations, even though it incurred an additional cost of one and a half times". Another expert describes, "We previously used trains for some materials imported from Asia, but the train service is currently unavailable due to the war. As a result, all shipments are being sent by sea or air, albeit at considerably higher costs".

3.2.4. Diversification of suppliers and supply chain shortening

To ensure a continuous supply, companies also took action, such as establishing connections with new suppliers and diversifying their supplier base. One respondent mentioned that they "Expanded their collaboration with new suppliers within the industry, even those serving competitive companies", another explained, "We scoured the globe for missing components", and yet another emphasised that they "aimed to have at least two suppliers for each raw material or semi-finished product. While this practice was routine, it gained much more importance today". The majority of companies sought alternative supply sources within regional and local markets. For instance, one respondent stated, "When we place orders from Korea, we don't solely rely on Korean suppliers because we understand that delivery times can vary. We also engage with local (I mean European) suppliers"; another noted, "Nowadays, we actively seek products on the Polish market"; and a third explained, "Our backup plan involved securing deliveries from Poland, especially for crucial components or custom-made items, which we could obtain within a week".

The respondents also mentioned actions such as making changes to the production plan to account for missing components and delayed deliveries. To a lesser extent, they discussed phenomena like backshoring. One respondent stated, "From my perspective, the only positive aspect was the relocation of some production from China to Poland and Europe". This could be attributed to the fact that these strategies are implemented over a more extended period. As one respondent explained, "Relocating factories is a complex endeavour. It involved diversifying the supplier portfolio and seeking suppliers of these raw

materials, often at a higher cost but closer. The majority of our products have factories in Europe, but they rely on various semi-finished products sourced from China, Pakistan, etc. Now, it's a two-year process, with some factories in other countries reintroducing these semi-finished products formerly produced in China. We also identified suppliers capable of meeting our quality standards. While the new ones are more expensive, their proximity to Europe allows for faster delivery".

One positive effect highlighted by experts is the increased innovation and the search for solutions that might not have been explored in a stable situation. As one expert put it, "Today, we are certainly opening more doors because we are forced to. For example, a certain type of granulate was not supplied to Europe, and there are only two sources in Europe to meet the demand. We received information that an American manufacturer is entering the European market. We were among the first to establish contact with them, and now we reap the benefits. Despite the allocation, we can now obtain this raw material at a very competitive price and in the required quantity. However, for certain sectors, materials, and components, with only two global producers, there is a challenge. Due to certain circumstances, we also managed to discover an overlooked material from another American company, which has been forgotten but can serve as a substitute, and so we are opening the door to overcome the lack of this raw material".

3.2.5. Importance of relationships network

Pre-existing relationships developed before a crisis had a notable impact on business during the crisis. As one respondent noted, "I believe that a well-established network of contacts played a role in ensuring supply continuity, where our supply chain partners often function as both our customers and suppliers. These relationships greatly assisted us in sourcing products locally, and it was certainly a significant help during that time".

First and foremost, existing and regular partners, especially key customers, received priority in the supply chain. For instance, one respondent stated, "We encountered no issues in acquiring products/materials, mainly because of the company's size and reach. We are the top customer for most suppliers, and for some, we are the sole buyer for specific products". Another emphasised, "Suppliers were focused on serving their most important customers. With aluminium allocations, for example, we couldn't purchase 3,000 tons, only 2,000 tons. When approaching another supplier, they'd explain they had allocations and could only deliver to their regular customers who had previously made purchases. These were the challenges we faced. Today, you need to request someone to sell to you".

The study's respondents also highlighted the significant role of interpersonal relationships in managing unforeseen events. One respondent emphasised, "What works today are interpersonal relations. Strong interpersonal relationships can sometimes influence logistics or sales policies in both directions. In my case, it is very evident". Another participant stressed, "The importance of interpersonal relationships has become increasingly significant. Positive relations between suppliers and buyers are especially valuable today".

Furthermore, the participants provided examples of initiatives that supported local partners during crises; for instance, respondents mentioned, "At one point, our production department sent out an email recommending outsourcing transportation to local transport companies to support these businesses".

3.2.6. Value of transparency and visibility of information

The exchange of information played a crucial role. Information was shared more frequently, and the timeliness of information became even more critical. Respondents highlighted constant communication with supply chain members. As one of them stated, "Yes, we maintained constant contact with our suppliers". Another mentioned, "We made an effort to stay in constant touch with our suppliers and respond promptly to any changes in demand or component availability. An encouraging development is the increased level of interaction with suppliers today. With tools like MS Teams, we can easily connect at any time of the day, which has proven to be quite positive. In the past, we typically met with company representatives from Switzerland or the USA only once a year during contract negotiations. Today, meetings on MS Teams and online video conferences, where we can see each other on camera, have become a part of our daily routine".

The respondents' statements reveal that open information exchange in some cases was challenging, with partners in the supply chain not being forthright about their problems. For instance, one respondent mentioned, "At first, it was a bit hidden [reduced

production plans]. The producers didn't want to say it was that bad. Production then fell to twenty per cent. Suppliers did not want to signal problems; they just wanted to wait so that no one would cancel their orders. So there was contact with them, but intermittent and not entirely clear, so even if they said that the goods would be available in, say, a month, we had to add half a month more because there was simply less production capacity. It was a bit of a cat and mouse game".

However, the prolonged crisis eventually led to greater transparency and collaboration in supply chains. As some respondents noted, "Behaviours varied. Initially, some of them tried to hide any crisis situations for fear of losing customers. The development and scale of the problems forced the exchange of information and joint arrangements and the search for solutions to emerging problems and crises."

The ability to track and monitor supply chain processes plays a vital role during times of uncertainty. Unforeseen events often lead to increased efforts to enhance visibility in the supply chain. For instance, one respondent mentioned, "Due to the difficulties, we have launched a system for providing information on the level of delivery to our suppliers". However, the transparency of these processes, as reported by respondents, can vary significantly. In some cases, there is a high degree of transparency, with one respondent stating: "We have many suppliers. In some cases, we can see right down to literally chemical components like sodium stearate, etc. The level of transparency depends on the product and category being considered". In contrast, more often, respondents indicated that supply chain transparency is low or limited to their first-tier suppliers or buyers. For instance, some respondents mentioned, "Unfortunately, I have no insight into suppliers" and "If I miss a valve, I ask what the problem is, I find out that the gasket. I have no contact with the company that supplies the gasket for our valve" or "Usually this is the first step, we have control down to the level of delivery to our suppliers".

This variability in transparency levels affects an enterprise's ability to quickly identify problems or bottlenecks in the supply chain flow, allowing corrective action to be taken in real-time. This may include re-routing a shipment, changing production schedules, or adjusting inventory levels. The respondents cited the possibility of tracking containers in sea transport as an example: "The publicly available tools for monitoring sea transport helped us a lot. I think this is also one of the reasons why many companies choose [this form of transport] (…) we can keep up to date with everything. If the container sails, we have its number; we stick it on the [website] of the shipowner, and we have information on whether it has been loaded on the ship or not. There are also public pages, and then you can monitor the load in real-time".

3.2.7. Significance of trust, partnership and cooperation

A positive aspect is the increased importance of partnership and cooperation in supply chains. As one respondent put it, "If I were to mention any positives, it would be a greater willingness to cooperate, better understanding of problems, greater involvement in joint search for solutions, and increased creativity". The respondents stressed the significance of inter-organisational relations within the supply chain. They highlighted that supply chain management acts as a "unifying force between suppliers and buyers".

Various activities were also emphasised, including conflict management, supplier development, building partnerships/alliances, early inclusion of suppliers, etc. Partners in the supply chain engaged in knowledge and experience sharing, and experience sharing and collaborated to find solutions to the issues at hand. One participant noted, "Of course, we have appropriate systems, but in this case, they did not work (…). We were looking for solutions more with the client than relying on the systems alone". Another mentioned, "As long as the problem can be resolved in consultation with the supplier, we try to do so. Sometimes a supplier tries to pull a product from someone who doesn't currently need it". Representatives of enterprises expressed that this increased collaboration enabled them "to communicate much more directly than before".

3.2.8. Importance of supply chain risk management and business continuity management

The conducted research highlights that the occurrence of unforeseen events such as the COVID-19 pandemic or war has led to an increased awareness among enterprises regarding the role and importance of supply chain risk management and business continuity management. As one participant stated, "As a positive, we can mention, among others, the ability to react faster to crisis situations, the ability to run

a company remotely, the ability to work under time pressure. We learned a lot during that time".

In response to recent events, enterprises have either developed new crisis procedures or enhanced their existing ones. Some are in the process of planning and implementing such procedures. For instance, one respondent noted, "We do not have crisis response procedures specifying how to deal with crisis situations, but it is in the company's plans".

4. Discussion

The resilience of the logistics system refers to its ability to deliver, maintain, and improve service quality in the face of changes and threats. It can be described as the capacity to respond to unexpected disruptions and restore continuity in supply chain processes or the ability to maintain, resume, and restore operations after being impacted by disruptions. Recent examples of unforeseen events that have significantly affected supply chain management include rising inflation, the war in Ukraine, the COVID-19 pandemic, and traffic disruptions, such as the Suez Canal blockade in March 2021.

The occurrence of unforeseen events leads to various challenges in supply chains and remedial actions taken in response to unforeseen events (Fig. 2).

Making a generalisation based on respondents' answers, the occurrence of unforeseen events in the supply chain affects almost all operations within the supply chain, i.e., procurement, planning (including inventory planning and maintenance of company resources and production lines), logistics management (including transportation), and order management. This finding aligns with the results of studies conducted by Chowdhury et al. (2021), Raj et al. (2022), Kumar et al. (2020), and Remko (2020), who examined the impact of the COVID-19 pandemic on supply chain management. The conducted research also highlighted such aspects as limited availability of goods, favouring selected customers, implementing allocations, and sometimes unjustifiably raising prices of offered raw materials and materials during crisis situations. Research findings also indicate a positive aspect of difficulties in meeting customer demand, as it sometimes leads to changes in customer preferences and the choice of new products not previously selected.

Actions taken in the supply chain in response to unforeseen events primarily aim to ensure continuous flows of goods, meeting production needs and satisfying customer demand. To achieve this, companies begin by building safety stock, transitioning from just-in-time to just-in-case inventory management. The significance of these actions during uncertain times has been emphasised by authors like Remko (2020). Shortening supply chains, often as a response to seeking production sources closer to the market, has been discussed by Nandi et al. (2021) and Chen et al. (2022), primarily in the context of the COVID-19 pandemic. Furthermore, diversifying supply sources and expanding into new markets, even beyond the pandemic, has been underlined by Lopes (2022) and Sheffi (2020). As highlighted by Golan et al. (2020), while globalisation exposes supply chain networks to disruptions, leading to increased complexity and uncertainty and numerous factors that can have unforeseen impacts, it also presents significant opportunities for optimising supply chains and diversifying sources of supply.

Research findings have demonstrated that during unforeseen events, cooperation and integration within the supply chain become even more crucial. According to Hu (2022) and Tabaghdehi and Kalatian (2022), the COVID-19 pandemic provided opportunities for developing and enhancing existing inter-organisational relationships and establishing new ones, contributing not only to resilient but also trust-based inter-organisational supply chains. Additionally, Panwar et al. (2022) discussed the reconfiguration of global supply chains into global value chains as one of the supply chain management practices in the short and long term. The perspective of transforming global supply chains into global value chains highlights the shift from competition towards more cooperative forms of collaboration (Ryciuk, 2020, Ryciuk, 2022).

Qualitative research results further indicated that communication with suppliers during the pandemic often presented challenges, with partners sometimes withholding information about emerging problems. However, over a longer period, this situation eventually led to greater transparency in supply chains, fostering closer relationships and collaborative problem-solving in response to disruptions. It is also worth noting that responding to unforeseen events poses greater challenges for supply chains with lower maturity levels.

The conducted research also shed light on the positive impact of unforeseen events on supply chain innovation. When asked whether the pandemic's impact on supply chain management was entirely

Challenges in supply chains due to unforeseen events

Disruptions, delays, shortages of goods, materials, and raw materials, as well as the introduction of allocations by manufacturers.

Difficulties in planning deliveries and managing inventory, exacerbated by the use of the crisis as a justification for disruptions.

Disruptions and delays in production.

Increased costs of holding inventory and capital freeze resulting from increased warehouse stock levels.

Challenges in transportation planning due to reduced transport infrastructure availability and increases in transportation costs.

Price increases due to limited availability of goods or deliberate policies of manufacturers.

The need to seek new sources of supply and bear higher procurement costs.

Significant fluctuations in demand, including cancellation of previously placed orders, difficulties in meeting demand, and price fluctuations.

Changes in customer preferences, decrease in customer loyalty.

Diminished significance of conventional supply chain management methods and tools.

Actions taken in response to unforeseen events

Increasing safety stock, both within the company and among suppliers, to act as a buffer against unexpected fluctuations in product demand and potential delays in raw materials deliveries, including continuous monitoring of product and raw material availability.

More frequent signing of framework agreements with suppliers, enabling better control over prices and delivery quantities.

Exploring alternative transport options, such as changing modes of transport, opting for more expensive but faster solutions, and prioritising deliveries.

Seeking new suppliers and exploring alternative sourcing options, especially from regional and local markets, even if they are sometimes more costly; this includes diversifying the supplier portfolio, especially for critical components or custom-made items; in some cases, considering backshoring as a longer-term strategy.

Adjusting production plans in response to component shortages and delivery delays.

Embracing innovation and seeking solutions, such as identifying substitute raw materials, which might not have been considered under stable conditions.

Recognising the increased importance of trust, inter-organisational relationships, and interpersonal contacts, with an emphasis on relationships established before a crisis emerges (benefiting from prioritising deliveries to key, regular customers).

Taking actions to support supply chain partners and local businesses during crises.

Placing greater importance on information with increased frequency and focusing on timely information sharing (especially if initially, information exchange was hindered or problems were concealed).

Enhancing supply chain visibility, tracking, and monitoring in the supply chain; Fostering collaboration and partnership relationships; encouraging knowledge sharing, experience exchange, and joint problem-solving.

Raising awareness among businesses about the role and significance of supply chain risk management and business continuity management, leading to the development or improvement of crisis management procedures.

Fig. 2. Main challenges in supply chain management that arise from the occurrence of unforeseen events and the actions taken in response to them

negative, the respondents disagreed. An example illustrating increased openness to innovations during challenging times is the sourcing of an alternative for a hard-to-obtain raw material. Similarly, Maternowska (2021) emphasised that the pandemic accelerated the development and adaptation of many technologies and practices, potentially enhancing supply chain resilience to future disruptions. Recent unforeseen events have also coincided with the emergence of new technologies within Industry 4.0 and the establishment of intelligent supply chains (Ryciuk, 2019).

However, the research findings did not demonstrate a significant impact of unforeseen events on the establishment of sustainable supply chains. Actions like backshoring or nearshoring, as pointed out by Milewska (2022), may lead to reduced CO2 emissions, but they appear to be somewhat unplanned consequences of responses to unforeseen events.

Conclusions

The purpose of the article was to identify the primary challenges in supply chain management resulting from the occurrence of unforeseen events, such as the COVID-19 pandemic or armed conflict in Ukraine, and to explore the responses within supply chains addressing them.

The research findings highlight several key challenges in supply chain management, including disruptions, delays, and limited availability of specific goods, materials, and raw materials, often exacerbated by manufacturers implementing allocations; difficulties in transportation planning due to restrictions in movement, reduced transportation infrastructure availability, and rising transportation costs; price driven by constrained availability of goods or deliberate strategies by manufacturers; the necessity to identify new supply sources and incur higher procurement costs; increased costs of maintaining inventories and capital freezing; fluctuations in commodity prices and substantial fluctuations in demand.

The primary corrective measures adopted by supply chains in response to unforeseen encompass various strategies, including augmenting safety stock and heightened monitoring of prices and availability of products and raw materials; more frequent engagement in frame agreements with suppliers; exploring alternative delivery methods, switching transportation modes, choosing faster albeit pricier solutions, and prioritising deliveries; actively seeking new suppliers and diversifying sources of supply to fortify supplier portfolios; encouraging innovations; placing a heightened emphasis on trust, cooperation, interorganisational relations, and interpersonal connections; fostering increased information exchange, knowledge sharing, and collaborative problem-solving; and raising corporate awareness about the pivotal role of supply chain risk management and continuity management.

The research findings provide a valuable foundation for discussions and investigations into the potential impact and consequences of unforeseen events on supply chain resilience. Today's challenges in supply chain management markedly differ from those of just a few years ago. The pandemic placed significant strain on supply chains, while the ongoing conflict in the East underscored the extent to which these chains rely on global political situations. These findings also invite reflection on the future of supply chains operating within specific countries or regions and their role in bolstering the competitive advantage of global economies. It is worth noting the remaining need for broader awareness among managers regarding supply chain management strategies, methods, and tools. Moreover, there is an observed prevalence of intuitive management, particularly when responding to unexpected events.

The study comes with certain limitations tied to its methodology. In qualitative research, context and specific cases play a pivotal role in elucidating the studied issue. The primary constraint of qualitative research may be the limited representativeness of the results and a certain degree of subjectivity, both in the assessments of respondents and in the interpretation of the findings. Nevertheless, the researchers made diligent efforts to mitigate subjectivity by emphasising objectivity and sensitivity to ensure the highest possible quality and value of the conducted research.

Noteworthy are the research findings, their limited generalisability, and the ability to derive overarching conclusions regarding the impact of unforeseen events on supply chains, which are influenced by the predominant focus on the COVID-19 pandemic. This pandemic is underscored as the primary unforeseen event occurring in the last three years. This emphasis on a specific event might constrain a more comprehensive understanding of the effects of various unforeseen events on supply chains.

Future research may involve complementing qualitative research with quantitative research. There are plans to conduct research on a representative sample of enterprise representatives and to develop

models of the impact of unforeseen events on actions taken in response to them. This approach aims to provide a more comprehensive understanding of the dynamics between unforeseen events and supply chain management, allowing for the formulation of data-driven strategies and recommendations for enhancing resilience in the face of uncertainties. Additionally, the research will explore how different industries and organisational sizes respond to these events, providing valuable insights for tailored risk mitigation strategies and adaptive measures.

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Sustainability and Industry 4.0 in the packaging and printing industry: a diagnostic survey in Poland

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ABSTRACT
Industry 4.0 (I4.0) became an important paradigm to bridge the gap between technologies and humans. The paper aims to diagnose sustainability performance and I4.0 maturity in Poland's printing and packaging sector and identify research areas where further actions for improvements are necessary. This article adopts a mixed-method study combining in-depth interviews of eleven heterogeneous enterprises, supported with a quantitative survey on a representative sample of 301 companies. The findings revealed an insignificant correlation from a statistical point of view (0.44) between the adopted I4.0 technologies currently used and sustainable best practices. Internet of Things technologies are more often adopted in the printing industry (27.2 %) than in the packaging industry (14 %). The study concludes that using I4.0 technologies boosts the execution of sustainable practices and/or realising sustainable development practices requires I4.0 technology adoption. The paper clarifies that more in-depth analyses are needed to help achieve sustainable objectives for printing and packaging companies through digital technologies. The methodology is replicable and might be applied in other economies across separate multinational enterprises to influence sustainable digitalised business strategy.

KEY WORDS
Industry 4.0, packaging, printing, smart manufacturing, survey, sustainability

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Introduction

The printing and packaging industry greatly contributes to European manufacturing, employing more than 600,000 employees and generating an overall turnover of about EUR 80 billion (Grace, 2021). This manufacturing sector has been widely influenced by the overall debate about business and production in the last few decades. In addition, the global financial crisis in 2008–2009 stimulated this debate (Barbier, 2010), and these concerns were translated into a vision of a "green economy" (Hesh-

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mati, 2018). This green economy transition led to reforming traditional economic models to address climate change, biodiversity loss, water scarcity, etc., promoting the challenges of technological change for sustainability (Söderholm, 2020; Szpilko & Ejdys, 2022). The reasons for this perspective change have been discussed in sociology, being referred to as the so-called "macro-trends" or "game-changers" (Avelino et al., 2017), among which the climate change is recognised as a big player, despite being "only the tip of the iceberg", and hiding a "societal transformation towards sustainability" (Campos et al., 2016). As noticed by Worthington and Patton (2005), the manufacturing sector experienced a change in business perspective from a profit-oriented one (Friedman, 1970) to a framework influenced by sustainability sensitivity (Holliday, Schmidheiny & Watts, 2017). Demjanovičová and Varmus (2021) presented a study on companies' attention to shift the perception of business values of environmental sustainability. It was also confirmed that companies that extend their performance through eco-efficiency measures might effectively contribute to sustainability (Heikkurinen, Young & Morgan, 2019). The sustainability concept, being the result of debates, was accelerated by the implementation of the so-called 2030 Agenda for Sustainable Development (SD Agenda 2030) and its 17 Sustainable Development Goals (SDG) (UN, 2022).

For this research, eleven enterprises were examined using descriptive statistics. The pilot study revealed that advanced technology has a positive impact on sustainability. Since the representative sample size was insufficient, the current paper extends previous considerations, enriching them with evidence from primary data collected through a quantitative questionnaire survey. In this context, a representative sample consisted of 301 enterprises from the printing and packaging industry. Based on the collected data, statistical analyses were performed to uncover a correlation between adopting sustainable practices and Industry 4.0 technologies.

Therefore, the paper aims to diagnose sustainability performance and I4.0 maturity in Poland's printing and packaging sector. The diagnosis, in its nature, is meant to constitute a basis for further studies.

The structure of the paper follows the commonly used IMRaD approach. Section 2 includes the objectives and formulated research questions and presents the materials and methods used in the article. Section 3 contains the results of the interviews and surveys conducted. Sections 4 and 5 discuss the results, conclusions and directions for further research.

1. Literature review

A well-known approach has been introduced by the Brundtland Report (World Commission on Environment and Development, 1987), which has brought to the so-called "Triple Bottom Line"(TBL), represented by "Economic", "Social" and "Environmental" perspectives (Elkington, 1994) but other valid interpretations have been given in this regard, such as the 3P (Profit, People, Planet) adopted by Kaptein and Wempe (2002) and extended to CSR (corporate social responsibility) relationship that insist more on an ethics perspective (Kaptein & Wempe, 2002). In this perspective, a work aiming at clarifying and further refining the concepts and definitions of sustainability concerning the company perspective has been published by Van Marrewijk (2003), showing that no universal meaning can be provided to describe this topic. Still, most existing frameworks addressing sustainability can be discussed using the same pillars: environment, economic, and social. Wilson (2015) argued that these three concepts can be seen as mutually complementary and influencing and can assess an entity's sustainability in the three dimensions. Treating any dimension separately is a misleading use of the sustainability approach (2020).

Even if these 3P frameworks can be inflected towards manufacturing practices, their influence in this domain cannot be addressed by neglecting the other trends characterising this sector. In particular, the topic is reflected in the so-called "Industry 4.0" (I4.0), which strongly addresses the digitalisation of manufacturing companies. I4.0 includes renovating companies' machines (with new or revamped ones able to produce structured data, enabling a more profound knowledge of the assets and production statuses) (Nucera et al., 2021). It also considers remodelling the companies' internal organisation towards structures closer to the informative systems implied in the manufacturing management, e.g., referring to the IEC 62264 standard (ISO, 2013), which relies on turning on the Purdue Enterprise Reference Architecture (Bernus, Nemes & Schmidt, 2003).

Today, sustainability and Industry 4.0 are leading concepts in the literature and industrial practice. Several studies have been carried out to demonstrate

the benefits of this paradigm adoption in the holistic manufacturing environment (Kiel, Arnold & Voigt, 2017; Dalenogare et al., 2018) and improvement programmes like lean manufacturing (Ejsmont et al., 2020). Few cited publications also addressed different specific areas of the manufacturing environment, such as internal logistics (Quadrini, Negri & Fumagalli, 2020; Fragapane et al., 2022), maintenance and asset management (Cattaneo et al., 2018; Polenghi et al., 2020), supply chain management (Ivanov et al., 2016; Ben-Daya, Hassini & Bahroun, 2019), and decision-making (Negri, Fumagalli & Macchi, 2017; Villalonga et al., 2021).

The importance of sustainability for the industry is also reflected in the United Nations Sustainable Development Goals initiative (UN, 2021) and addressed directly by UN SDG No. 9, i.e., build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation (UN, 2021). Several studies have been published regarding the interactions between Industry 4.0 adoption and sustainable development practices. In particular, a 2017 literature review depicted the adoption of Industry 4.0 as a means towards sustainability (Liao et al., 2017). More precisely, concerning the TBL approach, the first one has been widely studied, at least concerning the productivity and competitiveness-related benefits (Oesterreich & Teuteberg, 2016; Stock & Seliger, 2016; Müller, Buliga & Voigt, 2018). At the same time, several works addressed the environmental dimension, mainly referring to the energy management topic, given the fact that the data produced by the machines usually reflect or directly address the energy consumption of the monitored assets (Shrouf, Ordieres & Miragliotta, 2014; Baccarelli et al., 2017; Ghobakhloo, 2020) or sustainability impacts and assessments of specific technologies (Gladysz et al., 2020; Kluczek, Gladysz & Ejsmont, 2021). Recent literature review showed that relationships between Industry 4.0 and sustainability are bi-directional, i.e., Industry 4.0 impacts sustainability performances (possibly positively and negatively), and sustainability initiatives may impact Industry 4.0 adoption (possibly positively and negatively as well) (Ejsmont, Gladysz & Kluczek, 2020). Resilience is also an increasingly important aspect in terms of how businesses operate in the era of Industry 4.0 and increasing environmental awareness of companies. The COVID-19 pandemic highlighted the importance of resilience and manufacturing companies' continuity (Mubarik et al., 2021).

Some researchers have recently studied the relationship between Industry 4.0 and sustainable development in the printing sector, mainly focusing on the environmental bottom line of sustainability (Gladysz et al., 2021).

2. Research methods

Considering the aforementioned issues, the following research objectives are formulated:

- Enrich the existing literature on packaging and printing manufacturing with specific assessments about its reception of Industry 4.0-related technologies, given the fact that, despite its economic relevance, this sector has fewer materials than other ones, e.g., construction (Ghosh, Edwards & Hosseini, 2020);
- Investigate the evolution of the packaging and printing manufacturing sector towards sustainable development practice, particularly concerning the social dimension of the Triple Bottom Line approach.

To investigate these objectives, the authors answered the following research questions in the design of the work:

- Which Industry 4.0-related technologies are used (or intended to be used) in packaging and printing companies?
- Which sustainability practices are used or in progress in packaging and printing companies?
- Do packaging and printing companies expect any (business) benefit from I4.0 implementation?
- Do packaging and printing companies expect any (business) benefit from sustainability practices?
- Is there any relationship between the size of a company and the I4.0 implementation advancement in packaging and printing companies?
- Is there any relationship between the size of a company and sustainability implementation advancement in packaging and printing companies?
- Is there any perceived or hidden relationship between Industry 4.0 technologies and sustainability practices in packaging and printing companies?

This study collected quantitative data through a survey to provide evidence answers to the listed questions. It identified the current state, and its

description will be transformed into a consecutive research plan to address specific areas that emerged from the diagnosis. Due to its diagnostic nature, the presented study does not aim to address particular issues, indicate their potential or actual roots, or propose or verify possible solutions. The idea is to show the present status and suggest areas for further action. Pilot research involved interviews that were aimed at getting qualitative insights into companies to define a questionnaire for the survey. The gathered data were analysed quantitatively using statistical analyses (descriptive statistics) to verify whether correlations between the research questions (4–7) exist.

The reported work presents the results of a study conducted over a specific pool of companies belonging to the Polish printing and packaging sector: a purposive convenience sample numbering 11 companies, reflecting the overall Polish segmentation of this sector, has been considered. The representatives from selected companies were individually interviewed and guided during an online structured in-depth interview questionnaire by filling out a web-hosted form. Two interviewers conducted each so-obtained input to validate the data accuracy. An interviewee always authorised interview results.

Structured in-depth interviews (IDIs) are a qualitative data collection method that allows a lot of information to be gathered on a given topic. Structured IDIs have similarities to a conversation — although it is a conversation with a purpose, i.e., a research topic based on pre-developed questions. The advantage of structured IDIs is that the researcher can gain rich and deep information from the interview process (Jennings, 2005). An interview completed in this form provides reasonably objective information. Answers are likely similar and not intersubjectively variable if another interviewee conducts the study. Structured IDI protects against cognitive errors. IDIs allow for flexibility and discussion of topics that arose during the conversation and were not previously planned. Some degree of flexibility is crucial with the topic of Industry 4.0 and sustainability, where there are so many threads, application examples, and relations that it is impossible to identify them all before launching the study. The interviews were conducted online using Microsoft Forms and Teams (data collection questionnaire and videoconferencing conversation). Easy to use, with small barriers to use (no installation required), and widely used tools were chosen. That way made it convenient for participants, giving more flexibility in terms of time, as the place was not constraining the interview date. Obtained answers to the questions were then carefully analysed, and if there were any doubts, the disputed issues were clarified with the respondent. Respondents authorised final questionnaires. Misunderstanding and incorrect interpretation of answers were avoided.

At first, the sample of interviewed companies has been clustered according to the declared company size. The interviewed companies have been able to assess themselves, according to the number of their employees, as small (employees < 50, annual turnover ≤ EUR 10 m or balance sheet total ≤ EUR 10 m), medium (employees < 250, annual turnover ≤ EUR 50 m or balance sheet total ≤ EUR 43 m), or large (employees ≥ 250, annual turnover > EUR 50 m or balance sheet total > EUR 43 m) enterprises. Hence, the qualitatively interviewed sample was composed of two small enterprises, six medium enterprises, and three large enterprises. The interviewed companies' scope of operations was national (1), European (8), international (1), and global (1). The average duration of the interviews was about 75 minutes. Interviewees were selected from the management/top levels of the company to make sure they have knowledge of business strategies and sustainable development agenda. The interviewed companies are specifically involved in the production of printing products such as self-adhesive labels, wrap-around labels, heat-shrinkable labels, wet-glue labels, and in-mould labels. The sampled companies use technologies like flexographic, offset, and rotogravure and packaging products like bottles, cups, caps, containers, and similar products printed by dry-offset methods. The sample is the same basis as the work reported in the previous efforts by the authors (Gladysz et al., 2021).

After the qualitative research (interviews), quantitative research was conducted among companies registered in Poland using the CATI (computer-assisted telephone interviewing) technique supported by a structured questionnaire survey. The respondents were persons holding the following positions in companies: (i) owner/co-owner or (ii) a representative of the top management (executive), including persons supervising technical divisions or R&D — design and implementation of innovation. The inclusion of respondents in the survey depended on their preferences, decisions, and the completeness of contact details contained in the databases. In total, 301 effective surveys were carried out (i.e., those in which the answers to all questions were obtained) with representatives of companies within two sectors: printing and packaging (Table 1). As part of the study, it was

Tab. 1. Number of companies from selected sectors

Sector	Number of employees		
	1-49	50 and more	Total
Printing	127	24	151
Packaging	120	30	150

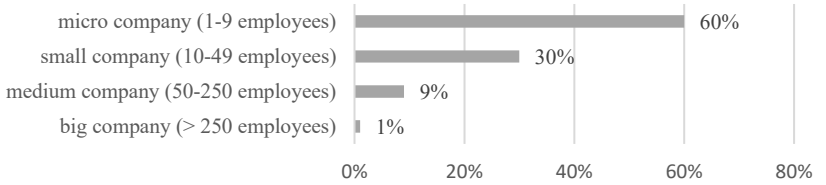

Fig. 1. Company size by the number of employees

used as the basis of the Bisnode (2022) database, which contains a total of data on over 7 million companies, of which 4.6 million are active and whose data is constantly updated (database update in daytime mode). The supplementations were the Eniro (2022) database (over 1 million enterprises) and Directan (2022) database (B2B records). The selection of the sample for the study was quota-losing, where the layers were:

- sector (the overwhelming sector of the company's activities divided into two categories: printing and packaging);
- size of the company calculated in the number of employees (divided into two cohorts: 1–49 employees and above 50 employees).

Detailed data on the selected sample is presented below. The structure of the sample (company size) is consistent with the structure of the population, as found in Statistics Poland (2022).

The survey included companies of different sizes divided by the number of currently employed people in two cohorts. Companies with 1 to 49 employees accounted for 90 % of the respondents, while the remainder were companies with 50 or more employees. The detailed distribution of companies whose representatives participated in the survey is presented in Fig. 1.

The respondent group comprised 24 % of women and 76 % of men. It had 218 owners or co-owners (72 %), while the remaining 28 % (83 persons) were executives, including those who oversee technical or R&D divisions. Surveys were conducted with companies throughout Poland. The territorial division was based on the question of the province in which the company is located. A minimum of 5 % of surveys were completed in each province. Quantitative data were used to check if a statistically important correlation exists between exploitation and plans for sustainability practices and Industry 4.0 technologies. Correlation coefficients were calculated depending on the nature of a variable. Statistically significant and strong correlations were discovered and discussed.

3. Research results

The answers to Industry 4.0-related questions have already been published in a previous work (Gladysz et al., 2021). To track the sustainable development awareness of the companies, the sample has been asked to assess its personnel's perception of SD practices according to the hierarchical levels of the

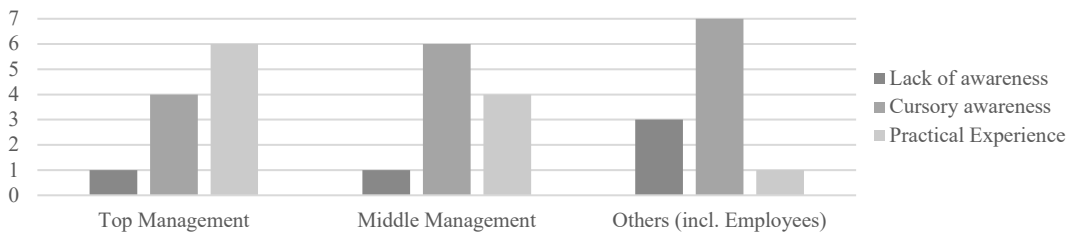

Fig. 2. SD awareness

different companies' employees. The outcome of this question is summarised in Fig. 2.

Interviewees were asked to frame the SD objectives according to the company strategies to estimate the management attitude towards sustainable development practices. To target the social dimension, companies were asked to evaluate their involvement in each sub-thematic area, as depicted in Fig. 3. Interviewees were also asked about the economic dimension to integrate the survey into the SD dimensions (Fig. 4). For the last evaluation area, so-called multiperspective (DESD, 2014) companies are framed according to Fig. 5. After this area-based assessment, the interviewed companies were asked to assess a stage of the SD practices. Possible options were given as:

- We have not considered this;
- We are planning the pilot implementation;
- We are planning the implementation in selected areas of the company;
- We are planning the implementation in the whole company;
- We are carrying out the pilot implementation;
- We are carrying out the implementation in selected areas of the company;
- We are carrying out the implementation in the whole company;
- We have finished the implementation of the SD concept, and continuous improvement is ongoing.

Fig. 6 shows the answers provided to the aforementioned questions, where, among the eight possible options, companies framed themselves only in four scenarios (nominally, the three ones referring to the most advanced implementations and one expressing a preliminary implementation purpose).

Figs. 7 and 8 show that cybersecurity is the most frequently used I4.0 technology currently by the surveyed printing and packaging companies. Respondents indicated the second most frequently used technology is Additive Manufacturing. Simulation is the third most often used technology. The last of the listed technologies of I4.0 respondents pointed to Autonomous Robots, Big Data and Cloud computing. The results are confirmed by industry articles (white papers) (Młynarczyk, 2022; Poligrafika.pl, 2023) highlighting the growing importance of 3D printing and simulation. The issue of cybersecurity, on the other hand, is crucial, not only for the printing and packaging companies but for all those that use I4.0 technologies that are interconnected (IoT, cloud, etc.). Table 2 presents a two-way table showing the frequencies of observed knowledge of I4.0 technologies and SD practices.

Respondents from the printing and packaging industries answered that they did not know the I4.0 technologies. Only 13 % of respondents from the printing industry and 15 % from the packaging industry answered that they knew of the I4.0 technologies. Only 20 % of surveyed respondents from the printing industry confirmed that they knew about SD practices, and 17 % of respondents from the packaging industry said the same. This demonstrates the still relatively low awareness of I4.0 and sustainability in Poland's printing and packaging sector. However, these are growth areas, as evidenced by the results shown in Figs. 7 and 8. It observed that many I4.0 technologies and SD practices are in the implementation or planned phases. It is also important to note that the respondents' lack of knowledge in these areas does not mean companies are not using I4.0 and/or SD practices.

Spearman's rank order correlation tool was used to analyse the correlation between the number of I4.0 technologies and the number of SD practices on different levels of implementation. The obtained results (Table 3), according to significance level $p<0.05$, show a correlation between the I4.0 technologies and the SD practices currently used at the level of 0.44, which is a medium correlation. A similar correlation was

Tab. 2. Two-way table: frequencies of observed knowledge of I4.0 technologies and SDGs depending on the industry. Red colour if p<0.05

Industry	Knowledge of I4.0 technologies - No	Knowledge of I4.0 technologies - Yes	Record	Knowledge of SDGs - Yes	Knowledge of SDGs - No	Record
Printing	131	20	151	30	121	151
Packaging	127	23	150	25	125	150
Total	258	43	301	55	246	301
Statistics	Chi^2	df	P	Chi^2	df	p
Chi^2 Pearson	0.268	df=1	p=0.605	0.516	df=1	p=0.472
Chi^2 NW	0.268	df=1	p=0.605	0.517	df=1	p=0.472

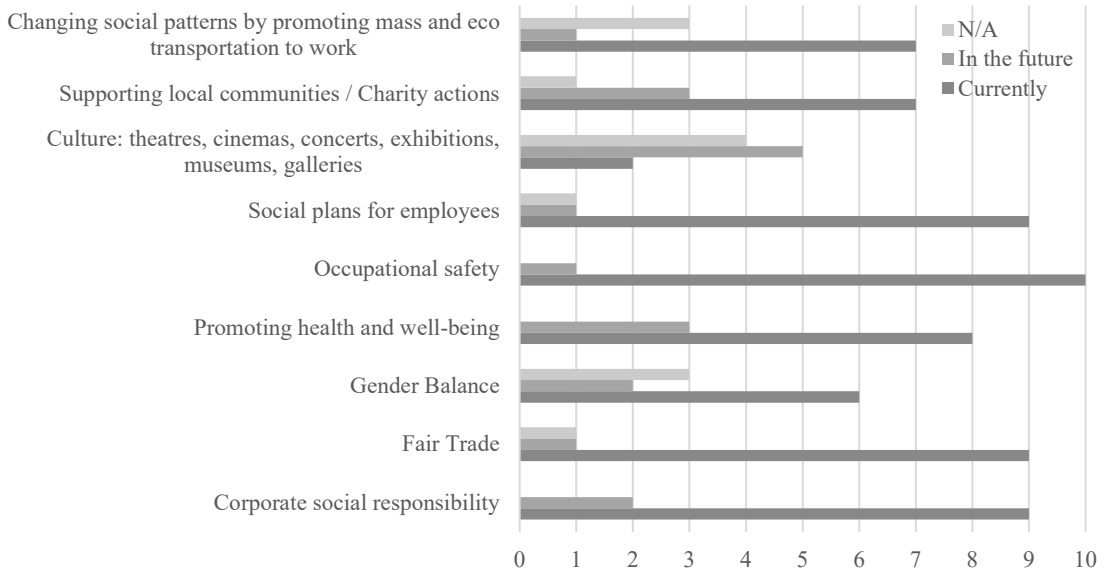

Fig. 3. Social areas

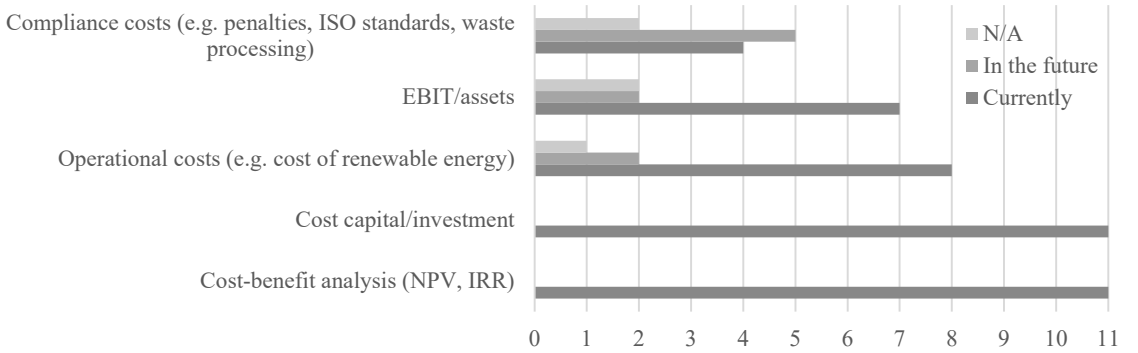

Fig. 4. Economic areas

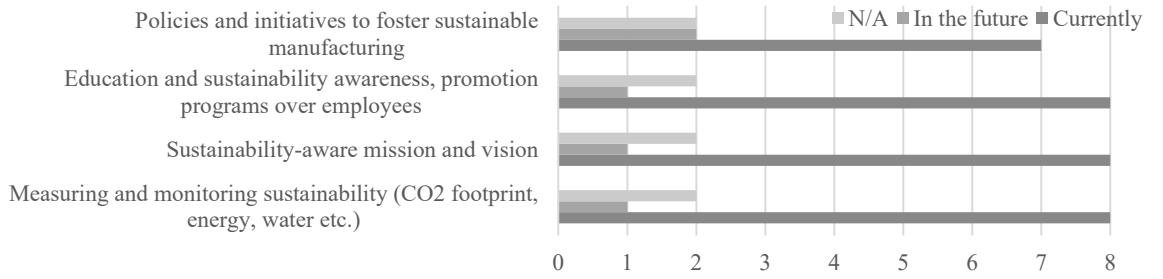

Fig. 5. Multi-perspective areas

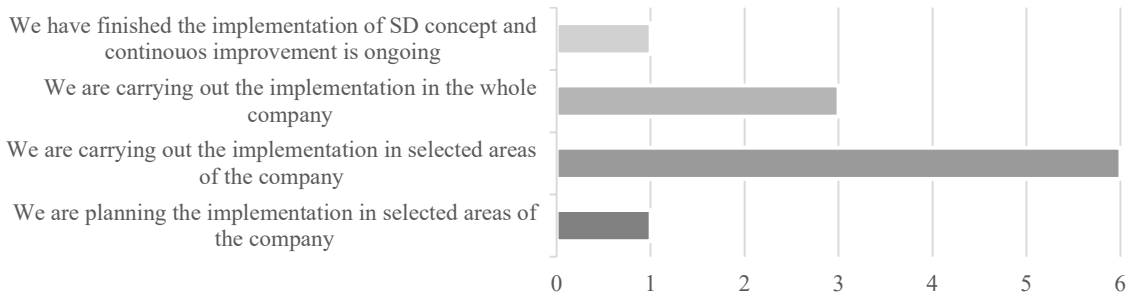

Fig. 6. Stage of SD concept

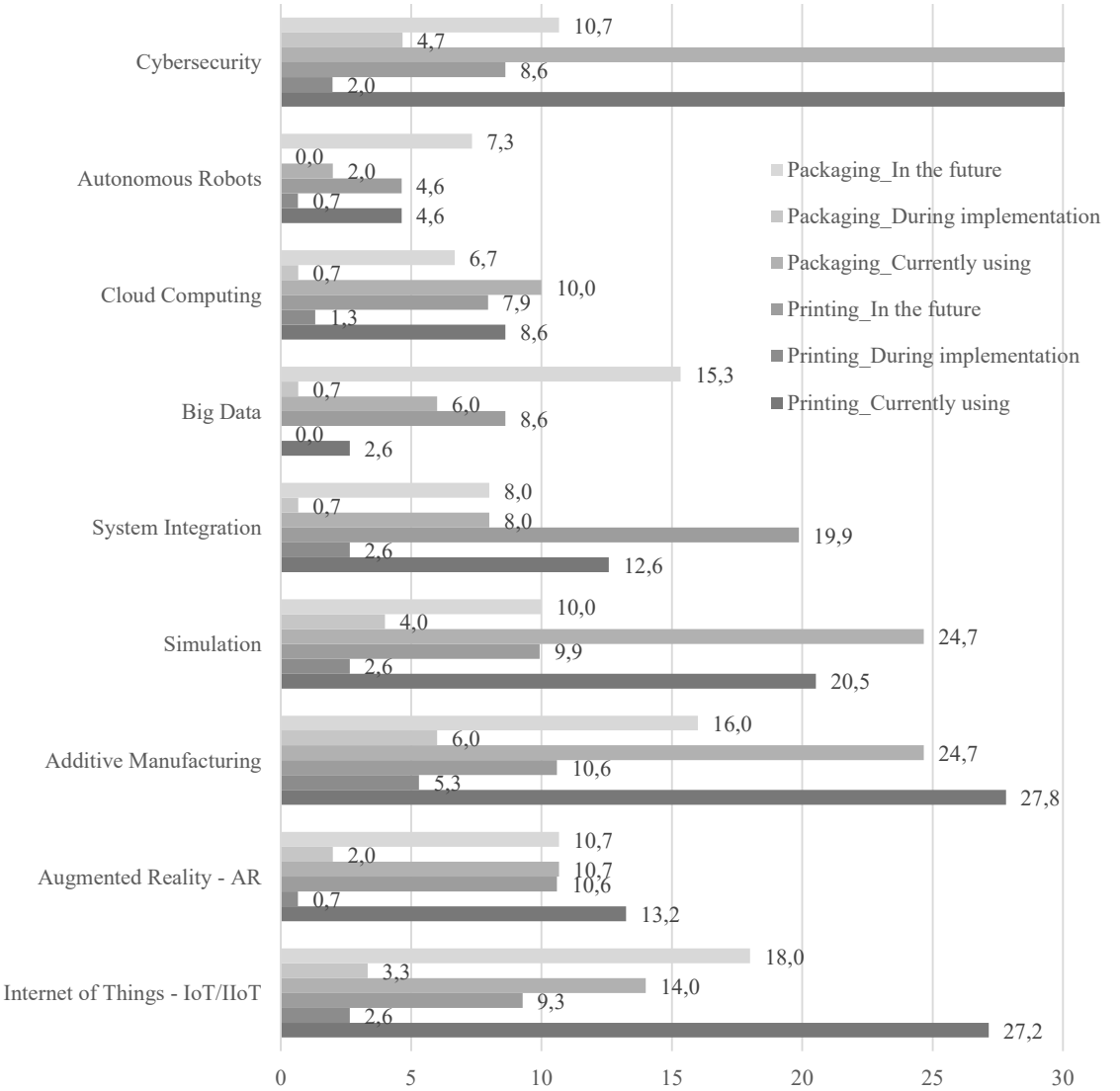

Fig. 7. Percentage of companies interested in the I4.0 technologies

Tab. 3. Spearman's rank order correlation (rho) for I4.0 technologies vs. SD practices on a different level of implementation. Red colour if p<0.05

Variable	SD_Currently using	SD_During implementation	SD_In the future
I4.0_Currently using	0.437	-0.027	-0.149
I4.0_During implementation	0.092	0.113	0.059
I4.0_In the future	0.077	0.098	0.412

achieved by comparing the I4.0 technologies and the SD practices in the future (0.41). Based on the results obtained, companies that use I4.0 technologies are also implementing SD practices. A similar situation applies to the future: companies that intend to use I4.0 technologies are also interested in implementing SD practices. Thus, a hypothesis can be put forward that should be subjected to more in-depth research: the use of I4.0 technologies enables/facilitates the realisation of SD practices and/or the realisation of SD practices requires the use of I4.0 technologies. Table 3 shows the three main reasons to implement I4.0 technologies for printing and packaging companies. Improvement of the quality of products and services was considered the most important, followed by reducing operating costs and opening new business opportunities and areas. Notably, most respondents identified these reasons as either main or

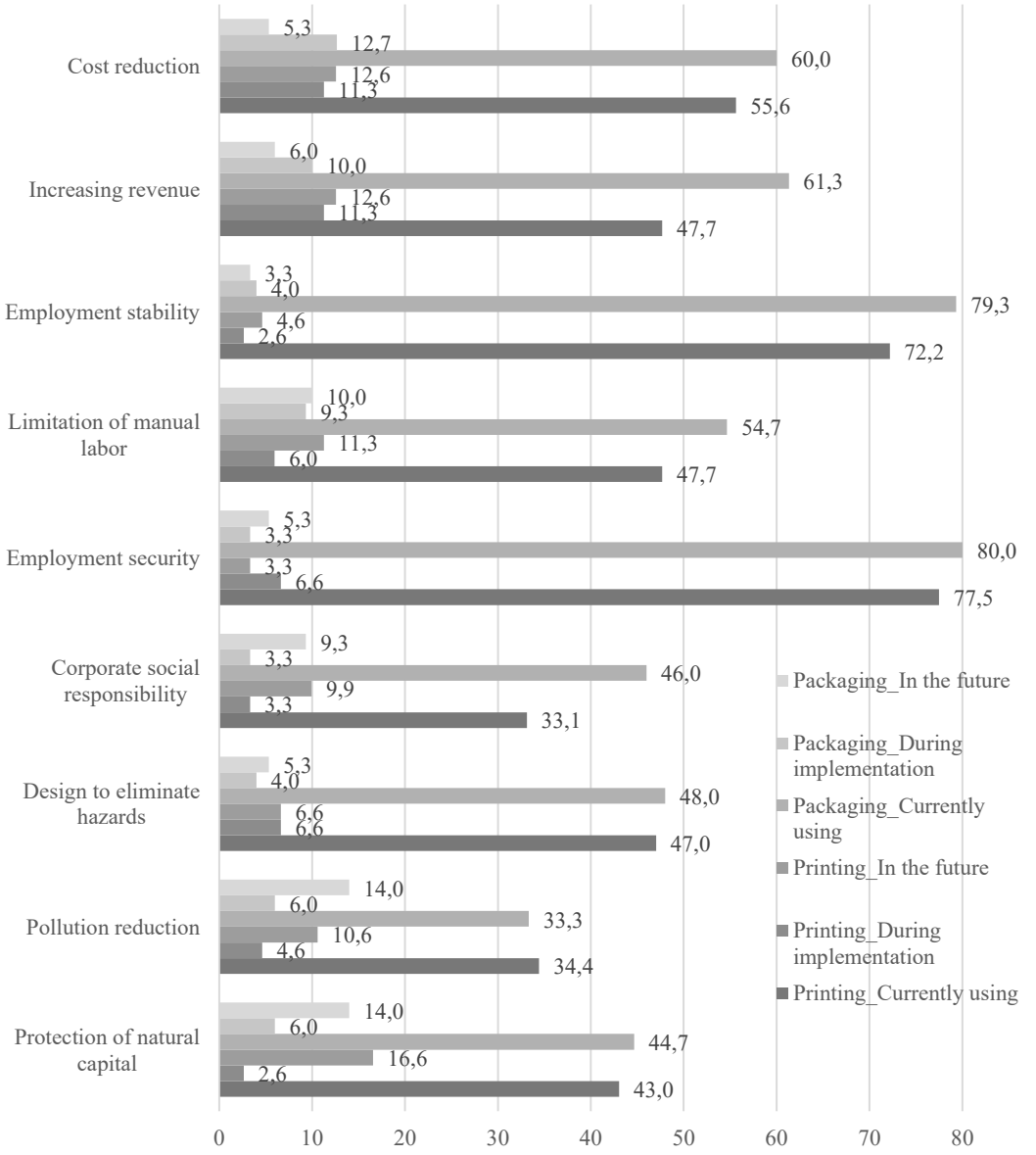

Fig. 8. Percentage of companies interested in the SD practices

additional. The results regarding the percentage distribution of responses are very similar for both industries. However, more respondents indicated the three reasons as the main in the packaging industry and as an additional in the printing industry.

Table 5 provides the reasons for implementing I4.0 technologies versus company size. Only those reasons for implementing the I4.0 technologies, which met the Chi-square test p-value <0.005 requirements and a minimum of four cases in each category, are presented. Concerning the above conditions of conducting chi-square tests, three main reasons for implementing the I4.0 technologies are statistically significant, i.e., (1) gaining a lasting strategic advantage, (2) opening up new opportunities and business areas, and (3) following market trends. Gaining a lasting strategic advantage was the main reason for implementing the I4.0 technologies more for small and medium companies rather than for micro companies. The latter group had no such reason. Nowadays, small (41 % of respondents) and mostly medium (50 % of respondents) printing and packaging companies need to demonstrate and gain strategic advantage by reaching for more advanced methods and techniques like Industry 4.0 technologies.

Looking at the next statistically significant reason for implementing the I4.0 technologies in the print-

Tab. 4. Two-way table: reasons for the implementation of I4.0 technologies depending on industry type. Red colour if p<0.05

	Industry	No reason	Additional reason	Main reason	Total
Reduction of operating costs	Printing	49.35%	61.00%	42.31%	143
	Packaging	50.65%	39.00%	57.69%	138
	Total	77	100	104	281
	Statistics	Chi^2	df	p	
	Chi^2 Pearson	7.228	df=2	p=0.027	
	Chi^2 NW	7.275	df=2	p=0.026	
Opening up new opportunities and business areas	Printing	44.19%	60.55%	44.05%	141
	Packaging	55.81%	39.45%	55.95%	138
	Total	86	109	84	279
	Statistics	Chi^2	df	p	
	Chi^2 Pearson	7.175	df=2	p=0.028	
	Chi^2 NW	7.216	df=2	p=0.027	
Improving the quality of products and services	Printing	42.22%	61.47%	45.38%	145
	Packaging	57.78%	38.53%	54.62%	139
	Total	45	109	130	284
	Statistics	Chi^2	df	p	
	Chi^2 Pearson	7.807	df=2	p=0.020	
	Chi^2 NW	7.861	df=2	p=0.020	

Tab. 5. Two-way table of main reasons for implementing I4.0 technologies vs. company size. Red colour if p<0.05

	Company size	No reason	Additional reason	Main reason	Total
I4.0 Gaining a lasting strategic advantage	Micro	52.69%	21.56%	25.75%	167
	Small	25.00%	33.75%	41.25%	80
	Medium	23.08%	26.92%	50.00%	26
	Total	114	70	89	273
		Chi^2	df	p	
	Chi^2 Pearson	22.14643	df=4	p=0.00019	
	Chi^2 NW	22.69090	df=4	p=0.00015	
I4.0 Opening up new opportunities and business areas	Micro	33.73%	38.55%	27.71%	166
	Small	29.76%	44.05%	26.19%	84
	Medium	20.00%	20.00%	60.00%	25
	Total	86	106	83	275
		Chi^2	df	p	
	Chi^2 Pearson	12.43334	df=4	p=0.01440	
	Chi^2 NW	11.39806	df=4	p=0.02244	
I4.0 Following market trends	Micro	39.88%	30.64%	29.48%	173
	Small	23.81%	45.24%	30.95%	84
	Medium	30.77%	23.08%	46.15%	26
	Total	97	97	89	283
		Chi^2	df	p	
	Chi^2 Pearson	10.93832	df=4	p=0.02727	
	Chi^2 NW	10.84133	df=4	p=0.02841	

Tab. 6. Two-way table of main reasons for implementing SD practices vs. company size. Red colour if p<0.05

	Company size	No reason	Additional reason	Main reason	Total
SD Gaining a lasting strategic advantage	Micro	47.88%	31.52%	20.61%	165
	Small	24.05%	35.44%	40.51%	79
	Medium	30.77%	26.92%	42.31%	26
	Total	106	87	77	270
		Chi^2	df	p	
	Chi^2 Pearson	18.09749	df=4	p=0.00118	
	Chi^2 NW	18.39029	df=4	p=0.00104	
SD Employment reduction	Micro	75.63%	18.13%	6.25%	160
	Small	57.14%	25.97%	16.88%	77
	Medium	50.00%	23.08%	26.92%	26
	Total	178	55	30	263
		Chi^2	df	p	
	Chi^2 Pearson	16.79438	df=4	p=0.00212	
	Chi^2 NW	15.83228	df=4	p=0.00325	
SD Quick improvements	Micro	38.65%	42.94%	18.40%	163
	Small	27.27%	41.56%	31.17%	77
	Medium	24.00%	28.00%	48.00%	25
	Total	90	109	66	265
		Chi^2	df	p	
	Chi^2 Pearson	13.31397	df=4	p=0.00984	
	Chi^2 NW	12.59180	df=4	p=0.01345	
SD Following market trends	Micro	37.95%	38.55%	23.49%	166
	Small	30.38%	37.97%	31.65%	79
	Medium	20.00%	20.00%	60.00%	25
	Total	92	99	79	270
		Chi^2	df	p	
	Chi^2 Pearson	14.70820	df=4	p=0.00535	
	Chi^2 NW	13.55807	df=4	p=0.00885	

ing and packaging industry, which is opening new opportunities and business areas, it is clear that it was the main reason for medium enterprises (60 % of respondents). For small companies, it was only an additional reason (44 % of respondents), as well as for micro companies (39 % of respondents). Following market trends was also the main reason for the medium enterprises (46 % of respondents) to implement the I4.0 technologies, rather than for the other companies, where again it was an additional reason for small companies (45 % of respondents), and it was no reason for micro companies (40 % of respondents).

Table 6 consists of four main statistically significant reasons for implementing the SD practices versus company size by the assumption: (1) the same conditions of chi-square tests as above and (2) listed four main reasons for implementing the SD practices, i.e., (1) gaining a lasting strategic advantage, (2) employment reduction, (3) quick improvements, and (4) following market trends. Gaining a lasting strategic advantage was the main reason for small (41 % of respondents) and medium companies (42 % of respondents), and it was no reason for micro companies (48 % of respondents). These results correlate with the same main reasons for the I4.0 technologies because micro-enterprises are not as interested in implementing I4.0 technologies and SD practices to achieve a strategic advantage. Employment reduction is statistically significantly important for implementing SD practices. Still, it confirmed that the respondents of each company size answered that employment reduction is not the main reason for implementing the SD practices. Respondents who mostly claimed that it was no reason were from micro-enterprises (76

%), small companies (57 % of respondents), and medium companies (50 % of respondents). Quick improvements were the main reason for medium companies' respondents (48 %). For micro and small companies, this was an additional reason for implementing the SD practices, respectively, 43 % and 42 % of respondents. Following market trends was the main reason for implementing the SD practices for medium printing and packaging companies, i.e., 60 % of respondents. This was only an additional reason in micro and small companies, respectively, 39 % and 38 % of all respondents.

4. Discussion of the results

This study aimed to diagnose the level of the use of I4.0 technologies and the best practices for SD. The research sample mainly included SMEs. While responses were obtained from four large enterprises, they were not considered for further analysis due to the sample size. Thus, surveys covered SMEs only. The level of awareness both in I4.0 and SD was higher in medium-sized enterprises than in small-sized ones. The research showed that advanced companies using I4.0 technologies also apply SD practices. This correlation is especially strong for medium-sized enterprises. Another important observation is that among enterprises interested in I4.0 and SD solutions, the largest percentage comprised those already using or intending to use them in the future. At the same time, the smallest number represented enterprises in the implementation process. These may prove to be relatively simple solutions that individual companies are interested in (i.e., short implementation time).

The research results indicate that for both I4.0 and SD, most surveyed enterprises are currently not interested in using I4.0 technologies and SD practices in their operations. However, the study does not show any significant (from a statistical point of view) correlation between the implemented I4.0 technologies and the implemented SD best practices.

In addition, the research shows that printing and packaging companies are more advanced in using SD best practices than in using I4.0 technologies. The authors believe this is mainly due to the requirements for products/services set by the surveyed enterprises for their customers. Due to growing environmental concerns about packaging and printing, environmental legislation and final consumer demands for sustainable packaging have increased, encouraging businesses to consider greener materials and cleaner manufacturing processes (Nguyen et al., 2020). In addition, businesses can utilise SD practices to attract investors by providing positive signals to the product and financial markets (Zhang, Wang & Dong, 2023). Typical technical considerations towards sustainable packaging include reducing raw materials, using single- and non-toxic materials, increasing recycled contents, optimising packaging size and volume, seeking reusable options, and providing clear labels to deliver correct recycling information.

Entrepreneurs lack conviction and understanding of how I4.0 technologies can generate added value for their business. For this reason, suppliers of solutions and/or technologies and business environment units should devote more effort towards promoting the I4.0 concept and SD best practices and propagating specific applications in business practice to build sustainable business performance. Companies in the packaging industry are more experienced in the use of I4.0 technologies than companies in the printing industry. Field research has shown differences between the technologies used in the printing and packaging industries. In the authors' opinion, this differentiation should be further examined, as there are no obvious reasons. In contrast, printing and packaging companies often exchange large files with customers (e.g., 2D/3D files with patented structural design in packaging), which requires a high level of cybersecurity in both industries.

The responded enterprises from the packaging and printing sectors reported that cybersecurity is the most frequently adopted I4.0 technology. Most industry sectors, including the packaging and printing sectors, are very active in having safer and more efficient cybersecurity systems as they are highly dependent on information technology infrastructure for the overall workflow (e.g., R&D, finance, manufacturing, and quality assurance)(Ani, He & Tiwari, 2017). Approximately a quarter of the studied companies in the packaging and printing sectors reported using additive manufacturing technology. In the packaging and printing industries, additive manufacturing technology, such as 3D printing, is typically applied to prototype physical mock-ups and fabricate packaging parts. More than 20 per cent of the companies that responded from both the packaging and printing industries also reported using simulation technologies. In the packaging industry, diverse simulation technologies are used to predict mechanical properties and interactions of packaging components

(e.g., finite element analysis), calculate the best packaging size and combination for optimised storage and shipping (e.g., packaging/pallet configuration analysis), and quantify the environmental footprint of packaging (e.g., life cycle analysis). Print simulation software that virtually reproduces various printing conditions in the printing industry is often used for training, performance enhancement, process analysis, and skills assessment. The results showed that Internet of Things (IoT) technologies are more often adopted in the printing industry (27.2 %) than in the packaging industry (14 %). This result implies that the digitalisation and automation levels of the surveyed printing industry are higher than those of the surveyed packaging industry. Manual operations may be involved in the surveyed packaging industry.

Enterprises perceive technologies as investments, particularly I4.0 ones. For this reason, the economic calculation related to implementing a given solution is crucial to them. It is worth noting that the smaller the enterprise, the shorter its planning horizon. This must also be considered when promoting I4.0 and SD solutions among enterprises. Other important reasons for implementing the I4.0 technologies are the reduction of employment and quick improvements, which may indicate the willingness of enterprises to improve operational efficiency. As costs are determined to be the biggest obstacle when implementing I4.0 technologies, as shown by the authors' of the other research (Gladysz et al., 2021), it is not surprising that micro-enterprises are not as interested in the implementation of these technologies to achieve a strategic advantage as small and medium companies, i.e., 53 % of respondents answered that there was no reason.

The quantitative research produced more results, but it is challenging to draw inferences. Initially, a correlation matrix of I4.0 technologies (Table A1) and SD practices (Table A2) was made, which allowed for the comprehension of the correlation between the relevant I4.0 technologies and SD practices. A dependency matrix was also created between I4.0 technologies and SD practices (Table A3), allowing a preliminary assessment of how individual I4.0 technologies are linked to SD practices. However, these results require more in-depth research because little can be deduced from the statistical analyses.

Integrating the use of I4.0 technologies and SD practices to influence business strategy is a future research direction. Additional research may be focused on the application of individual solutions in an individual (multinational) enterprise, i.e., technology and/or good practices, in terms of the separate SDGs to build sustainable business strategies. The authors believe this requires additional studies among enterprises with experience in I4.0 technologies and SD best practices. Wider research might include examining the "supply part", i.e., enterprises offering, integrating, and implementing I4.0 technologies and the SD best practices for other entities. Despite the insignificant correlation (0.44) between the adopted I4.0 technologies and SD practices, finding synergies and trade-offs is still a long way to go. It indicates that the topic needs to be more widely discussed across multinational enterprises, and their experiences need to be disseminated and compared to boost enterprises' awareness of sustainable implications through digitalisation. On the other hand, "awareness is crucial for inclusive actions" (Gupta & Rhyner, 2022), accelerating entrepreneurs to make more sustainable decisions through rational investments in technology 4.0. Moreover, other research in the field may lead to different findings and conclusions.

Conclusions

The interviews that formed the basis for the quantitative research allowed for the conclusion that printing and packaging companies have a good or cursory awareness of the implementation of SD objectives at all three levels of management. This was also confirmed by responses regarding SD activities: various initiatives are implemented in each TBL area in line with SD policies and objectives. The picture becomes complete with the finding that SD implementation is, for most companies interviewed, at the implementation stage in selected areas or the whole company.

This allowed the authors to conclude that companies in the printing and packaging sector are quite advanced in achieving sustainability. It was also found during the interviews that some I4.0 technologies are being used in the printing and packaging sector, although the degree of progress in implementing/using I4.0 was not as high as for SD. Therefore, it was decided to investigate the degree of implementation of I4.0 and SD practices in printing and packaging companies with a representative sample and to see if and to what extent I4.0 technologies support the implementation of SD. This, in turn, allowed verifying (survey) the qualitative results (interviews) quantitatively and disclosing a complete view of the

advanced level of companies in the areas of I4.0 technology and SD practices.

The authors' investigations state that adopting I4.0 technologies and sustainability practices must establish a "mechanism" of decision-making and actions that profile integrated thinking influenced by sustainability practices. In this way, these enterprises reinforced by sustainable initiatives may contribute to achieving sustainable development objectives through leveraging digital technologies. The implications for decision-makers underlie the understanding and adoption of sustainable best practices and digital transformation requirements. It helps boost and create value with implications for sustainable business models (George & Schillebeeckx, 2022).

The study is limited due to the considered sampling and implementation of selected statistical analyses. The study is focused on selected SD and I4.0 relationships. Those limitations, however, are due to the diagnostic nature of the study and, at an early stage of research, seem unavoidable. The purpose of the study was to initially identify the existing relationships between SD and I4.0 in the selected sector, which will allow for more in-depth analysis and research in the future, e.g., more companies will be examined, the geographical coverage will increase, statistical analyses will be extended, the relationships identified within this paper will be examined.

The study was conducted in the Polish economy, where the studied sectors (printing and packaging) play important roles. Therefore, findings are limited to the Polish economy and SMEs and are mostly of a diagnostic nature. Broader generalisation would require deepening and widening the scope of the study. A plan of multiple case studies will achieve this research direction. Multiple case studies would deepen the study's scope and enable more detailed explanations of phenomena lying behind diagnosed state-of-art. In parallel, the study is currently widened by introducing it to the setting of another economy. For this purpose, the Canadian printed packaging sector was chosen, and the study was already triggered.

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Appendices

Tab. A1. Spearman's order correlation (rho) matrix of I4.0 technologies. Relevant variables in red colour (p<0.05)

VARIABLE	INTERNET OF THINGS - IOT/IIOT	AUGMENTED REALITY - AR	ADDITIVE MANUFACTURING	SIMULATION	SYSTEM INTEGRATION	BIG DATA	CLOUD COMPUTING	AUTONOMOUS ROBOTS	CYBERSECURITY
INTERNET OF THINGS – IOT/IIOT	1.000	0.424	**0.428**	0.409	0.161	0.281	0.357	0.294	0.315
AUGMENTED REALITY – AR	0.424	1.000	0.378	0.418	0.214	0.245	0.378	0.289	0.256
ADDITIVE MANUFACTURING	**0.428**	0.378	1.000	0.408	0.205	0.357	0.310	0.177	0.393
SIMULATION	0.409	0.418	0.408	1.000	0.297	0.270	0.379	0.297	0.266
SYSTEM INTEGRATION	0.161	0.214	0.205	0.297	1.000	0.216	0.176	0.291	0.197
BIG DATA	0.281	0.245	0.357	0.270	0.216	1.000	0.279	0.291	0.158
CLOUD COMPUTING	0.357	0.378	0.310	0.379	0.176	0.279	1.000	0.425	0.281
AUTONOMOUS ROBOTS	0.294	0.289	0.177	0.297	0.291	0.291	0.425	1.000	0.225
CYBERSECURITY	0.315	0.256	0.393	0.266	0.197	0.158	0.281	0.225	1.000

Tab. A2. Spearman's order correlation (rho) matrix of SD practices. Relevant variables in red colour (p<0.05)

VARIABLE	PROTECTION OF NATURAL CAPITAL	POLLUTION REDUCTION	DESIGN TO ELIMINATE HAZARDS	CORPORATE SOCIAL RESPONSIBILITY	EMPLOYMENT SECURITY	LIMITATION OF MANUAL LABOUR	EMPLOYMENT STABILITY	INCREASING REVENUE	COST REDUCTION
PROTECTION OF NATURAL CAPITAL	1.000	0.470	0.276	0.432	0.275	0.253	0.219	0.274	0.373
POLLUTION REDUCTION	0.470	1.000	0.384	0.453	0.227	0.177	0.188	0.313	0.248
DESIGN TO ELIMINATE HAZARDS	0.276	0.384	1.000	0.377	0.247	0.175	0.092	0.241	0.293
CORPORATE SOCIAL RESPONSIBILITY	0.432	0.453	0.377	1.000	0.398	0.370	0.231	0.380	0.347
EMPLOYMENT SECURITY	0.275	0.227	0.247	0.398	1.000	0.281	0.323	0.302	0.272
LIMITATION OF MANUAL LABOUR	0.253	0.177	0.175	0.370	0.281	1.000	0.204	0.222	0.178
EMPLOYMENT STABILITY	0.219	0.188	0.092	0.231	0.323	0.204	1.000	0.346	0.299
INCREASING REVENUE	0.274	0.313	0.241	0.380	0.302	0.222	0.346	1.000	**0.559**
COST REDUCTION	0.373	0.248	0.293	0.347	0.272	0.178	0.299	**0.559**	1.000

Tab. A3. Spearman's order correlation (rho) matrix of I4.0 technologies vs. SD practices. Relevant variables in red colour (p<0.05)

VARIABLE	PROTECTION OF NATURAL CAPITAL	POLLUTION REDUCTION	DESIGN TO ELIMINATE HAZARDS	CORPORATE SOCIAL RESPONSIBILITY	EMPLOYMENT SECURITY	LIMITATION OF MANUAL LABOUR	EMPLOYMENT STABILITY	INCREASING REVENUE	COST REDUCTION
INTERNET OF THINGS – IOT/IIOT	0.337	0.311	0.185	0.405	0.128	0.268	0.148	0.194	0.153
AUGMENTED REALITY – AR	0.268	0.249	0.178	0.304	0.170	0.226	0.089	0.161	0.192
ADDITIVE MANUFACTURING	0.401	0.361	0.223	0.343	0.194	0.325	0.173	0.170	0.189
SIMULATION	0.312	0.301	0.157	0.316	0.150	0.152	0.069	0.085	0.102
SYSTEM INTEGRATION	0.191	0.218	0.186	0.212	0.198	0.230	0.188	0.175	0.160
BIG DATA	0.233	0.185	0.103	0.190	0.086	0.258	0.046	0.084	0.046
CLOUD COMPUTING	0.230	0.251	0.178	0.259	0.125	0.157	0.141	0.122	0.140
AUTONOMOUS ROBOTS	0.130	0.190	0.127	0.172	0.051	0.139	0.161	0.082	0.101
CYBERSECURITY	0.302	0.351	0.177	0.382	0.189	0.186	0.181	0.182	0.257

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The future of European universities on the path to sustainable development

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ABSTRACT

The article addresses the issue of the future of European universities on the path to sustainable development. The main aim of the article is to describe foreseeable future directions of the sustainable development of universities and ways to achieve Sustainable Development Goals. In effect, the authors identify weaknesses, assess threats and recommend coordinated solutions and alternatives for the sustainable development of universities. This research will contribute to future work by explaining what the future of universities will look like on their sustainability journey. The results of the Delphi study conducted with the participation of 201 experts from 47 countries allowed for the identification of factors shaping the future of universities on the path to sustainable development.

KEY WORDS

university, sustainable development, Sustainable Development Goals, European Green Deal, artificial intelligence, resources, education, Delphi method

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Introduction

For at least a decade, the literature has argued that universities can be the main actors supporting sustainable development through research, education and implementation of solutions in the area of sustainable development in their organizations (Von Hauff & Nguyen, 2014). The future of European universities on the path to sustainable development is a crucial and multifaceted topic that involves various dimensions, such as environmental, social and economic, aiming to contribute to the sustainable develop-

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ment of stakeholders (Deleye 2023; Fisher et al., 2015; Lozano et al., 2010; Velazquez et al., 2006). Various perspectives have emerged on the concept of a sustainable university (Deleye, 2023). One perspective underscores the significance of universities in addressing global environmental challenges through education, research and community engagement, framing it as the idea of a sustainable university (Sart, 2022; Lozano et al., 2013). Another perspective revolves around the concept of an engaged community, where universities actively involve their stakeholders in initiatives promoting sustainable development (Deleye, 2023). Meanwhile, a different discourse introduces the notion of a green-tech campus, emphasizing the incorporation of sustainable technologies and practices into the university's operations (Deleye, 2023; Anthony, 2021). Higher education institutions (HEIs) address sustainable development concerns across various structural and organizational dimensions, as well as aspects related to infrastructure and energy efficiency. They pursue strategic initiatives spanning education, research, knowledge transfer and engagement with stakeholders, including partnerships and community involvement.

In contemporary discourse, universities are integrating elements of sustainable development into their strategic plans, prioritizing such goals as providing high-quality education and establishing resilient infrastructure (Abello-Romero et al., 2023). It is underscored in scholarly works that the inclusion of sustainable development issues in study programs is vital not only for ensuring high-quality education but also for contributing to the realization of the Sustainable Development Goals (Gigauri et al., 2022). The literature emphasizes that universities possess both the knowledge and influence to spearhead the transformation towards a more sustainable world (Sart, 2022; Rotondo et al., 2023).

Based on the above considerations, the aim of the article is describe foreseeable future directions of the sustainable development of universities and ways to achieve Sustainable Development Goals (SDGs).

However, very little attention has been paid to the issue of the future role of universities in sustainable development. In particular, it is important to identify factors that limit and support university activities for sustainable development.

1. Literature review

Sustainable initiatives and activities within Higher Education Institutions (HEIs) are multifaceted, occurring across various domains, as outlined by Fischer et al. (2015) and Lozano et al. (2015). Consequently, HEIs assume a catalytic role in fostering societal engagement with sustainability, as emphasized by Christensen et al. (2009). The realization of Sustainable Development Goals is contingent upon robust partnerships between academia and industry (Bodley-Scott & Oymak, 2022). Collaboratively, universities and the business sector can assume a pivotal role in addressing global environmental challenges through research, education and cooperative efforts, actively seeking ecologically sound solutions (Panait et al., 2022).

The European Union (EU) Commission has reaffirmed its commitment to implementing the 2030 Agenda for Sustainable Development to protect the environment, reduce land degradation and prevent biodiversity loss by reducing its dependence on the use of natural resources (Camilleri, 2020). Several EU policies and initiatives promote sustainable development, and universities may be indirectly influenced or encouraged to align their activities with these principles. Some relevant areas with a focus on sustainability include:

- European Green Deal (Skjærseth, 2021), as a comprehensive set of policy initiatives by the EU aimed at making the EU's economy sustainable. While it primarily focuses on climate action, it encompasses broader sustainability goals. Policies related to education and research may indirectly encourage universities to contribute to sustainable development.
- Erasmus+ Program (Nogueiro et al., 2022). While not explicitly focused on sustainable development, it supports projects and activities that can contribute to broader societal goals, including environmental sustainability.
- Horizon Europe (Lages et al., 2023). The EU's framework program for research and innovation, Horizon Europe, may include themes and calls related to sustainability. Universities participating in research projects funded by Horizon Europe may find opportunities to contribute to sustainable development goals.
- National legislation. The factors of transforming universities towards sustainability can also be considered in the national context, due to the provisions of national law (Dlouhá et al., 2017). National legislation within EU member states may also address sustainability in higher education. Some countries may have specific requirements or expectations for universities to

incorporate sustainable practices into their operations and academic programs.

Certainly, universities are recognized as key players in fostering innovation and contributing to sustainable development (Purcell et al., 2019; Sonetti et al., 2019, Lima et al., 2023, Baker-Shelley et al., 2017; Brundiers & Wiek, 2011, Casado-Aranda et al., 2020; Narasimharao, 2013; Dlouha et al., 2018). Here are several arguments why universities play a fundamental role in creating and developing innovations and products aligned with the principles of sustainable development:

- Research and development – universities are hubs for research and development. They conduct studies, experiments, and investigations across various disciplines, providing the foundation for new ideas and innovations that can contribute to sustainability (Sedlacek, 2013).
- Interdisciplinary collaboration – many sustainability challenges require interdisciplinary solutions. Universities, with their diverse faculties and departments, facilitate collaboration among experts in different fields, fostering holistic approaches to sustainable development (Yarime et al., 2012).
- Education and training – universities educate and train the next generation of professionals, including scientists, engineers, policymakers, and business leaders. By integrating sustainability principles into curricula, universities can instil a mindset of responsibility and innovation among students (Menon & Suresh, 2020).
- Technology transfer – universities often engage in technology transfer, helping to bring academic research into practical applications. This transfer of knowledge and technology can lead to the development of sustainable products, processes and technologies (Lee, 2000).

An important aspect for strengthening universities towards sustainable development is additional financial support. Such support is necessary to achieve the goals of the European Green Deal (Sukiennik et al., 2021). Universities have a key role to play in the innovation pipeline from research to industry, and in connecting academia and society through education (Cini et al., 2023) but universities are also the main centres where the drivers of innovation for sustainability and decarbonization of the built heritage are investigated and developed (Violano & Cannaviello, 2022).

Taking into account the main mission of the university, which is to educate personnel for the needs of the labour market, universities should focus on developing key competencies of students for sustainable development (Kioupi & Voulvoulis, 2019). Education aligns with the broader recognition of the importance of sustainability in various aspects of society, including the job market (Purcell et al., 2019). Here are some ways in which universities may prioritize the development of key competencies for sustainable development in their educational programs: Incorporating Sustainability into Curricula (Tasdemir & Gazo, 2020); Introducing Interdisciplinary Approaches (Zielinski et al., 2018), Ethical Decision-Making (El-Zein et al., 2018), Developing Communication Skills, Innovation and Entrepreneurship (Shu et al., 2020). By focusing on these key competencies, universities can contribute to preparing students for the needs of the future European job market, where there is an increasing emphasis on sustainability and responsible citizenship.

On the path to sustainable development, the university can be supported by artificial intelligence, which has dominated the issues of the future in many sectors in the last few years (Tanveer et al., 2020, Szpilko et al., 2023b). Certainly, technologies based on artificial intelligence (AI) can play a significant role in aiding universities on their path towards sustainable development (Kamalov et al., 2023; Casado-Aranda et al., 2020).

In summary, universities are crucial drivers of innovation and play a pivotal role in creating and developing solutions that align with the principles of sustainable development. Through research, education, collaboration and practical initiatives, universities contribute significantly to addressing global sustainability challenges.

2. Research methodology

The research presented in this article was based on one of the expert methods, the Delphi method. It is widely used in a variety of sectors, including education (Popov et al., 2019, Tran et al., 2020). The implementation of the Delphi study is justified in situations of high uncertainty, in this case – future directions of the sustainable development of universities (Beiderbeck et al., 2021; Niederberger & Spranger, 2020).

2.1. Development of the theses

In the classical approach, the Delphi study is preceded by the formulation of Delphi theses or projections and ancillary questions. The Delphi theses refer to the future description of dependencies between issues arising from the field of the study and a setting determined by the goal of the conducted research (Kuźmicz et al., 2022; Szpilko, 2014; Ejdys & Szpilko, 2023).

The purpose of developing the theses was to describe foreseeable future directions of the sustainable development of universities.

The research process consisted of six stages (Figure 1). It began with a detailed review of the literature on the topic of sustainable universities and their determinants. As a result, at the second stage of the research process, the initial set of 25 theses was identified. Moreover, the literature review allowed for the recognition of 30 contributing factors and 8 barriers. The final list of 5 theses on future directions of the sustainable development of universities together with contributing factors and barriers (6 items each) was prepared at the third stage. Some reductions were made by removing repetitions and eliminating the items with lower significance for the analysed topic.

The next stage covered the realisation of the first round of the Delphi survey by sending it to 6,800 experts. As a result, 207 respondents filled in online surveys. The second round of the Delphi survey allowed for the collection of responses from 201 experts. At the last stage of the research process the data were analysed and the results were developed.

The final list of the theses is presented in Table 1.

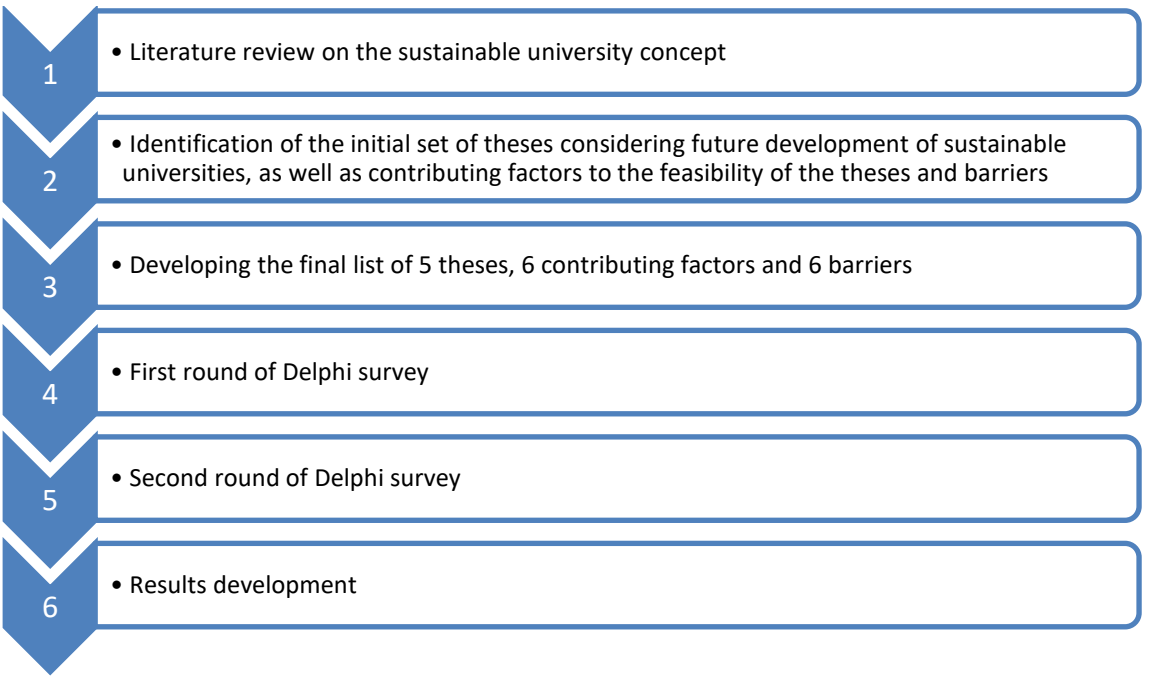

Fig. 1. Stages of research process

Tab. 1. Delphi theses

Symbol of the thesis	Final formulation of the thesis
T1	European Union's policy will obligate universities to implement and monitor the principles of sustainable development
T2	Universities will play a fundamental role in creating and developing innovations and products in line with the principles of sustainable development
T3	European Union countries will invest additional financial resources in the sustainable development of universities to fulfil the objectives of the European Green Deal
T4	In educating students for the needs of the future European job market, universities will focus on developing key competencies for sustainable development
T5	Technologies based on artificial intelligence will aid universities on their path towards sustainable development

The below final set of five theses included in the research process are presented and justified accordingly.

Thesis 1. European Union's policy will obligate universities to implement and monitor the principles of sustainable development

By obligating universities to implement and monitor the principles of global sustainable development goals, the EU aligns with international efforts to address environmental, social and economic challenges (Fernandez-Izquierdo et al., 2019; Sonetti et al., 2019; Szydło et al., 2023). Moreover, embedding sustainable development principles in education prepares students for workforce increasingly focused on sustainability. Graduates will possess the knowledge and skills needed to contribute to sustainable practices in various industries and sectors. What is also crucial is that universities often receive funding and support from the European Union. Compliance with sustainable development principles may become a criterion for eligibility, encouraging universities to align with these principles to access resources and opportunities (Filho et al., 2017).

Thesis 2. Universities will play a fundamental role in creating and developing innovations and products in line with the principles of sustainable development

Universities are centres for research and development. They have the intellectual capital and infrastructure to conduct in-depth research on sustainable technologies, materials and practices (Purcell et al., 2019). Universities as hubs of research and innovation can be encouraged to prioritize research projects that contribute to sustainable development, fostering technological advancements and solutions. Universities employ experts across various disciplines. By leveraging the interdisciplinary expertise of faculty members and researchers, universities can contribute valuable insights to the development of sustainable innovations (Lima et al., 2023). Those innovations can be commercialized and they can reach the market to have a tangible impact on industries. Collaborative efforts between universities and industries can lead to the development of sustainable products. Industry partnerships provide resources, funding and real-world applications for university research (Ávila et al., 2017). Many universities have incubators and innovation centres that support the development of startups and entrepreneurial ventures (Vardhan & Mahato, 2022; Kobylińska & Irimia-Dieguez, 2023). These entities can focus specifically on sustainable innovations, fostering a culture of entrepreneurship in line with sustainable development principles.

Thesis 3. European Union countries will invest additional financial resources in the sustainable development of universities to fulfil the objectives of the European Green Deal

The European Green Deal is a comprehensive strategy aimed at making the EU's economy sustainable. Investing in the sustainable development of universities aligns with the overarching goals of the European Green Deal, making it likely that financial resources will be allocated to support this initiative (Eckert & Kovalevska, 2021). The European Green Deal emphasizes the importance of education and research in achieving sustainability objectives (Szpilko & Ejdys, 2022). Universities, as key players in education and research, are expected to receive increased financial support to contribute to the implementation of the Green Deal. EU frameworks, such as Horizon Europe, the EU's flagship research and innovation program, place a strong emphasis on sustainability. Universities engaging in projects that align with the European Green Deal may access additional funding through these frameworks (Eckert & Kovalevska, 2021).

Thesis 4. In educating students for the needs of the future European job market, universities will focus on developing key competencies for sustainable development

The future European labour market is expected to have a growing demand for professionals with skills and knowledge related to sustainable development. Universities, recognizing this trend, will prioritize the development of competencies that make graduates more attractive to employers in environmentally conscious industries (Brundiers & Wiek, 2011). Competencies related to such sustainable development as eco-design, renewable energy and circular economy principles (Gospodarowicz et al., 2023), will prepare students to adapt to changing work environments and industry expectations. Sustainable development often requires innovative solutions to complex problems. Following that, it is crucial developing students' critical thinking, problem-solving and innovation skills, preparing them to address sustainability challenges in their future careers (Murga-Menoyo, 2014; Rollnik-Sadowska, 2023; Kobylińska & Ryciuk, 2022; Rollnik-Sadowska et al., 2023). As sustainability issues are inherently interdisciplinary, universities should emphasize the development of competencies that enable students to work across disciplines, fostering collaboration and ensuring that graduates can contribute to holistic solutions in various professional settings.

Thesis 5. Technologies based on artificial intelligence will aid universities on their path towards sustainable development

AI technologies can optimize resource allocation and utilization within universities, leading to more efficient energy usage, reduced waste and cost savings. Smart systems powered by AI can help manage campus facilities in a way that minimizes environmental impact. Moreover, AI enables universities to analyse large sets of data to make informed decisions about sustainability initiatives. From energy consumption patterns to waste management, AI-driven analytics provide valuable insights that guide universities in implementing effective and targeted sustainability strategies. Additionally, AI-powered virtual learning platforms can facilitate remote education, reducing the need for physical travel and campus infrastructure (Kamalov et al., 2023; Casado-Aranda et al., 2020; Szpilko et al., 2023a). This not only contributes to sustainability but also increases accessibility to education. AI technologies can also accelerate research in sustainable development by analysing vast amounts of data, simulating complex scenarios and identifying patterns that contribute to the advancement of green technologies and practices.

2.2. Experts selection

In the Delphi study it is crucial to select appropriate experts, which significantly influences the reliability of research results (Schuckmann et al., 2012). In selecting the expert panel for the Delphi study it

Tab. 2. The structure of Delphi experts by category of stakeholder [N=201]

Category of stakeholder	Share
scientists/researchers	75.62%
teachers	52.24%
university staff	26.87%
students	2.99%
companies/industry	2.99%
national policy-makers	1.00%
NGOs	6.47%
special interest groups e.g., volunteer contributors and citizen scientists	3.98%
other	2.49%

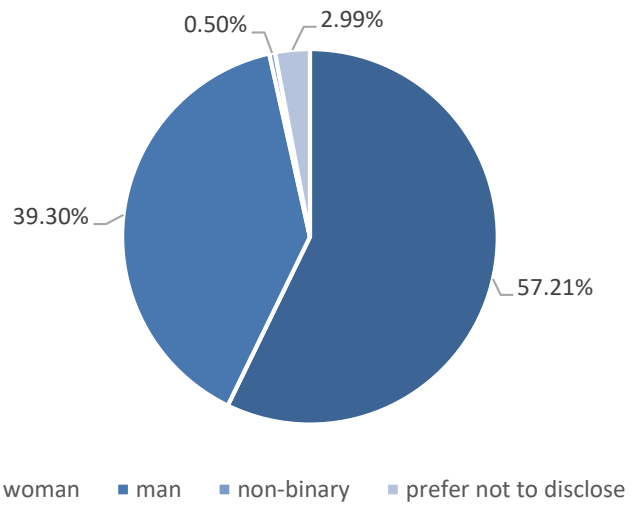

Fig. 2. The structure of Delphi experts by gender [N=201]

Tab. 3. The structure of Delphi experts by country [N=201]

COUNTRY	SHARE		COUNTRY	SHARE
Austria	1.49%		Ukraine	8.96%
Belgium	0.50%		Serbia	2.99%
Bulgaria	1.49%		Norway	1.49%
Croatia	2.49%		Brazil	1.49%
Czechia	1.99%		United Kingdom	1.99%
Denmark	0.50%		Basque Country	0.50%
Estonia	0.50%		Belarus	0.50%
Finland	1.99%		Canada	0.50%
France	1.49%		Ecuador	0.50%
Germany	4.48%		Egypt	0.50%
Greece	2.49%		Iceland	0.50%
Hungary	1.00%		India	0.50%
Ireland	1.00%		Jordan	0.50%
Italy	2.49%		Kosovo	0.50%
Latvia	3.48%		Malaysia	0.50%
Lithuania	2.49%		North Macedonia	0.50%
Netherlands	1.49%		Russia	0.50%
Poland	10.95%		Russian Federation	0.50%
Portugal	9.95%		Switzerland	0.50%
Romania	7.96%		Thailand	0.50%
Slovakia	0.50%		Turkey	0.50%
Slovenia	1.49%		Ukraine and Germany	0.50%
Spain	15.92%		United Arab Emirates	0.50%
Sweden	3.48%			

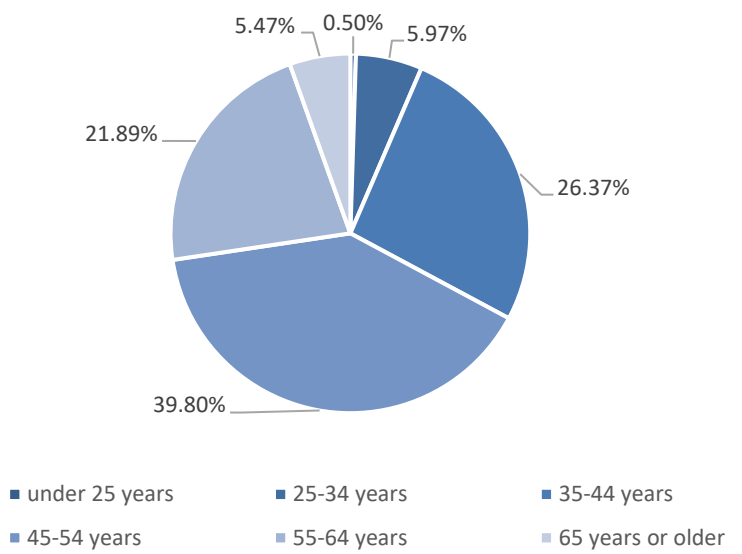

Fig. 3. The structure of Delphi experts by age [N=201]

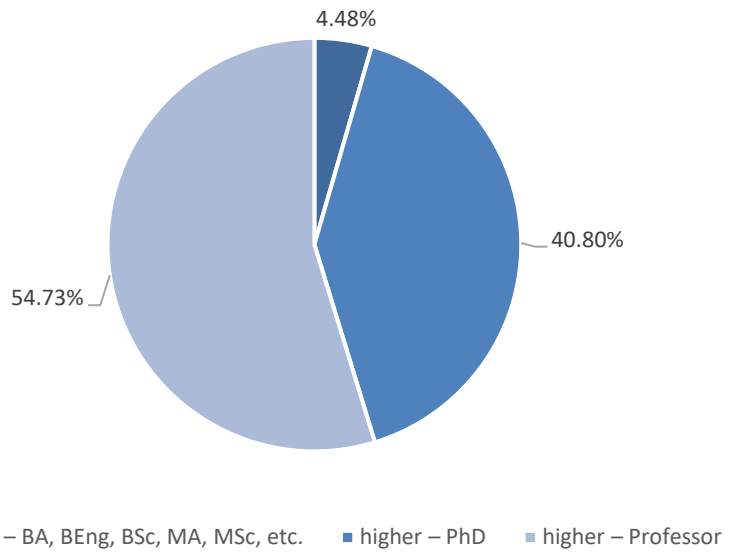

Fig. 4. The structure of Delphi experts by education [N=201]

needs to be stressed not only finding a heterogeneous group willing to participate but also considering their professional background, location and expertise (Melander, 2018). There are different approaches to select Delphi experts, one of them is to invite experts who have at least one international publication in Web of Science/Scopus indexed Journals on the analysed topic (Tran et al., 2020). For that study the experts were identified through the Web of Science database as 6,800 of them are the authors of publications on the topic of sustainable universities.

Experts represented different categories of stakeholders, some of them more than one (Table 2).

The Delphi survey participants came from all over the world (Table 3). However, the biggest shares, exceeding 10% were represented by the respondents from Spain and Poland. The majority of experts (57%) were women (Figure 2). The respondents were diversified by age (Figure 3). The biggest share of experts – 40% were 45-54 years old, 26% were 35-44 and 22% were 55-64.

The experts participating in the study were well-educated as all of them had higher education (Figure 4). The majority of them – 55% – held a Professor's position and 41% – PhD.

2.3. The procedure of conducting the Delphi study

The significance (Si) of the theses for the sustainable development of universities were assessed according to the formula (based on Kononiuk et al., 2021; Ejdys et al., 2023):

$$S_i = \frac{100*n_{VH}+75*n_H+50*n_A+25*n_L+0*n_{VL}}{n} \quad (1)$$

where:
n_{VH} –number of responses 'very high',
n_H – number of responses 'high',
n_A – number of responses 'average',
n_L – number of responses 'low',
n_{VL} – number of responses 'very low',
n – number of responses,
I – number of Delhi round.

The indicator S_i takes values from 0 to 100. The closer the value is to 100, the greater the importance of the thesis for development of sustainable universities.

The experts assessed also the impact of the contributing factors and the barriers on the feasibility of the thesis. The contributing factor indicators (C) and the barrier indicators (B) were calculated according to formula (2) and formula (3) respectively (based on Kononiuk et al., 2021; Ejdys et al., 2023).

$$C = \frac{100*n_{VH}+75*n_H+50*n_A+25*n_L+0*n_{VL}}{n} \quad (2)$$

where:
nVH – number of responses 'very high',
nH – number of responses 'high',
nA – number of responses 'average',
nL – number of responses 'low',
nVL – number of responses 'very low',
n – number of responses.

$$B = \frac{100*n_{VH}+75*n_H+50*n_A+25*n_L+0*n_{VL}}{n} \quad (3)$$

where:
nVH – number of responses 'very high',
nH – number of responses 'high',
nA – number of responses 'average',
nL – number of responses 'low',
nVL – number of responses 'very low',
n – number of responses

3. Results

The study was divided into two rounds. The experts assessed the significance of individual theses for the sustainable development of universities. The conducted analyses were presented in a comparative approach. The significance indicators from both rounds showed high convergence, the focus was on presenting the results of the second round. All five theses were evaluated as important to very important, as evidenced by the value of the significance indicators (Figure 5).

In the analysed set of the theses, the highest significance indicator was recorded for Thesis 3. European Union countries will invest additional financial resources in the sustainable development of universi-

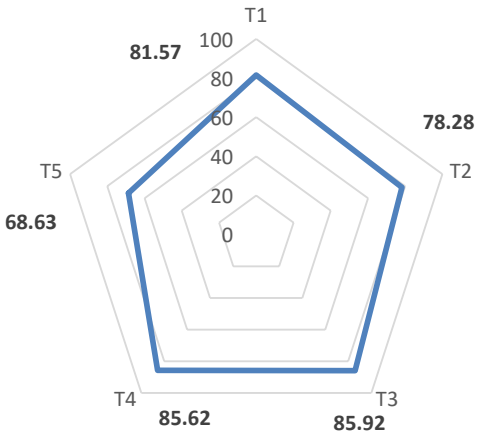

Fig. 5. Significance indicators for the theses in the University Sustainable Development (Round II results)

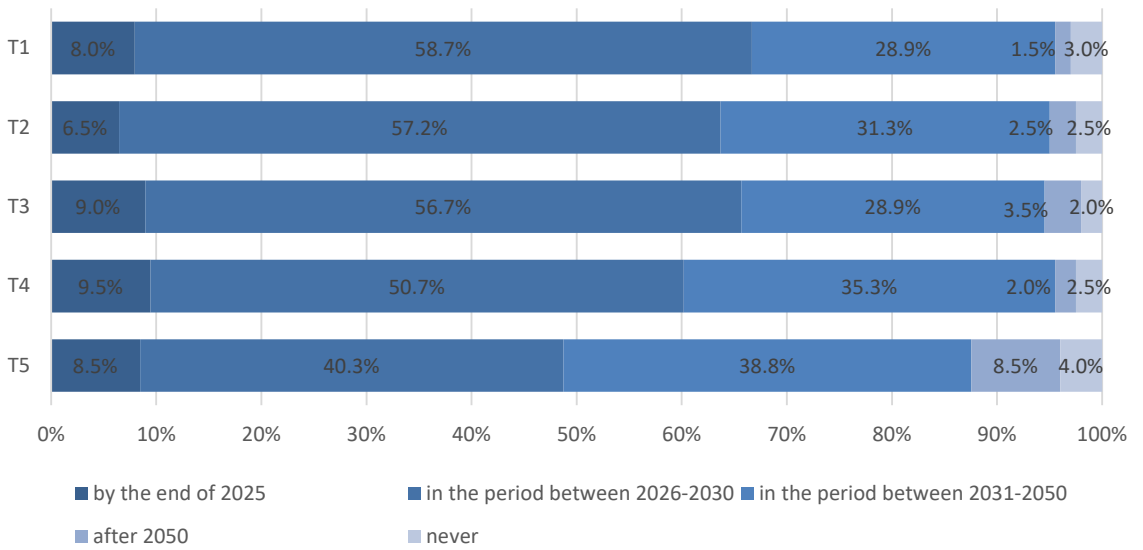

Fig. 6. Time horizon for the implementation of the theses

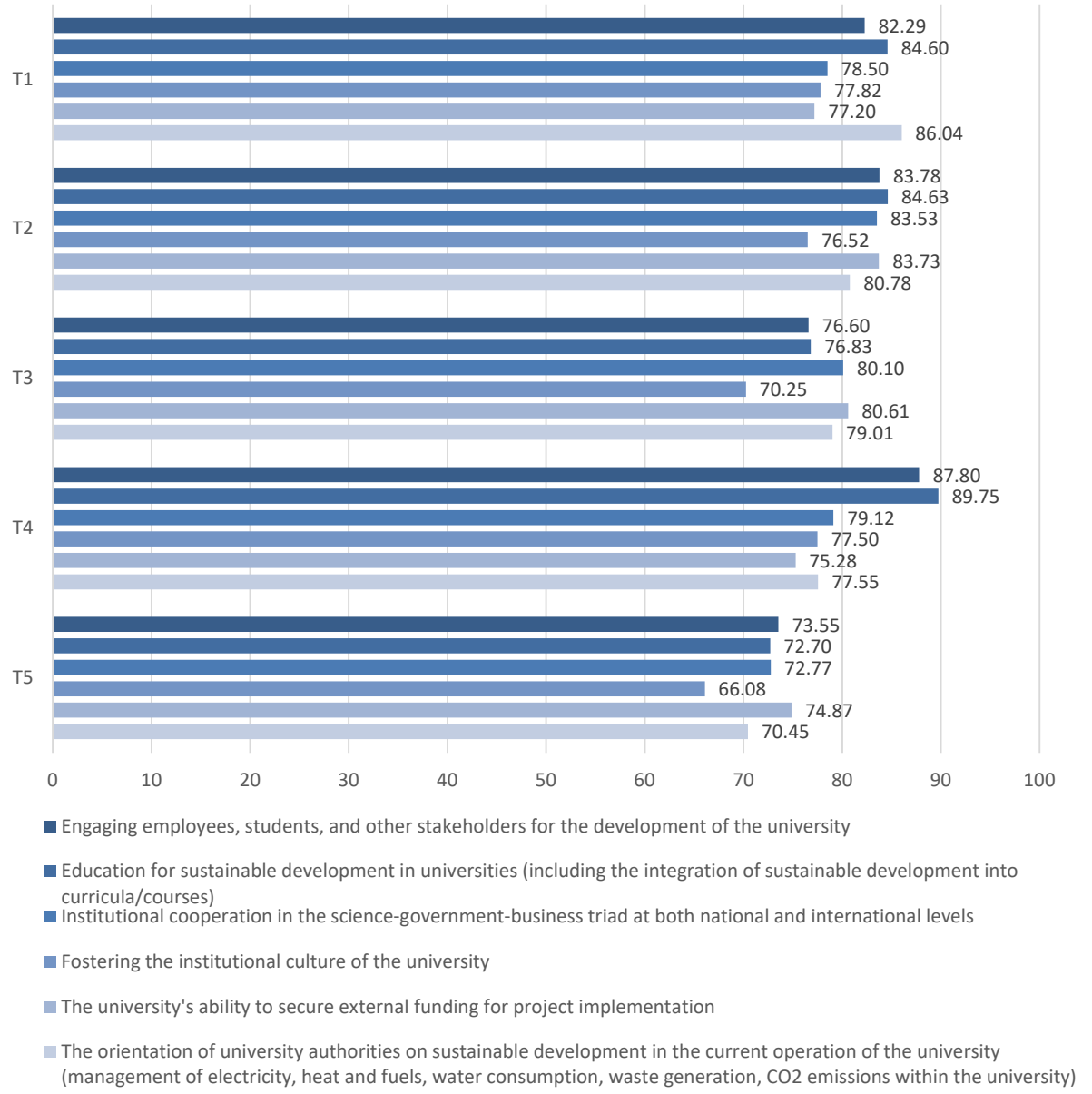

Fig. 7. Indicators of the impact of the contributing factors on the feasibility of the theses

ties to fulfil the objectives of the European Green Deal. The experts concluded that financial support would significantly impact the sustainable development of universities. Another very high indicator was related to Thesis 4. In educating students for the needs of the future European job market, universities will focus on developing key competencies for sustainable development. After the first round, it was 83.45, and after the second round, it increased to 85.62. In this case, the experts emphasized the importance of education. Another high indicator was noted for Thesis 1. European Union's policy will obligate universities to implement and monitor the principles of sustainable development. After the first round, it was 79.86, and after the second round, it increased to 81.57. The experts recognized the validity of implementing sustainable development goals and monitoring the various stages of this process. High indicators were also observed for Thesis 2. Universities will play a fundamental role in creating and developing innovations and products in line with the principles of sustainable development. After the first round, it was 77.54, and after the second round, it increased to 78.28. The experts appreciated this innovative approach by universities to sustainable development issues. The lowest significance indicator, although

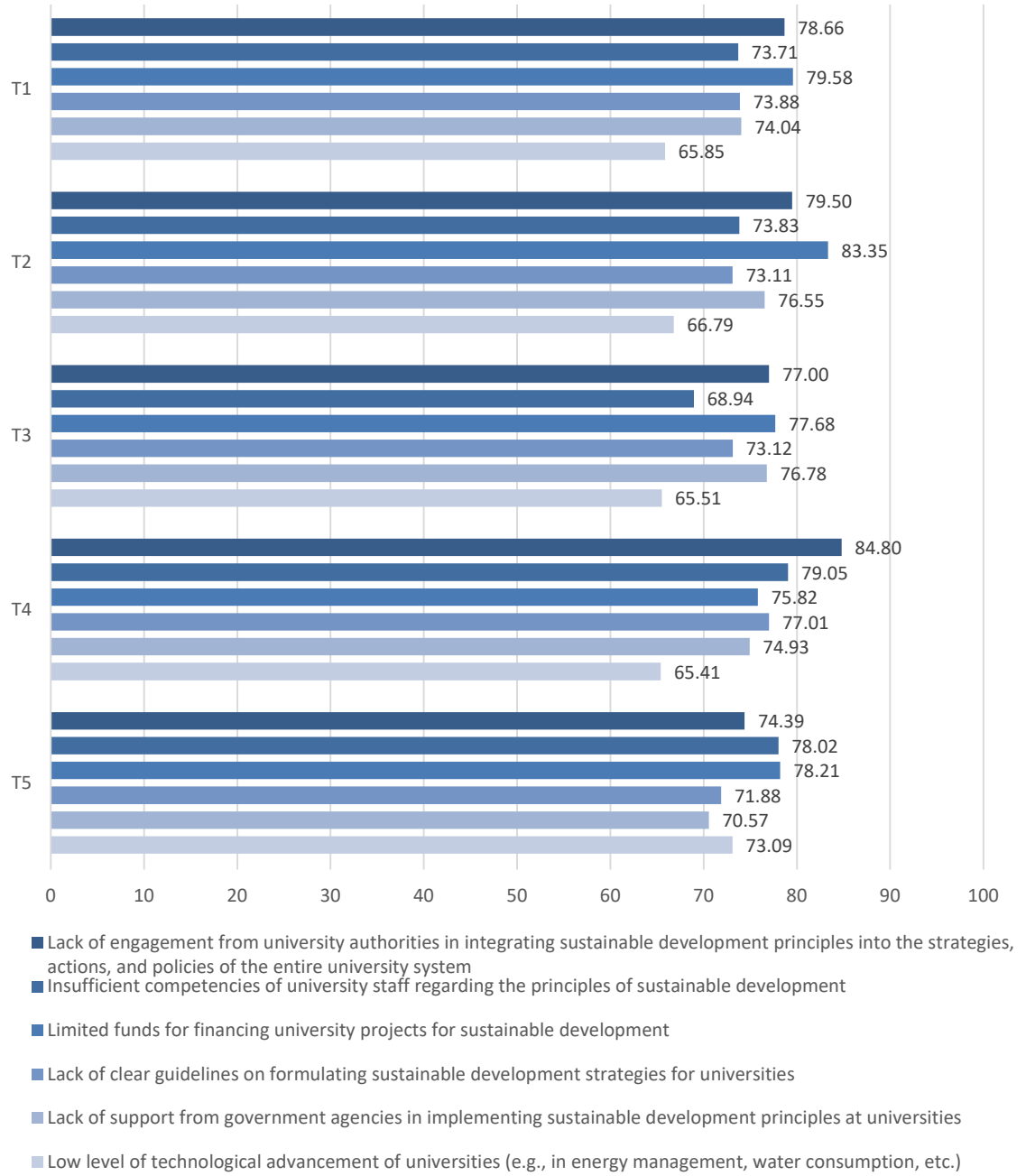

Fig. 8. Indicators of the impact of the barriers on the feasibility of the theses

still relatively high, pertained to Thesis 5. Technologies based on artificial intelligence will aid universities on their path towards sustainable development. After the first round, it was 68.45, and after the second round, it increased to 68.63. The experts took into account the importance of artificial intelligence in supporting sustainable development goals.

In the second part of the survey, the experts gave their opinion on the estimated time of realisation of theses. The implementation time of the theses was evaluated by selecting one of the five responses: 'by the end of 2025,' 'in the period between 2026-2030,' 'in the period between 2031-2050,' 'after 2050' and 'never' (Figure 6). It should be emphasized that the assessment of the schedule for implementing the theses is characterized by a similar pattern of responses, as in the prior case. There were no discrepancies in the results between the two rounds.

In the opinion of the majority of experts (around 80%), the statements included in the theses will be implemented in the years 2026-2030 or in the years

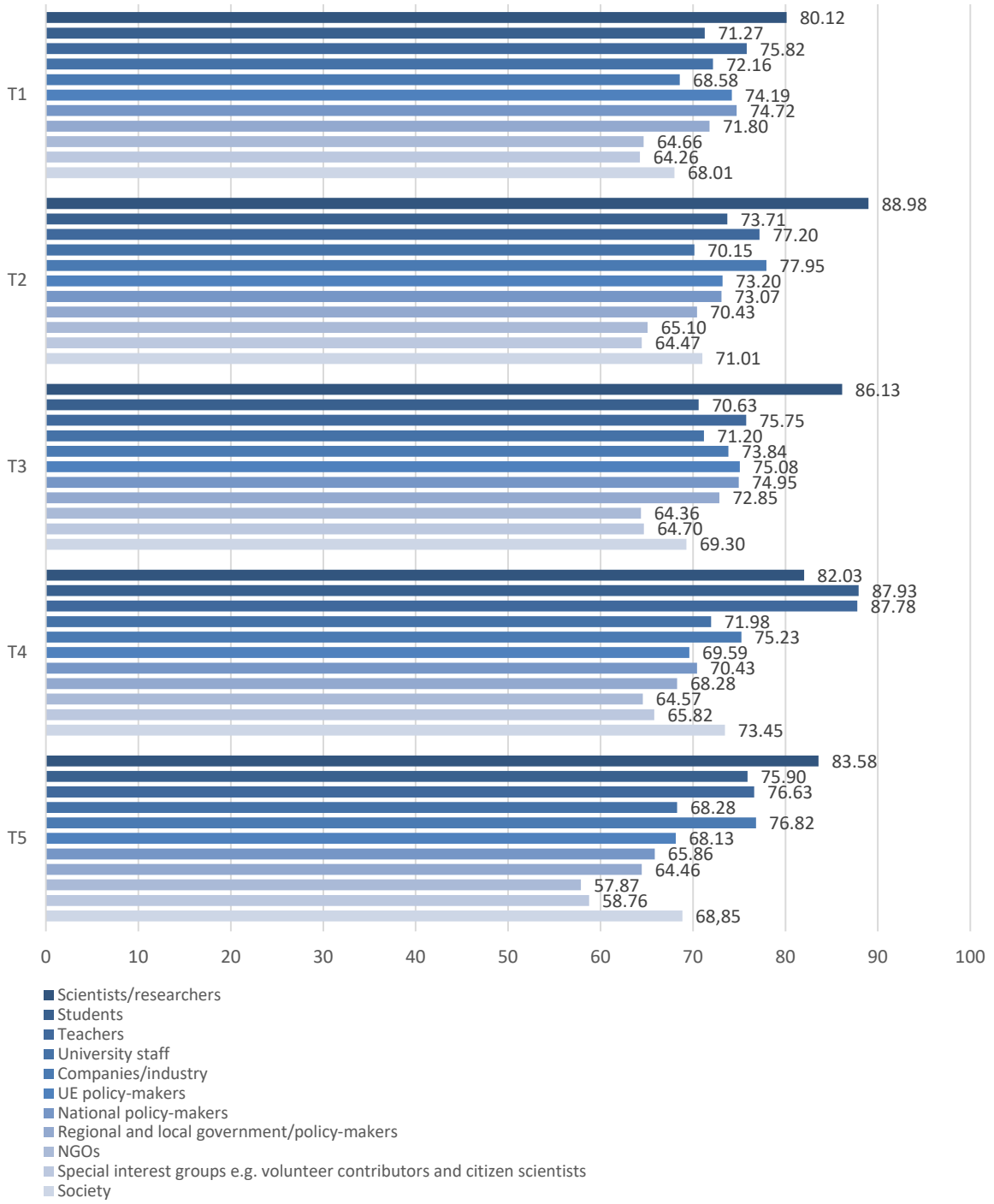

Fig. 9. Stakeholder impact indicator

2031-2050. For T3 and T4, only about 9% of experts believe that they will be implemented by the end of 2025. Regarding T1 and T5, about 8% of the experts share this view, while for T2, the percentage of the experts is slightly lower (6.5%). As for a longer time perspective, only in the case of T2, just over 8% of the respondents believe that the assumptions of the thesis will be implemented after 2050. In other cases (T1-T4), considerably fewer respondents believe this to be the case (about 2%). Analysing the data presented in Figure 6, it can also be observed that a low percentage of the experts (between 2-4%) claim that the relationships described in theses T1-T5 will never occur.

The next stage focuses on factors that support the implementation of the thesis. The results are presented in Figure 7.

Regarding Thesis 1. European Union's policy will obligate universities to implement and monitor the principles of sustainable development, the most supportive factor is I6 – the orientation of university authorities on sustainable development in the current operation of the university (management of electricity, heat and fuels, water consumption, waste generation, CO2 emissions within the university) (indicator value: 86.04). Other significant factors include I2 – education for sustainable development in universities (including the integration of sustainable development into curricula/courses) (indicator value: 84.60) and I1 – engaging employees, students and other stakeholders for the development of the university (indicator value: 82.29). The remaining factors proved to be only slightly less important than those mentioned earlier. These include I3 – institutional collaboration in the science-government-business triad at both national and international levels (indicator value: 78.50), I4 – fostering the institutional culture of the university (indicator value: 77.82) and I5 – the university's ability to secure external funding for project implementation (indicator value: 77.20).

For Thesis 2. Universities will play a fundamental role in creating and developing innovations and products in line with the principles of sustainable development, four out of the six factors proved to be very important: I2, I1, I3, and I5 (indicator values: 83.53-84.63). Slightly less significant were factors I6 (indicator value: 80.78) and I4 (indicator value: 76.52).

Analysing the results related to Thesis 3. European Union countries will invest additional financial resources in the sustainable development of universities to fulfil the objectives of the European Green Deal, the most supportive factors were I5 (indicator value: 80.61) and I3 (indicator value: 80.10), while the least supportive factor was I4 (indicator value: 70.25).

For Thesis 4. In educating students for the needs of the future European job market, universities will focus on developing key competencies for sustainable development, the most supportive factor is I2 (indicator value: 89.75). It is worth noting that this is the highest value in the entire study. Another significant factor is I1 (indicator value: 87.80). The remaining indicators have values below 80.

Regarding Thesis 5. Technologies based on artificial intelligence will aid universities on their path towards sustainable development, all factors had values below 75. The most important factor was I5 (indicator value: 74.87), and the least significant factor was I4 (indicator value: 66.08).

According to the experts' opinions, 'engaging', 'education', and 'institutional cooperation' are considered to contribute the most to the feasibility of the majority of the theses (T1-T4).

A summary of the respondents' assessment of the barriers to the feasibility of the thesis is presented in Figure 8. The values of indicators vary in the range from 65.41 to 84.80.

In relation to Thesis 1. European Union's policy will obligate universities to implement and monitor the principles of sustainable development, the most significant barrier is B3 – limited funds for financing university projects for sustainable development (indicator value: 79.58). Another obstacle to the thesis implementation may be B1 – lack of engagement from university authorities in integrating sustainable development principles into the strategies, actions, and policies of the entire university system (indicator value: 78.66). Other barriers include: B5 – lack of support from government agencies in implementing sustainable development principles at universities (indicator value: 74.04), B4 – lack of clear guidelines on formulating sustainable development strategies for universities (indicator value: 73.88) and B2 – insufficient competencies of university staff regarding the principles of sustainable development (indicator value: 73.71). The least burdensome barrier might be B6 – low level of technological advancement of universities (e.g., in energy management, water consumption, etc.) (indicator value: 65.85).

For Thesis 2. Universities will play a fundamental role in creating and developing innovations and products in line with the principles of sustainable development, the most significant barrier may be B3 (indicator value: 83.35). It is important to note that B1 may also be of significant importance (indicator value: 79.50). Similar to Thesis 1, barrier B6 might be the least significant (indicator value: 66.79).

Analysing the results related to Thesis 3. European Union countries will invest additional financial resources in the sustainable development of universities to fulfil the objectives of the European Green Deal, the most burdensome factors also turned out to be B3 (indicator value: 77.68) and B1 (indicator value: 77.00). B4 obtained a similar indicator value.

The implementation of Thesis 4. In educating students for the needs of the future European job market, universities will focus on developing key competencies for sustainable development undoubtedly can be hindered significantly by B1 (the highest indicator in the study: 84.80), and the least by B6 (indicator value: 65.41).

In the case of Thesis 5. Technologies based on artificial intelligence will aid universities on their path towards sustainable development two barriers are particularly significant: B3 (indicator value: 78.21) and B2 (indicator value: 78.02).

According to the experts' opinions, 'lack of engagement from university authorities,' 'insufficient competencies of university staff' and 'limited funds' are considered to be the most significant factors that can hinder the implementation of all the theses.

The implementation of sustainable development principles in universities largely depends on the attitude of authorities, the willingness of staff to develop, the ability to collaborate with various entities, and the acquisition of funding. These factors can be both the greatest support and the greatest constraint in achieving Sustainable Development Goals. The experts also emphasize this in their comments: 'universities should create a conducive atmosphere for research, provide financial support, and collaborate with businesses for technology transfer. International cooperation: participation in international exchange programs and collaboration with universities from other countries expand opportunities for students and faculty, fostering the exchange of knowledge and ideas.' Literacy and competencies are essential to enable critical thinking on effective action. This combined with external and internal policy drivers with implementation timelines and funding support then buoys the universities forward.

The universities must create a culture of sustainable development. 'University leaders should be pushed towards personal development: getting touch with themselves, their personal needs and personal values. After that they should be trained in upholding their ethical values in their working environment. They should be supported to a nurturing team surrounding them. Such micro-communities could change university culture so the sustainable development process might be taken in a fair and just way.' For the sustainable development of universities, it is necessary to take a number of actions covering various aspects of university activities: development and implementation of a development strategy.

The study also assessed the strength of the theses' impact on stakeholders (Figure 9). The values of indicators vary in the range from 57.87 to 88.98.

Regardless of the statements presented in the theses, it is clear that the highest values of the indicators were obtained for the impact of the theses on scientists/researchers who are among the main stakeholders of the implemented research. High scores for the theses' impact indicators were also obtained for teachers, students as well as companies and industries. In contrast, the lowest indicator values, regardless of the thesis, were obtained for NGOs and special interest groups, e.g., volunteer contributors.

The experts acknowledge that sustainable development is essential for universities to establish responsible and resilient academic institutions capable of meeting the needs of present and future generations. Achieving sustainable development in universities necessitates a long-term and comprehensive commitment to environmental, social and economic responsibility. 'Universities play a vital role in educating future leaders and can influence positive change in society through their own sustainable practices and the values they instil in students and staff.' Building relationships with decision-makers at various levels is also important.

University researchers, academic staff and students should work in partnership with citizens, the private and the public sector, co-creating in this way knowledge to produce solutions required for sustainable development.

4. Discussion

The expert study shows that the main priorities of sustainable development – operating responsibly and with future generations in mind – are part of the basic objectives of higher education. It is not surprising, then, that the argument that sustainable development can be seen as the fourth mission of Higher Education Institutions (HEIs) is often cited in the literature (Hueske et al., 2022; Ozdemir et al., 2020; Bien & Sassen, 2019). Universities, as leaders of intellectual social and economic life, can set the course for activities conducive to the implementation of the Green Order strategy on many levels: didactic, scientific, organisational, as well as being centres of innovation, culture, awareness and social activity (Cuesta-Claros et al., 2022; Berchin et al., 2021; Szydło & Grześ-Bukłaho, 2020).

The respondents to the survey underline that sustainable development at universities is a continuous process that requires commitment, collaboration and a holistic approach covering different aspects of university activities: academic, financial, administrative, social, campus operations etc. To ensure the sustainable development of universities, it is necessary to take a number of actions and measures

that will contribute to improving the quality of education and the competitiveness of educational institutions.

It is therefore not surprising that the results of the study unequivocally confirm theses T1 – T3. Parr et al. (2022) observe that 'if universities do not embrace the 2030 Agenda, it will be difficult, even impossible, to achieve.' Although the institutional context recognizes the importance of the role of HEIs in achieving the Sustainable Development Goals (SDGs), the respondents point to the expectations of higher education institutions regarding the implementation of the new regulatory framework by the European Union, which on the one hand will force action in this area in HEIs, and on the other hand – will create new rules for financing higher education. The study thus shows that real efforts to implement the SDGs are lagging behind in many academic centres which are waiting for the establishment of new guidelines and new funding rules. Thus, previous studies indicating that HEIs are predominantly in the early stages of SD are confirmed. For instance, Aleixo et al. (2018), assuming five stages of implementing SD: (i) innovators, (ii) early adopters, (iii) early majority, (iv) late majority and (v) laggards, claims that the majority of Portuguese higher education facilities are currently at the stages: laggards and late majority. They also add that although universities are beginning to consider all dimensions of sustainable development in their strategic and communication plans, the majority of practices related to these dimensions still remain in the planning stages. It seems, therefore, that HEIs themselves should undertake broader actions to accelerate their transition towards sustainable development. As noted by Hueske and Guenther (2021), international and national institutions can be both drivers for the implementation of SDGs in HEIs, but on the other hand, they may contribute to the creation of new legislative barriers and inefficiencies in the allocation of public funds.

The experts also unanimously confirm thesis T4. As Sady et al. (2019) indicate, 'there is a consensus among researchers that universities play an important role in meeting the challenges of sustainable development through education.' The majority of academic literature explorers highlight the role of education as a tool for the implementation of SDGs (Serafini et al., 2022).

Still, a relatively lowest number of responses 'very high significance' concerned thesis T5. Although it was confirmed, the experts were divided on the scope of using technologies based on artificial intelligence (AI) in achieving SDGs. This can be explained by the research by Vinuesa et al. (2020), who observe that AI might impact – both positively and negatively – all aspects of sustainable development. They find that AI can enable the accomplishment of 134 targets agreed in the 2030 Agenda for Sustainable Development across all the 17 SDGs, but it may also inhibit 59 targets. However, that add that 'the fast development of AI needs to be supported by the necessary regulatory insight and oversight for AI-based technologies to enable sustainable development. Failure to do so could result in gaps in transparency, safety, and ethical standards.' This does not change the fact that current and future managers of HEIs must be prepared to understand and leverage opportunities related to the use of modern technologies as a supporting tool for SDGs (Goralski & Tan, 2020).

The respondents of the study also point out the main barriers to the implementation of sustainable development, which are: i) lack of engagement from university authorities in integrating sustainable development principles into the strategies, actions and policies of the entire university system, ii) limited funds for financing university projects for sustainable development, but also iii) lack of clear guidelines on formulating sustainable development strategies for universities. This is confirmed by Hueske and Guenther (2021), who also identify these barriers as crucial to improve sustainability implementation strategies in institutions of higher education. The results of the study also correspond to previous findings by Blanco-Portela et al. (2018, 2017). Many scientists conclude that HEIs, as slow-moving institutions, are resilient to change (Hueske & Guenther, 2021; Filho et al., 2019; Lozane et al., 2013).

Therefore, the authors of this paper wish – based on additional comments and suggestions of the experts – to propose the Framework of implementation of SDGs in HEIs (Figure 10).

The authors propose a framework by identifying four main areas.

1. Institutional framework:
    - Regulatory support:
        - modernization of the entire education system in terms of implementing SDGs and making education and research for sustainable development a priority;

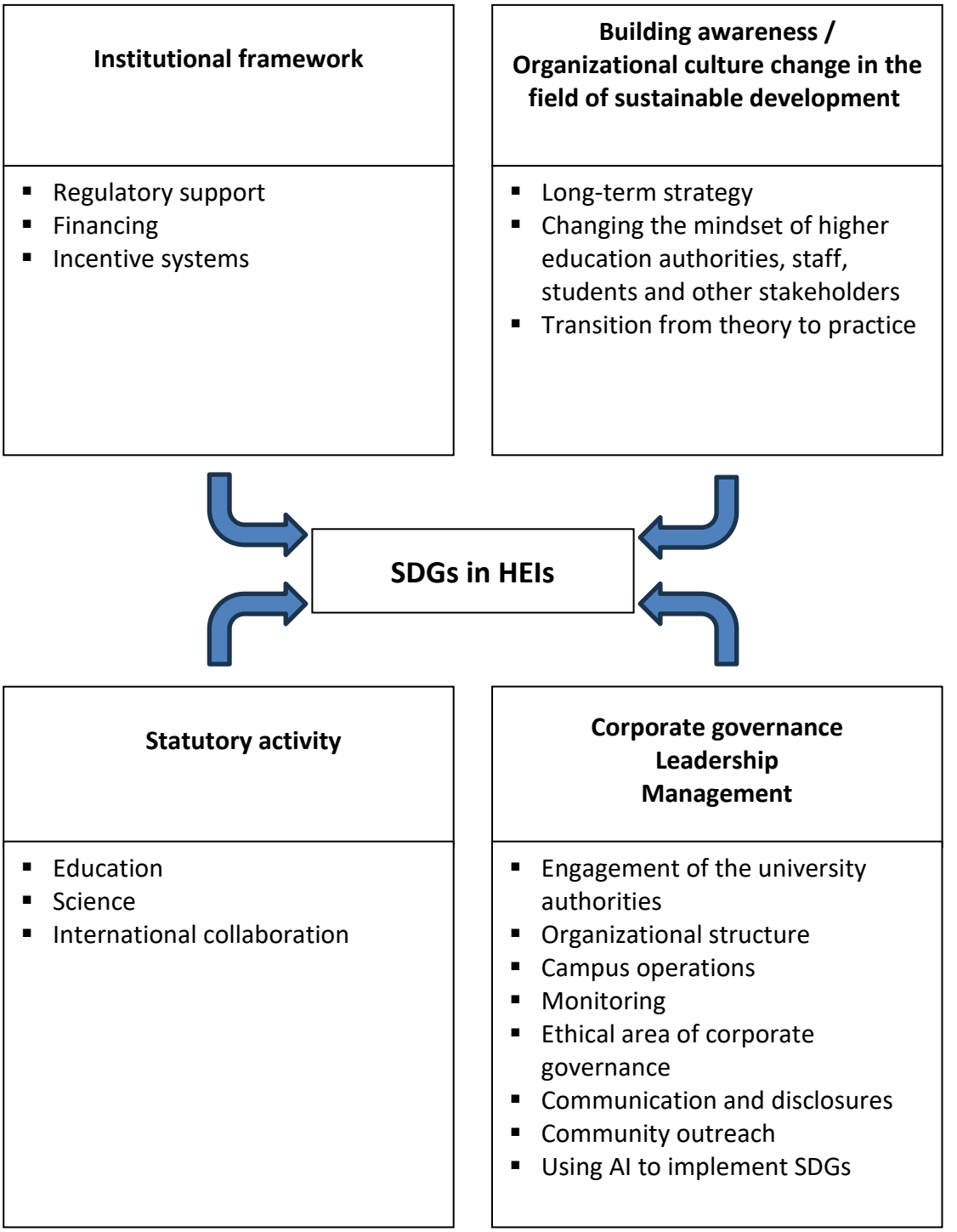

Fig. 10. Framework of implementation of SDGs in HEIs
Source: own study based on the comments of the experts.

- limiting funds for actions contrary to the sustainable development goals of universities.

- Financing:
  - funding universities in their three core activities: teaching, research and knowledge transfer;
  - assigning funding sources to actions for sustainable development.
- Incentive systems:
  - creation and implementation of dedicated programs and supportive tools for supporting sustainable development;
  - development of programs supporting the green transformation of HEIs, especially in terms of infrastructure;
  - establishment of funds or grants supporting sustainable development projects initiated by scientists, educators and students.

2. Building awareness / Organizational structure change in the field of sustainable development:
   - Long-term strategy:
     - reclaiming the role of the university as an active entity in the necessary ecological-social transformation of European society;
     - defining a strategic plan tailored to achieve sustainable development goals;
     - establishing a roadmap for reducing the emission balance of HEIs by 2050.
   - Changing the mindset of university authorities, staff, students and other stakeholders:
     - supporting a culture of sustainable development through awareness campaigns, events and initiatives conducted by both the academic staff and students;
     - developing skills in the field of sustainable development and climate change as well as basic competencies enabling effective action for sustainable development (e.g., future-oriented thinking, systemic thinking, etc.).
   - Transition from theory to practice:
     - practical application of knowledge, skills, and research conducted for sustainable development;
     - involvement of all employees (from top to bottom), students and external stakeholders in the implementation of SDGs.
3. Statutory activity:
   - Education:
     - continuous professional development for lecturers and the entire university staff (a significant portion of academic teachers may have never received formal education related to sustainable development);
     - creating spaces for employee development (training and education, support for development);
     - integrating SD concepts into a wide range of university programs in curricula, syllabi and learning outcomes;
     - adopting a holistic approach to teaching methodology;
     - implementing modern teaching methods;
     - introducing new subjects into educational programs related to education for sustainable development (e.g., sustainable development economics, innovation management for sustainable development etc.).
   - Science:
     - promoting and stimulating scientific research and research projects aimed at expanding knowledge about sustainable development and their transfer to society;
     - supporting research and innovation focused on energy-efficient technologies, ecological materials and sustainable practices;
     - ensuring closer interdisciplinary collaboration;
     - creating a motivational system that includes the awarding of rewards for research achievements with SD themes.
   - International collaboration:
     - participation in international programs fostering the exchange of experiences, the application of best practices and ideas in the implementation of sustainable development. Inspiration can be drawn from several advanced universities that educate and apply the principles of sustainable development.
4. Corporate governance / Management / Leadership:
   - Engagement of university authorities:
     - convincing employees that changes in strategies to achieve SDGs are essential;
     - coordinating actions in the process of implementing the strategy;
     - setting and monitoring sustainable development goals, regularly assessing progress and continuously improving actions for sustainable development;
     - reducing tension and resistance to change.

- Organizational structure:
  - optimization of the organizational and competency structure for sustainable development;
  - creating dedicated units and positions in the organizational structure, e.g., Chief Sustainability Officer.
- Campus operations:
  - efficient management of existing resources;
  - implementation of measures to reduce the consumption of utilities (electricity, water, heat, natural gas, fuel, etc.), typical office materials (paper, toner, etc.) and minimizing the generation of municipal waste and air-polluting emissions;
  - creation and maintenance of green areas on campus, promotion of biodiversity, and education of students and staff on local ecosystems;
  - construction and renovation of buildings in accordance with principles of green and sustainable design, including efficient insulation, renewable energy, and green roofs.
- Monitoring:
  - incorporating environmental indicators in performance assessment and managerial reporting;
  - implementing procedures for collecting and aggregating data, including identifying data sources as well as control mechanisms to monitor the effectiveness of processes aimed at achieving SDGs.
- Ethical area of corporate governance:
  - maintaining the principle of diversity, tolerance and non-discrimination regarding the employment structure at every level of the organization and in relation to salaries;
  - conflict of interest management;
  - charitable activities;
  - efforts towards transparency in managerial processes and the application of objective criteria within them.
- Communication and disclosures:
  - developing a process for communicating information to stakeholders about the university's activities and outcomes in environmental, social and management areas;
  - establishing standards and reporting cycles for issues related to sustainable development.
- Community outreach:
  - collaboration with other universities, non-governmental organizations, government agencies and partners to leverage resources, share best practices and promote sustainable development;
  - collaboration with local communities.
- Using AI to implement SDGs:
  - increased involvement in the development of artificial intelligence technologies in the activities of universities, including the implementation of sustainable development;
  - improvement of material and technical infrastructure for the implementation of AI technologies;
  - developing stronger IT skills and future-oriented thinking in education and management (e.g., in the design of teaching programs, evaluation).

It should be noted that – in addition to indications of drivers of SDGs – the responses of the experts also included statements suggesting caution in the uncritical implementation of SDGs in HEIs. The experts pointed out that sustainable development, while crucial, should not be the sole determinant guiding the evolution of the university system and its adaptation to contemporary challenges. Many experts emphasized that the fundamental principle should be a thorough explanation of the advantages and disadvantages of the applied solutions in the field of SD, and the creation of a balance between potential benefits and risks. In their view, the benefits arising from the implementation of SD principles in one area should not be offset by losses in other areas. The role of HEIs should therefore be to reduce information noise related to SDGs, counteract the particular interests of the green business, prevent greenwashing, and, above all, counteract the waste of resources: time, effort, energy, and financial resources allocated to often centrally imposed solutions.

Conclusions

In summary, the future of European universities on the path to sustainable development involves a comprehensive and integrated approach that encompasses education, research, campus practices, international collaboration and societal engagement. It requires a commitment to fostering a sustainable

mindset among students, faculty and staff, and actively contributing to the broader global efforts toward a more sustainable future.

The article addresses the incorporation of SDGs into higher education. This research will contribute to the foreseeable future directions of the sustainable development of universities. The results obtained by this study indicate that transformations of universities are necessary. In this study, based on expert recommendations, the authors outline the framework for the implementation of SDGs in HEIs, relying on four key factors: Institutional framework, Building awareness / Organizational culture change in the field of sustainable development, Statutory activity, and Corporate governance / Leadership / Management. The uniqueness of our holistic approach lies in specifying the elements of successful achievement of sustainable development goals in HEIs, covering strategic, operational and functional areas. The authors of this study also emphasize that one of the most crucial determinants of SDGs implementation is changing the attitudes of all stakeholders of HEIs – both internal and external – and creating incentive systems at the institutional and individual levels.

This study aims to present an integrated view of higher education in the context of sustainable development actions and identify key factors for success in implementing SDGs. The proposed concept can serve as a guide for university managers who wish to implement or enhance the status of sustainable development in their academic institutions. It serves as a reference point in identifying drivers and barriers of sustainable development in universities, aiming to inspire and support the former while effectively addressing the latter. It may also assist in identifying and planning targeted actions at the university level to make the transition to sustainable development more evolutionary. The results of this study suggest significant implications for controlling departments at universities and individuals involved in developing new strategies. The article can also contribute to increasing awareness among researchers about sustainable development actions and stimulate them to address research gaps observed in the subject matter.

The study also has its limitations. The presented analysis represents the perspective of selected experts, individuals involved in this field. The perception of this issue by other stakeholders may be drastically different. While the employed research methods aim to minimize the subjectivity of expert assessments, it cannot be ruled out that the obtained results in this study might differ when applied to different respondents. Another limitation – and simultaneously a suggestion for future research – is the lack of stratification of the studied sample based on the type of HEIs: universities, technical universities, academies of applied sciences, etc., and on public and private institutions. It also seems reasonable to conduct similar studies in the future, taking into account the respondents' prior involvement in SD issues at their respective institutions.

Acknowledgements

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Consumer engagement in sustainable consumption: do demographics matter?

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ABSTRACT

This study investigates the relationship between internal and external factors of pro-environmental and pro-social engagement, sustainable consumption behaviour and personal characteristics such as age, gender, financial situation and level of education in the Lithuanian population. A quantitative method was used to collect data from 904 respondents in Lithuania. The study results suggest that women are more concerned about pro-environmental and pro-social issues. In addition, pro-environmental commitment, biospheric values, personal norms and perceived responsibility were important for women. Meanwhile, egoistic values, self-efficacy, social norms, biospheric values, and attachment to place were identified as more important for men. The results reveal that older age increasingly correlates with a stronger expression of place attachment, egoistic values and self-efficacy, pro-environmental and pro-social engagement, and sustainable consumption behaviour. The results of this empirical study allow for identifying the determinants that have the most significant impact on men and women or different age groups. Knowledge of factors that significantly impact pro-environmental and pro-social engagement, which promotes sustainable consumption behaviour as a mediator, can allow policymakers, community representatives or leaders to organise social campaigns and/or provide guidelines for project activities.

KEY WORDS

engagement in sustainable consumption, determinants of engagement in sustainable consumption, sustainable consumption behaviour, demographics

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Introduction

Sustainable consumption that ensures a clean and healthy environment and improves the quality of life for present and future generations is an integral part of the sustainable development agenda (Oslo Roundtable on Sustainable Production and Consumption, 1994). Sustainable consumption could reduce risks related to human health and the environment (Lawrence & Friel, 2019), as consumers play a key role in facilitating social change (Balderjahn et al., 2013). According to the Eurobarometer survey

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(2021), Europeans consider climate change the world's most serious issue. Furthermore, 69 % of consumers indicate that sustainability has become more important to them as they become more aware of climate change issues and their impact on personal well-being and health (Nielsen, 2022). The category of LOHAS consumers that see the link between their health and that of the planet is increasing. In particular, the segment with such values and beliefs consists of about 100 million people worldwide, and approx. 20 % of the population in Europe.

In addition, it is worth mentioning that 28 July 2022 was declared Earth Overshoot Day, meaning that humanity now uses 75 % more resources than the planet's ecosystems can regenerate. Thus, based on European climate law, EU countries must cut greenhouse gas emissions by at least 55 % by 2030 to achieve a climate-neutral EU by 2050 (European Commission, 2023). According to the NielsenIQ 2022 Sustainability report, consumers are one of three of the most important forces, apart from local governments and brands, that are most responsible for making progress in sustainable development. In addition, the consumer role in decreasing climate change and addressing societal challenges is urgent; thus, their high engagement in sustainable consumption remains one of the most important tasks for sustainable businesses and policymakers (United Nations, 2016).

According to Milfont and Schultz (2016), consumer interest in environmental, social and economic issues is growing, and they are increasingly willing to engage and actively participate. Consumers who are more aware of the power of their decisions are likely to choose more responsible consumption (Ciegis & Zeleniute, 2008; Leary et al., 2014). Several studies on engagement in sustainable consumption in Lithuania (Piligrimiene et al., 2019; Capiene et al., 2022) have emphasised that consumers do engage in sustainable consumption, and various factors affect their behaviour toward sustainable consumption. Vivek et al. (2014) found that consumers who are concerned about environmental and social issues are more likely to be engaged in sustainable consumption. Relationships between consumers and companies in deeper forms of engagement and involvement create a sense of community and connected consumption, e.g., through circular products (Otero et al., 2018). Kadic-Maglajlic et al. (2019), who called this phenomenon pro-environmental and pro-social engagement, emphasise that it relates to consumer communities that focus on environmental and social issues. In addition, engagement in sustainable consumption is one of the main factors affecting sustainable consumer behaviour (Kadic-Maglajlic et al., 2019).

Engagement in sustainable consumption can be affected by various external (i.e., promotion, context, and social norms) and internal (i.e., environmental knowledge, self-efficacy, pro-environmental identity and commitment, perceived responsibility, environmental values or attitude, personal norms, place attachment, and satisfaction with life) factors and could mediate the link between them and sustainable consumption behaviour (Kadic-Maglajlic et al., 2019; Piligrimiene et al., 2020; Szpilko et al., 2023). Also, it was found that engagement in sustainable consumption differs according to the socio-demographic characteristics of consumers (Piligrimiene et al., 2020; Sanchez et al., 2016).

In recent years, there has been a growing interest in gender and age differences among people engaged in sustainable consumption. Sanchez et al. (2016) found that women demonstrate a significantly higher level of engagement in green purchasing behaviour compared to men. Similarly, Piligrimiene et al. (2020) found that women, younger consumers and those with families and kids are also more engaged. In contrast, Wang, Liu and Qi (2014) reported that men demonstrate a slightly stronger intention to act sustainably than women. Janmaimool and Denpaiboon (2016) found that younger consumers living in rural areas reported low engagement in sustainable consumption. A different study by Tabernero et al. (2015) revealed that older people exhibit a higher level of environmental concern than younger people and are more engaged in recycling. Finally, research by Filimonau et al. (2020) showed that older consumers are more likely to implement environmentally responsible consumption practices in their daily routines, while the youth are more likely to promote fair and sustainable practices in restaurants that use food waste management practices. The same study demonstrated that the more educated consumers are, the more they are likely to be engaged in pro-environmental behaviour at home and restaurants. Therefore, results on the relationship between demographic characteristics and pro-environmental and pro-social engagement are not consistent and point to the need for further research. Furthermore, previous studies on pro-environmental and pro-social engagement in sustainable consumption have been limited to one or two single demographic characteristics and did not

explore the links between determinants of engagement and all demographic characteristics.

Given the above, this study aims to investigate the relationship between internal and external factors of pro-environmental and pro-social engagement, sustainable consumption behaviour and personal characteristics, such as age, gender, perceptions about one's financial living situation, and level of education in the Lithuanian population. Thus, the key questions are as follows: Is there a relationship between consumer personal characteristics and internal/external factors of pro-environmental and pro-social engagement, and how does this engagement relate to sustainable consumption behaviour? This paper sheds new light on pro-environmental and pro-social engagement in sustainable consumption in a low SDG index country (Europe Sustainable Development Report, 2021) during the COVID-19 pandemic-caused lockdown. The findings of this study have practical implications for marketers and policymakers, providing information on demographic characteristics that are very important in developing social marketing strategies.

The concept of consumer pro-environmental and pro-social engagement in sustainable consumption is analysed in the literature in the first section of the work. This analysis identifies the external and internal factors that contribute to this engagement as well as the connections between consumer pro-environmental and pro-social engagement in sustainable consumption and sustainable consumption behaviour. After presenting a research methodology in the second section of the work, the relationship between the personal qualities of consumers and the internal and external elements of pro-environmental and pro-social involvement, as well as sustainable consumption behaviour, is examined. Research design and logical progression, the definition of quantitative research, and the tools utilised in the study are all covered. The third part of the paper presents the results of quantitative research. The quantitative research reveals the links between personal consumer characteristics such as age, gender, perceptions about financial and living situations, and level of education and the external and internal factors of pro-environmental and pro-social consumer engagement in sustainable consumption and their impact. The results are interpreted and explained in the fourth section of the findings, which also discusses the limits of the results and suggests potential research possibilities. The results are compared to the literature.

1. Literature review

In recent years, scholars have become increasingly interested in the concept of engagement (Steg & Vleg, 2009; Kadic-Maglajlic et al., 2019; Balan, 2020). Based on the systematic analysis of Balan (2020), engagement could be categorised into several different concepts, i.e., consumer awareness of sustainable products, green consciousness, consumer responsibility, consumer beliefs, consumer attitudes, psychological variables, willingness to buy and willingness to pay for green and organic products, consumer purchase behaviour, etc. Consumer engagement in an environmental and social context can also be seen as a form of behaviour (Steg & Vlek, 2009), as a concern about emerging issues (Hirsh, DeYoung and Peterson, 2009), as an interest of members of a community to support others and to volunteer in common activities (Algesheimer, Dholakia, & Herrmann, 2005). In the context of environmental and social problems, this engagement is called pro-environmental and pro-social and is defined as participation in and connection with environmental and social issues (Vivek et al., 2014; Kadic-Maglajlic et al., 2019). Thus, according to researchers (Vivek et al., 2014; Vivek, Beatty, & Morgan, 2012), pro-environmental and pro-social engagement can combine both psychological and participatory processes. This study focuses on the concept of pro-environmental and pro-social engagement of consumers based on the approach of Kadic-Maglajlic et al. (2019), which describes the phenomenon as a psychological state of willingness to act on environmental and social issues.

Based on the systemic review of sustainable consumption (SC) by Quoquab and Mohammad (2020), pro-environmental and pro-social engagement has been analysed as a mediator between various factors and sustainable consumption behaviour in several studies (Capiene et al., 2022; Kadic-Maglajlic et al., 2019; Piligrimiene et al., 2020). Kollmuss and Agyeman (2002) identified the most important factors influencing consumer engagement in sustainable consumption: motivation, environmental knowledge, understanding, values, attitude, emotions, control, responsibility, and priorities. Kadic-Maglajlic et al. (2019) discussed how self-identity and consumer values affect engagement that shifts to sustainable consumption behaviour. Piligrimiene et al. (2020) found that antecedents of consumer engagement in sustainable consumption are environmental

attitudes, perceived responsibility, perceived behavioural efficiency, conditions for SC, social environment and SC promotion. Wang et al. (2019) investigated felt obligation, altruistic concern, pro-environmental identification and commitment as engagement determinants in pro-environmental behaviour. To summarise, researchers usually tend to focus on one or a couple of external or internal determinants of engagement, rarely categorising them as internal or external factors. Noticing this gap, the authors of this article chose to employ such categorisation in their study. Janmaimool and Denpaiboon (2016) proposed to divide internal factors into three groups: cognitive (environmental knowledge, self-efficacy, pro-environmental identity, pro-environmental commitment, and perceived responsibility), attitudinal (environmental values, personal norms, environmental attitude, and attachment to place) and psychosocial (satisfaction with life). External factors affecting engagement in sustainable consumption are contextual factors, promotion and social norms (Ojala, 2012; Wang, Liu & Qi, 2014; Janmaimool & Denpaiboon, 2016; Piligrimiene et al., 2020).

Studies on the relationship between demographics (age, gender, education, and income) and engagement in sustainable consumption have been a neglected area in the field. Nevertheless, studies related to engagement in sustainable consumption identify gender, age, and education as control variables. Most studies emphasise that engagement in sustainable consumption is most often found in women (Sanchez et al., 2016; Piligrimiene et al., 2020). Considerations of generational or age factors have provided various findings (Janmaimool & Denpaiboon, 2016; Filimonau et al., 2020; Ajibade & Boateng, 2021). Very little is known about the role of education in engagement in SC. One study has revealed that men with higher education levels show stronger intentions to engage in sustainable consumption (Filimonau et al., 2020). Previous work has failed to address income aspects in pro-environmental and pro-social engagement in the SC context.

Links between sustainable consumption behaviour and demographics have received more attention than engagement in recent years. The study by Bulut, Kökalan and Doğan (2017) revealed that younger consumers (i.e., Gen Z) and women behave more sustainably. Also, the authors emphasised the role of education as the fundamental determinant of sustainable behaviour. In addition, Turkish consumers with higher incomes are more inclined to shop sustainably.

Determinants of engagement in SC and gender have revealed different results that depend on cultural and economic contexts. D'Souza, Taghian, Lamb and Peretiatko (2007) found that attitudes towards green labels are not related to gender. However, most studies show that women tend to express higher pro-environmental attitudes than men (Felonneau & Becker, 2008; Panzone et al., 2016). In addition, women with high self-efficacy and social norms reported higher engagement in sustainable consumption (Janmaimool & Denpaiboon, 2016). Women who identify as environmentally conscious individuals (i.e., having an environmental identity) are more prone to engage in SC (Pirani & Secondi, 2011; Unanue et al., 2016; Sánchez et al., 2016). Similarly, Sánchez et al. (2016) found that women have stronger environmental values that, in turn, lead to higher engagement in SC. In most studies, personal norms were a more important determinant for women than men, as they affect their engagement in environmentally aware purchases and energy saving (Abrahamse & Steg, 2011; Ojala, 2012). In addition, women were shown to be more attached to places and possess higher perceived responsibility (Janmaimool & Denpaiboon, 2016; Piligrimiene et al., 2020). External determinants, such as contextual factors and promotion, also have a greater effect on engaging in SC for women (Liu, Liu, & Jiang, 2019; Piligrimiene et al., 2020). One interesting note is a study by Weber (2012), who demonstrated that optimistic individuals can be more engaged in pro-environmental behaviour; however, the gender effect was not investigated in the study. Even previous research on the links between pro-environmental commitment and engagement received attention in the literature (Wang, Wang, Li, & Yang, 2020), but gender has not been addressed.

Previous research established a relationship between various factors of engagement in SC and age; however, most studies were conducted with younger consumers. In one case, younger respondents were shown to be less critical and less committed to opting for environmentally sound modes of transport, as well as to engage in everyday pro-environmental behaviour less often (Zsóka et al., 2013). Several authors (Lubell et al., 2007; Janmaimool & Denpaiboon, 2016) found that attachment to place, social norms and self-efficacy do not affect consumer engagement in SC. Furthermore, contextual factors and promotion have no significant effect on engagement in SC with young respondents (Wang, Liu,

& Qi, 2014; Piligrimiene et al., 2020). Other research showed older individuals to be more responsible and more likely to implement environmentally benign consumption practices in their day-to-day lives (Filimonaua et al., 2020). Likewise, older people are more self-efficient and recycle the most (Tabernero et al., 2015). Sánchez et al. (2016) also found that older people who have stronger environmental values are more likely to engage in pro-environmental behaviour. Moreover, middle-aged and elderly people with a positive environmental attitude demonstrate a high level of eco-friendly behaviour (Pirani & Secondi, 2011). Abrahamse and Steg (2011) demonstrated that older respondents have weak relationships with personal norms and reported low engagement in pro-environmental behaviour using more energy. However, life satisfaction, pro-environmental identity, personal norms and pro-environmental commitment in the context of engagement in sustainable consumption regarding age have not gained attention in the literature. Likewise, education and income have not received considerable interest as determinants for engagement in SC, as there have been few cases of samples reflective of the population's education and income levels. In our paper, we also focus on age and gender aspects as determinants of engagement in SC, engagement and sustainable consumption behaviour.

2. Research methods

Sample and data collection. For the purposes of this study, a survey questionnaire was developed, pretested, and distributed digitally among individuals over 18 years of age living in Lithuania. The authors aimed to explore consumer engagement in sustainable consumption and the differences between their gender and age depending on the level of engagement and sustainable consumption behaviour. The authors used quota sampling to target women and men and ensure the representation of consumers from all age groups. Data was collected during the pandemic period, from October to November 2020. A total of 1165 questionnaires were collected. Excluding incomplete questionnaires, a total of 904 samples were used in the further analysis. The study sample maintained the same gender ratio as the general population, but in the case of age, more answers were collected from the younger generation. The educational background of the respondents was divided into six groups from primary to tertiary. The largest share of respondents had received tertiary education (466 respondents; 51.5 %). Respondents were also asked to indicate their perceptions about their financial and living situations. More than half of the respondents, 58.6 %, stated living like most people in Lithuania, while 30.8 % indicated living slightly better than most people in Lithuania. The demographic profile of the sample broadly reflects the demographic composition of Lithuanian residents in terms of age and gender. The sample structure (within age and gender) is presented in Table 1.

Measures. Previously established and validated scales were used to measure constructs. The questionnaire assessed engagement in sustainable consumption on a 7-point Likert scale, which was developed by Kadic-Maglajlic et al. (2019). Sustainable consumption behaviour was measured using 23 items proposed by Quoquab, Mohammad, and Sukari (2019), environmental attitudes — 15 items proposed by Dunlap et al. (2000), personal norms — Vining and Ebreo (1992) 5-item list, perceived responsibility

Tab. 1. Structure of the sample

	Population	Population distribution	Distribution in the study	Number of fully completed questionnaires
Males	868288	47%	47.7%	431
Females	903729	53%	52.3%	473
16–29	389843	18.6%	25.3%	229
30–39	372123	15.9%	22.6%	204
40–49	354406	15.6%	20%	181
50–59	301242	17.6%	13.1%	118
60 and more	354403	32.4%	19%	172
In total: 904				

— seven items proposed by Paço and Rodrigues (2016), self-efficacy — four items proposed by Abraham, Pane and Chairiyani (2015), pro-environmental self-identity — four items developed by Whitmarsh and O'Neil (2010), and pro-environmental commitment — four items proposed by Su et al. (2019). Place attachment was measured with the help of eight items (Song & Soopramanien, 2019), life satisfaction — 5-item measurement scale by Clench-Aas et al. (2011), external factors, such as contextual factors, — the 7-item scale by Wang, Liu and Qi (2014), social norms — five items by Kim and Seock (2019), and promotion — three items (Zhu, Li, Geng & Qi, 2013). To measure all mentioned scales, the 7-point Likert-type scale was used (1 being "strongly disagree" and 7 — "strongly agree"). Environmental values were measured using 13 items adopted from Howell (2013) and Van Riper and Kylie (2014), as based on Schwartz (1994). From these, four items reflect biospheric values, four — altruistic values, and 5 — egoistic values. Respondents were asked to rate the importance of each value on a 7-point scale from 1 (not important at all) to 7 (very important). Finally, for environmental knowledge, eight items were used as proposed by Polonsky, Garma and Grau (2011). Responses were evaluated by selecting "True" or "False" for a given statement.

Also, questions were inserted regarding the respondents' age, gender, education and perceptions about their financial living situation in the research instrument.

3. Research results

Validity and reliability. The reliability of the variables used in this research was evaluated within exploratory factor analysis, using the principal components method of extraction (varimax rotation). This analysis removes statements with low factor loadings, multiple factor loadings, or factors explaining a small proportion of the variance. This analysis assesses the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy. A scale is suitable for factor analysis if KMO ≥ 0.6 and Bartlett's sphericity criterion has a significance level of $p < 0.05$ (Pallant, 2013). The results of EFA are presented in Table 2.

Tab. 2. Exploratory analysis

Factor	No of items	Cronbach Alpha	KMO	Range of Factor Loading	Variance Explained by Each Factor, %
Environmental knowledge	8	0.719	0.597	-0.646-0.598	2.693
Self-efficacy	4	0.812	0.707	0.677-0.913	21.01
Pro-environmental self-identity	4	0.693	0.5	0.827-0.876	4.022
Pro-environmental commitment	4	0.873	0.737	0.809-0.886	14.920
Perceived responsibility	5	0.842	0.829	0.721–0.854	26.33
Biospheric values	4	0.890	0.823	0.676–0.864	12.01
Altruistic values	3	0.821	0.793	0.651–0.839	6.79
Egoistic values	5	0.794	0.693	0.671–0.827	24.91
Personal norms	5	0.809	0.817	0.600–0.851	25.71
Environmental attitude	11	0.730	0.819	0.852–0.737	19.21
Place attachment	8	0,840	0.851	0.596-0.839	38.806
Life satisfaction	5	0.826	0.817	0.689-0.858	26.300
Contextual factors	7	0.633	0.658	0.604-0.804	4.758
Promotion	3	0.897	0,519	0.938-0.938	4.854
Social norms	5	0.884	0.772	0.758-0.872	23.741
Pro-environmental and pro-social engagement	8	0.893	0.866	0.600–0.856	63.63
Sustainable consumption behaviour	23	0.863	0.813	0.608–0.747	27.93

The analysis indicated that constructs of pro-environmental and pro-social engagement and sustainable consumption behaviour were modified and became single factors; therefore, in the following analysis, both are analysed as one dimension-based constructs. All Cronbach alpha values of the above-mentioned factors are over the recommended 0.7 value (Pallant, 2013), except for the pro-environmental self-identity and contextual factors. The scales of each construct were scored, and means, standard deviations, and minimum and maximum values were determined (Table 3).

The cluster comparison test and correlation analysis were used to analyse the relationship of these variables with the constructs. A comparison analysis of the expression of the constructs was carried out using the Kruskal–Wallis test (which is designed to compare more than two independent samples) and the Mann–Whitney test (which is designed to compare two independent samples in a non-parametric way). According to these tests, the results are statistically significant at $p < 0.05$ (Table 4).

Correlation analysis revealed that the older the age group, the better their environmental knowledge, the stronger their pro-environmental identity, place attachment, pro-environmental and pro-social engagement, and the more sustainable their consumption behaviour. However, older age also correlated with weaker altruistic values, a poorer attitude and lower appreciation of the environment, as well as lower incentive (Spearman's rank correlation coefficient $p < 0.05$). The age group variable does not correlate with self-efficacy, pro-environmental commitment, perceived responsibility, biospheric values, egoistic values, personal norms, life satisfaction and social norms. However, according to the p-values of the Kruskal–Wallis test of the latter scales, only the means (sum of ranks) of the life satisfaction and social norms scales do not differ between age groups.

The gender (women) variable is statistically significantly associated with all scales (Spearman's correlation coefficient and Mann–Whitney U test $p < 0.05$), with the exception of place attachment and contextual factors. Similarly, in the case of the education variable, only some factors (environmental attitude and social norms) are not statistically significantly ($\alpha = 0.05$) correlated or do not differ between education groups (Table 4).

The financial situation variable is unrelated to slightly more than half of the factors: pro-environmental identity, biospheric values, altruistic values,

Tab. 3. Numerical characteristics of the scales (N-904)

Factor	Mean	SD	Asymmetric coefficient	Excess coefficient
Environmental knowledge	4.708	1.212	-0.346	-0.334
Self-efficacy	4.526	1.146	-0.397	0.313
Pro-environmental self-identity	5.,231	1.003	-0.818	1.122
Pro-environmental commitment	5.690	0.965	-0.954	1.496
Perceived responsibility	5.159	1.027	-0.606	0.657
Biospheric values	6.075	0.868	-1.417	3.011
Altruistic values	6.235	0.868	-1.789	4.792
Egoistic values	4.893	0.996	-0.607	0.879
Personal norms	5.661	1.015	-0.824	0.651
Environmental attitude	5.181	0.728	-1.055	1.174
Place attachment	5.129	1.037	-0.712	0.853
Life satisfaction	4.971	1.022	-0.804	1.033
Contextual factors	4.945	1.092	-0.494	0.391
Promotion	5.449	0.977	-0.55	0.219
Social norms	5.631	1.101	-1.09	1.898
Pro-environmental and pro-social engagement	4.926	0.998	-0.453	0.329
Sustainable consumption behaviour	5.351	0.79	-0.712	0.847

Tab. 4. Non-parametric p-values and Spearman's rank correlation coefficients for non-parametric tests of control variables and factors

Control variables	Age		Gender (women)		Education		Financial living situation	
Factor	Kruskal–Wallis test p-value	Spearman coef.	Mann–Whitney U test p-value	Spearman coef.	Kruskal–Wallis test p-value	Spearman coef.	Kruskal–Wallis test p-value	Spearman coef.
Environmental knowledge	0.000	0.132*	0.015	-0.081*	0.221	0.087*	0.174	0.080*
Self-efficacy	0.055	0.005	0.007	0.090*	0.009	0.114*	0.000	0.119*
Pro-environmental self-identity	0.000	0.212*	0.005	0.092*	0.002	0.099*	0.037	-0.016
Pro-environmental commitment	0.017	-0.051	0.000	0.263*	0.001	0.141*	0.087	0.068*
Perceived responsibility	0.010	-0.032	0.000	0.210*	0.033	0.100*	0.002	0.072*
Biospheric values	0.001	0.002	0.000	0.196*	0.084	0.093*	0.591	0.015
Altruistic values	0.027	-0.088*	0.000	0.195*	0.068	0.081*	0.783	0.014
Egoistic values	0.025	0.061	0.004	-0.095*	0.001	-0.110*	0.476	0.007
Personal norms	0.002	-0.051	0.000	0.310*	0.000	0.173*	0.006	0.048
Environmental attitude	0.000	-0.194*	0.000	0.161*	0.669	-0.043	0.376	-0.006
Place attachment	0.000	0.197*	0.273	0.036	0.175	0.067*	0.248	0.018
Life satisfaction	0.394	0.063	0.017	0.080*	0.002	0.119*	0.000	0.225*
Contextual factors	0.002	-0.096*	0.316	0.033	0.000	-0.154*	0.001	-0.131*
Social norms	0.163	-0.057	0.001	0.111*	0.672	0.047	0.015	0.111*
Promotion	0.000	-0.149*	0.000	0.146*	0.330	0.059*	0.194	0.064*
Pro-environmental and pro-social engagement	0.001	0.125*	0.000	0.188*	0.066	0.082*	0.006	0.043
Sustainable consumption behaviour	0.000	0.190*	0.000	0.188*	0.007	0.054*	0.002	-0.001

** p < 0.05; no correlation; average correlation; strong correlation*

egoistic values, personal norms, environmental attitude, place attachment, pro-environmental and pro-social engagement and sustainable consumption behaviour.

To understand how men and women tend to engage in sustainable consumption and actual sustainable behaviour and how different factors are distributed according to gender, the authors compared the dichotomised median scales and their values. The scales were dichotomised according to the median value (above the median is a high score, and below or equal to the median is a low score). Fig. 1 shows the percentage distribution of high scores for men and women across all constructs. The results revealed that the proportion of women scoring above the median for the constructs is significantly higher than for men. Only in cases of environmental knowledge and egoistic values, men exceed women by almost three per cent. The factors with the highest scores among women are pro-environmental commitment (31.19 %), biospheric values (29.87 %), personal norms (29.76 %), sustainable consumption behaviour (29.31 %), and pro-environmental and pro-social engagement (29.3 %). The lowest scores were given to environmental knowledge (12.5 %) and promotion (15.3 %). Incentives also received the lowest number of high scores in the men's group (9.4 %). However, the men's group had the highest number of high scores

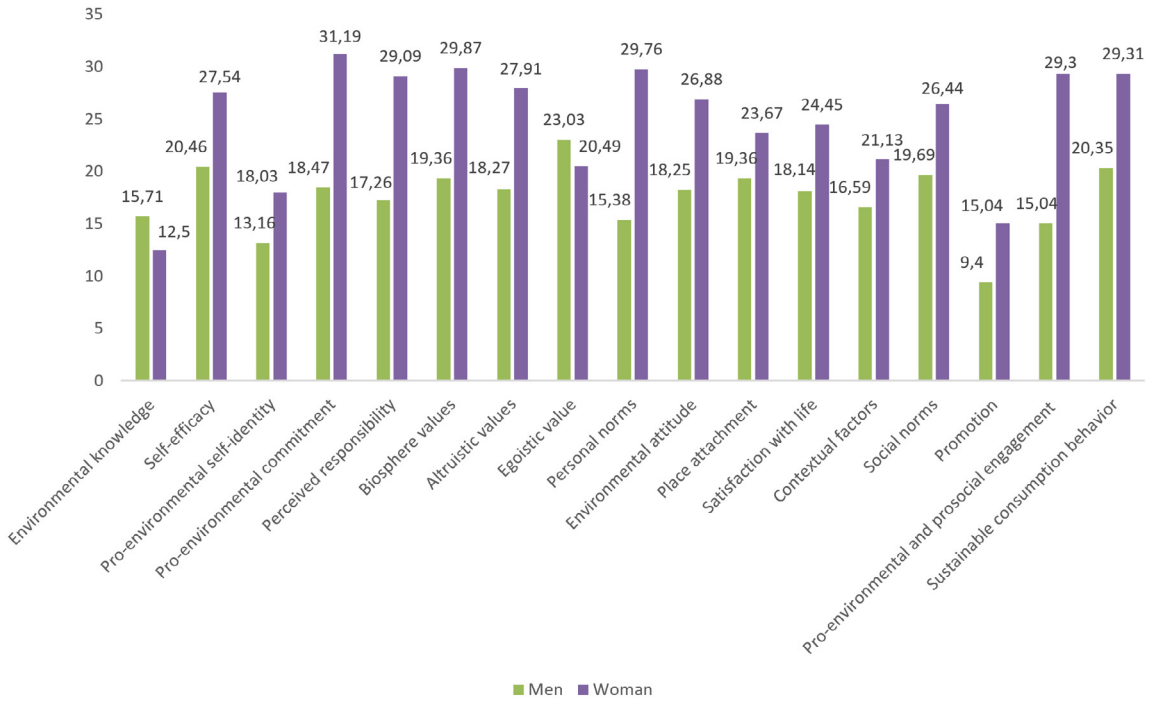

Fig. 1. High score results for women and men on the dichotomised median scales (%)

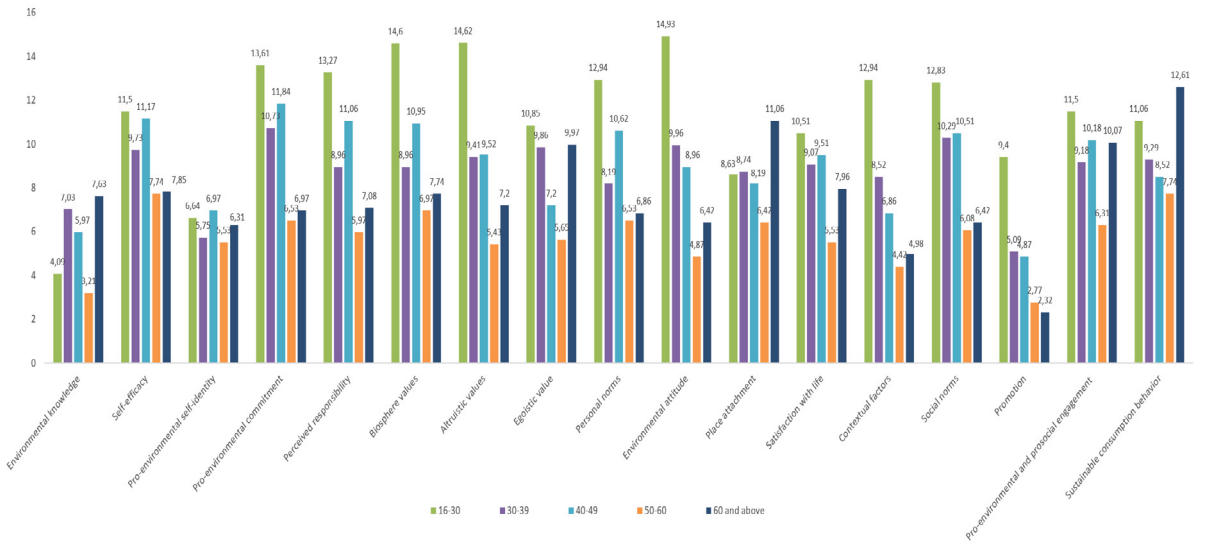

Fig. 2. Dichotomised median scale high score results based on age group (%)

for the factors compared to the women's group. The factors with the highest scores were egoistic values (23.03 %), self-efficacy (20.46 %), sustainable consumption behaviour (20.35 %), social norms (19.69 %), and place attachment and biospheric values, both scoring 19.36 %.

The study also focused on specificities of different age groups for the investigated factors. The data analysis obtained from the comparison of the five age groups focuses on the percentage of estimates above the median (Fig. 2).

In the first age group (16–29 years), the factors with the highest scores were environmental attitude (14.93 %), biospheric and altruistic values and reversal of environmental attitudes (14.6 %), pro-environmental commitment (13.61 %), engagement in sustainable consumption (11.5 %) and sustainable consumption behaviour (11.06 %). The lowest scores were for environmental knowledge (4.09 %) and pro-environmental identity (6.64 %).

In the second age group (30–39), pro-environmental commitment (10.73 %), social norms (10.29 %), environmental attitude (9.96 %), egoistic values (9.86 %) and self-efficacy (9.73 %) were the highest rated factors. Pro-environmental and pro-social engagement in sustainable consumption (9.18 %) and sustainable consumption behaviour (9.29 %) were very close to the top five highest-scoring factors. The lowest scoring factors were incentive (5.09 %) and pro-environmental identity (5.75 %).

In the third age group, the following factors received the highest scores: pro-environmental commitment (11.84 %), self-efficacy (11.17 %), perceived responsibility (11.06 %), biospheric values (10.95 %), and personal norms (10.62 %). Pro-environmental and pro-social engagement in sustainable consumption (10.18 %) were close to the top five factors, but sustainable consumption behaviour (8.52 %) had a slightly lower percentage of scores above the median. The lowest scores were promotion (4.87 %) and environmental knowledge (5.97 %).

In the fourth age group (50–59), the factors with the highest scores were self-efficacy and sustainable consumption behaviour (7.74 %), perceived responsibility (6.97 %), personal norms and pro-environmental commitment (6.53 %), and pro-environmental and pro-social engagement in sustainable consumption (6.31 %). The lowest scores were for promotion (2.77 %) and environmental knowledge (3.21 %), the same as in the third age group.

In the fifth age group (60+), the highest scoring factors were sustainable consumption behaviour (12.61 %), place attachment (11.06 %), involvement in sustainable consumption (10.07 %), egoistic values (9.97 %) and life satisfaction (7.96 %), whereas the lowest scoring ones were promotion (2.32 %), and contextual factors (4.98 %).

4. Discussion and conclusions

Most research on pro-environmental and pro-social engagement has been carried out on young people (Kadic-Maglajlic et al., 2019; Ojala, 2012). The present study explored significant differences in pro-environmental and pro-social engagement stimuli and results (i.e., sustainable consumption behaviour) for people of different age groups, gender, education and financial and living situations in Lithuania. The results revealed that as the age of the test group increases, the stronger the demonstrated place attachment, egoistic values, and self-efficacy become, and the more pro-environmental and pro-social engagement, and sustainable consumption behaviour are likely to be exhibited. This could be because older respondents are more attached to their place of residence and may even identify with it, perceiving themselves as environmentally friendly individuals and possessing environmental knowledge.

However, it should be noted that the older the age group, the weaker the relationship with altruistic values, the poorer the environmental attitude, the lower the appreciation of the contextual conditions, and the weaker the link with promotion. These results suggest that older respondents may show lower levels of self-sacrifice and reliance on incentives or conditions. Surprisingly, however, environmental attitudes, which reveal a certain perception of the world and a certain level of knowledge, correlate more weakly than environmental knowledge. For this reason, the authors suggest further developing research on pro-environmental and pro-social engagement in sustainable consumption to clarify the differences between knowledge and attitude.

This research shows that different determinants of engagement to sustainable consumption, the engagement itself and actual behaviour are expressed differently across age groups. However, one dimension of environmental values factor — biospheric values — dominated across the different respondents, scoring high in four of the five age groups. Thus, to encourage consumers from 16 to 49 years of age to engage in SC, the positioning of biospheric values

would be the right choice. It should be noted that egoistic values, which reflect the focus on personal gain, were dominant among respondents from 30–39 and 60+ age groups. Egoistic values could lead to pro-environmental and pro-social engagement in sustainable consumption by promoting a personal perception of the need to strive for what is good for oneself or one's children. The pro-environmental commitment, reflecting the individual's relationship with the environment and their perceived sense of duty towards it, emerged among respondents aged 16 to 49. Thus, it would be appropriate to include measures to promote pro-environmental commitment in designing social marketing strategies for this group. In addition, self-efficacy is revealed in these groups and that reflects the consumer's belief that their individual contribution can help solve global problems. Therein lies the nudging strategy of promoting individual people's success stories and the power for change that each person has.

Among the respondents, the older consumers were found to be more attached to the place. It could be argued that when attachment and identification with the living environment and the people and community within it are established, place attachment becomes an important factor that can change consumer behaviour. These results are in line with the study by Janmaimool and Denpaiboon (2016), in which younger individuals expressed low attachment to place and reported low engagement in sustainable consumption.

Meanwhile, the perceived responsibility, which is associated with life changes, a certain maturity of personality and perhaps the importance of family and children, is more linked to consumers from 40 to 60 years of age. These consumers realise the consequences of their actions and take responsibility for themselves personally. These results are in line with the study by Filimonaua et al. (2020), in which older individuals were more responsible and would be more likely to implement environmentally benign consumption practices in their day-to-day lives. Therefore, to focus on encouraging this group of consumers to engage in sustainable consumption, it would be appropriate to use measures that remind them of the responsibility for the actions they have taken.

As predicted, the youngest segment of respondents (i.e.,16–29) are more affected by social norms. Therefore, these consumers more often follow the behaviour of others in social groups and networks. Meanwhile, personal norms, those that determine the individual's personal perception of correct behaviour in a certain social environment, are more relevant among 40–60 years-old-Lithuanian consumers.

The study aspects related to gender are in line with study results by Banyte et al. (2020), which revealed a statistically significant relationship in a sample of women when examining engagement in sustainable consumption both at home and at work. In the research described by this article, the gender (women) variable is statistically significantly related to all factors except place attachment and contextual factors. It could be argued that women are more concerned with pro-environmental and pro-social issues in Lithuania. These results are in line with research by Janmaimool and Denpaiboon (2016), Wang, Liu and Qi (2014), Ojala (2012) and Piligrimiene et al. (2020).

In addition, the research described in this article revealed that the pro-environmental commitment, which reveals an individual's perceived sense of duty to the environment (even though such behaviour is not favourable to them personally), was dominant among the women respondents. Thus, the promotion of pro-environmental commitment, biospheric and altruistic values, personal norms and perceived responsibility among women could foster their engagement as well as actual sustainable behaviour. Meanwhile, social marketing strategies related to egoistic and biospheric values, self-efficacy, social norms and place attachment could be emphasised when targeting men. In conclusion, measures to encourage sustainable consumption should be adapted specifically to men and women.

Demographic variable education correlates statistically significantly with all scales except social norms, i.e., the external environment, regardless of the acquired education, affects consumers and shapes their behaviour. The links between education and other factors could be explained by the fact that most respondents who participated in the study had higher education, and if more people with lower levels of education had been part of the group of respondents, the results might have been different.

The current findings reveal the links between the consumers' financial and living situation and environmental knowledge, self-efficacy, pro-environmental commitment, perceived responsibility, life satisfaction, social norms and promotion, such that the better the subjective financial situation, the stronger the correlation. Economic factors are very important for those willing to pay a higher price for green or circularity-based products (Wei, Ang,

& Jancenelle, 2012; Pretner et al., 2021). However, the subjective financial situation reflects how the consumer evaluates their financial situation, but not price-related decisions. For this reason, it would be appropriate to develop research on pro-environmental and pro-social engagement in sustainable consumption to clarify the influence of economic factors.

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Analysis of health warning signs on alcoholic beverage packaging using the eye-tracking method

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ABSTRACT

Producers must mark packaging with various warning signs, including the harm of alcohol consumption. The most popular warnings inform about the required consumer age (e.g., "alcohol only for adults"), consequences of drunk driving (e.g., "don't drink and drive"), and advisable abstaining from drinking during pregnancy.

The study's main objective was to analyse the perception of warning signs on alcoholic beverage packaging using the eye-tracking method, which allows the observation and measurement of the focus of study participants. The research positively verified the ability to use the eye-tracking method to assess the perception of warning signs. The obtained research results were used to investigate the perception of warning signs placed on glass beer bottles. The study showed that the presence of pictograms (i.e., graphic symbols) does not guarantee the focus of potential buyers' attention. The obtained results clearly indicated that the efficiency of perception results from many elements, including the sign's placement, size and colours, a connection between graphic and textual information, and the colour of the packaging material and label.

The study's results can be useful for non-profit organisations and other entities responsible for the social marketing of alcoholic beverages. Moreover, the study could be seen as a starting point for researchers, beverage packaging industry representatives, and policymakers to test, introduce and promote packaging innovation solutions. The research filled the gap by providing a better understanding of the effectiveness of warning signs on alcoholic beverage packaging and furnished clues as to how alcohol stakeholders and public institutions should react to enhance alcohol health literacy in society.

KEY WORDS

eye-tracking technique, alcoholic beverage warnings, warning signs, perception of warning signs

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Introduction

Europe consumes the most alcohol in the world (11 litres of pure alcohol per person per year), which necessitates the investigation of alcohol drinking habits in European countries (Anderson & Baumberg, 2006; Cortes et al., 2016; Espejo et al., 2012; Glińska & Siemieniako, 2018; Guillemont & Leon, 2008; Kuntsche, Rehm & Gmel, 2004; Measham & Ostergaard, 2009; Popova et al., 2007; Ruutel et al., 2014; Siemieniako & Kubacki, 2013; Viner & Taylor, 2007). The direct costs of dealing with the conse-

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quences of harmful alcohol consumption are estimated to reach EUR 125 billion per year (Stewart & Wild, 2014).

The European Union (EU) strategy on alcohol was launched in 2006 to support Member States in reducing alcohol-related harm (European Commission, 2006). Informing, educating, and raising awareness on the impact of harmful and hazardous alcohol consumption was identified as one priority theme for action in the strategy.

In the United Kingdom (UK), the Campden and Chorleywood Food Research Association (CCFRA) studied the 2007 self-regulation agreement. Results showed that most manufacturers did not follow the agreed format and content of the labels. Only 2.4 % of the samples carried the Chief Medical Officer's (CMO) lower-risk guidelines in the agreed format (CCFRA, 2008). Alcohol Concern, the UK's national agency on alcohol misuse, surveyed the labelling of alcoholic beverages in the UK. The results are worrying and show limited interest from many producers on this issue (Velleman, 2011). So far, no research is available investigating the impact of such labels on drinking behaviour in the UK.

Consumers need to be provided with proven information on the negative health effects and consequences of alcohol so that they can take precautions to lessen the risk. As part of broader health policies to reduce alcohol-related harm, health messages on the labels of alcoholic beverages can be an effective measure to raise awareness of the risks related to alcohol consumption.

The study aimed to analyse the perception of warning signs on the packaging of alcoholic beverages using the eye-tracking method. The eye tracking method is used to research the packaging of different products groups, e.g., dietary supplements (Kabaja, 2018), energy drinks (Cholewa-Wójcik, 2016), shower gels (Cholewa-Wójcik & Kawecka, 2015), and tobacco (Kessels & Ruiter, 2012; Maynard, Munafo, & Leonards, 2013; Sussenbach, Niemeier, & Glock, 2013). Research on the packaging of alcoholic beverages is also found in the literature (Escandon-Barbosa & Rialp-Criado, 2019; Kersbergen & Field, 2017; Monk et al., 2017; Pham et al., 2018). The study aimed to explore the perception of warning signs communicating such messages as:

- alcohol only for adults,
- don't drink and drive,
- it is the safest not to drink while pregnant.

The relationship between the size, location, orientation, and colour of warning signs will represent the foundation for solutions and strategies to improve sign visibility and attention-catching. The study could be the starting base for researchers, beverage packaging industry representatives, and policymakers to test, introduce and promote packaging innovation solutions.

1. Literature review

Warning signs on alcoholic beverage packaging were researched from different perspectives and revealed different issues. Product labels are an important marketing tool that contributes to the image of the product. Moreover, product labels are one cheap and potentially effective way to inform consumers (Mackey & Metz, 2007). Alcohol labels have the highest exposure among the heaviest drinkers (Greenfield, 1997). In communication campaigns, the more channels are used to convey the message, the greater the likelihood of reaching target groups and strengthening the message through repetition. Food labelling falls under the Regulation (EU) 1169/2011. Labelling of wine, beer, or spirits is regulated additionally. These regulations govern the naming of alcoholic beverages and information given, e.g., on types of grapes used in the production or on the geographical origins of the product. The design and positioning of health warning labels are fundamental for their effectiveness (Regulation (EU) 1169/2011). Despite that, there is an ongoing debate among EU countries on issues that are linked directly to alcoholic beverage labelling regulations. In 2021, the European Commission launched Europe's Beating Cancer Plan, which is structured around four key areas. Among them, the EU proposed new alcohol policy solutions involving mandatory alcohol labelling for ingredients and nutritional value (European Commission, 2021). In addition, in 2022, Ireland notified the European Commission and the Member States of its plan to tighten regulations on the alcohol health warning labelling within its territory. The country intends to place information about a link between alcohol consumption and cancer or liver diseases on labels of alcoholic beverages, and this decision implements the regulations established through the Public Health (Alcohol) Act 2018 (Critchlow, Crawford & Jones, 2022). The decision was perceived as controversial by some EU countries and raised objections from the alcohol industry, but it was accepted by the European Commission (European Parliament, 2023). Based on

studies, the impact of health warning labels on drinking behaviour is shown to be insignificant (Agostinelli & Grube, 2002; Grube & Nygaard, 2001; MacKinnon & Nohre, 2006; Al-Hamdani & Smith, 2015).

On the other hand, many studies showed greater awareness among consumers of the risks highlighted in the warnings (Hassan & Shiu, 2018; MacKinnon et al., 2000; Stockwell, 2006; Wilenson & Room, 2009; European Commission & CRIOC, 2011). A study conducted in Australia, Canada and Poland revealed that adults are not sufficiently informed about alcohol and its effects on their health (Rundle-Thiele et al., 2013). The results from the Global Drug Survey (GDS) in 2018 showed that alcohol consumers are not aware of all the consequences of drinking alcohol, including the possibility of getting seven types of cancer, which was the least known fact (Winstock et al., 2020). Placing warning signs on alcohol labels and bottles might be one of the most important measures in raising public awareness of the harmful effects of alcohol. Such an opinion was confirmed, among others, by a national online survey in Australia (Miller et al., 2016).

In 2020, the Australian government introduced new requirements for mandatory pregnancy warning labels on packaged alcoholic beverages sold in Australia and New Zealand. Labels must contain the pregnancy warning pictogram, the signal words "Pregnancy Warning", and the statement "Alcohol can cause lifelong harm to your baby" (Australia New Zealand Food Standards Code, 2020). The deadline for producers to implement the new regulations is 31 July 2023. The studies in which authors test different formats of health warning labels in relation to their effectiveness in informing about the harmful effects of alcohol consumption are in line with these amendments and improvements (Grummon et al., 2023; Brennan et al., 2022; Hassan et al., 2022; Jones et al., 2021).

Information about the alcohol content is among the most important and should influence the lower alcohol consumption. In Germany, a study conducted by the Federal Institute for Health Education looked into the effect of the age limit label on alcopops. It showed that 17 % of alcohol consumers aged 12–17 renounced buying alcopops due to this label (Federal Centre for Health Education, 2005). For example, in Australia, alcohol standard unit labelling (1 unit = 10 g pure alcohol) of alcoholic beverages became mandatory in 1995. Tracking research found evidence of growing awareness of the "standard drink" concept since the introduction of the labels (Loxley et al., 2004). A study confirmed these results; however, the researchers found that the standard drink label helps young people to choose the strongest drinks at the lowest cost (Jones & Gregory, 2009). Also, in the US, a study among college students showed that the format used on labels to inform on alcohol concentration impacts the ability to accurately pour a standard drink. The traditional format that is used by producers (alcohol by volume, ABV) is less effective than a standard drink labelling for drinkers to enable them to track their alcohol intake and to facilitate responsible drinking purchases and behaviours (Brunk, Becker, & Bix, 2020). Based on a literature review, similar conclusions were highlighted by Kerr and Stockwell (2012).

Other studies focused on testing the effectiveness of different labelling types; however, findings on the impact of pictorial (image-and-text), text-only labels or non-labels have been mixed and do not unequivocally indicate the advantage of any of the forms of warnings (Staub & Siegrist, 2022; Jones et al., 2022; Clarke et al., 2021). Simultaneously, in some studies, researchers noticed that pictorial health warnings were associated with stronger emotions, such as fear of health risks related to alcohol consumption (Wigg & Stafford, 2016).

In Italy and France, research was conducted among Generation Y consumers to investigate their attitudes towards different formats of health warnings on wine labels. The results showed little attention to alcoholic beverage labels in general and a low level of visibility of placed health warnings. As a result, the authors pointed to the ineffectiveness of health warning labels in changing consumption behaviour and affecting consumer awareness of alcohol harmfulness (Annunziata et al., 2019).

In the US, a series of experiments were conducted to analyse the factors affecting the perception and the noticeability of warning labels (Laughery et al., 2002). Fig. 1 presents the determinants of warning label perception identified in that research.

In a Canadian study, authors focused on different formats and texts of alcohol labels with cancer and pregnancy warnings and tested if they promoted more informed and safer alcohol consumption (Hobin et al., 2020). In Australia, an ongoing qualitative study is conducted by the Victorian Health Promotion Foundation (2009). Based on the results, health warnings should be factual and informative. Other most relevant results are as follows:

- labels linked with existing media campaigns are most likely to be effective,

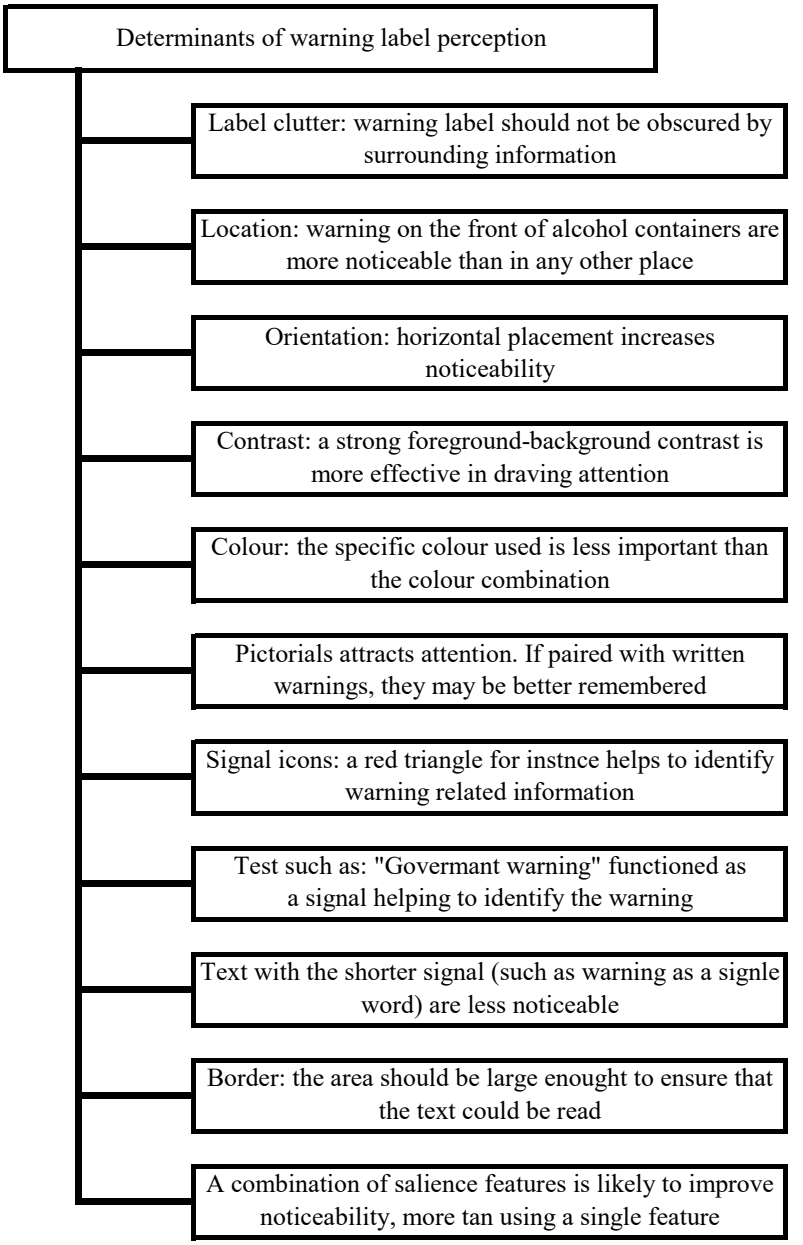


Fig. 1. Determinants of warning label perception
Source: elaborated by the author based on Laughery et al., 2002.

- included images are more effective if they are linked with other elements of a social marketing campaign,
- messages should not tell the consumers what to do.

Participants with personal bad experiences of their drinking behaviour are especially reluctant to these types of messages. "Health Warning" was the most preferred wording. A series of qualitative studies were conducted with youngsters from six EU countries in the framework of the Protect project (European Commission and CRIOC, 2011). The results showed that if health warning labels were to be used, young people would be more receptive to a combination of pictures and informative texts, such as "Alcohol increases the risk of breast cancer". In eye-tracking studies, researchers draw conclusions that a pictorial form has a greater impact on respondents. Research conducted by Monk et al. (2017) and Pham et al. (2018) proved that images in alcohol warnings appear beneficial for drawing attention. Dwell times were significantly higher for the image as opposed to

the text, which was also studied and confirmed by Kersbergen and Field (2017). Moreover, the size of warning labels and types of colours had a positive impact on drawing attention (Sillero-Rejon et al., 2020).

Researchers use an eye-tracking method to examine various aspects of warning label designs. Thomsen and Fulton (2007) used an integrated head–eye tracking system to investigate whether adolescent readers (aged 12–14) paid attention to responsibility or moderation messages included in printed advertisements for alcoholic beverages included in magazines. The results showed that these messages were the least frequently viewed areas of advertisements, both textual and visual. On the contrary, Monk et al. (2017) and Pham et al. (2018) proved that images in alcohol warnings appear beneficial for drawing attention. Dwell times were significantly higher for the image as opposed to the text, which was also studied and confirmed by Kersbergen and Field (2017). In France, researchers used an eye-tracking method to investigate the potential influence of pregnancy warning label designs on women's attention and alcohol product choices. In general, the results showed that French warning labels currently placed on the bottles attract no attention from study participants. However, if labels were larger and colourful, combining text and pictogram, they would attract far more attention (Lacoste-Badie et al., 2022). In Australia, two studies were conducted to investigate the market's attention to alcohol warning labels and examine whether that attention could be enhanced by changing the colour and size of warning labels. The authors used a self-report survey to measure attention and an eye-tracking method to examine whether respondents paid attention to the size and colour of warning labels on alcoholic beverages.

The results of the studies utilising eye-tracking provide valuable guidance for developing more effective health warning labels on alcoholic beverages. However, Kokole et al. (2021) indicated that most reviewed studies were conducted online or in a laboratory setting and not in the real world.

The research results referred to consumer behaviour and the role of warning signs on alcoholic beverage packaging. In this context, the in-depth analysis of those studies formed the basis for investigating the literature on warning signs placed on the packaging and consumer perception. It revealed a lack of research and full analyses of consumer perception of health warning signs on alcoholic beverage packaging.

2. Research methods

The research concerned the perception analysis of warning signs on the packaging and their elements that may influence the focus of attention. The research subject was glass bottles of beer with alcohol content available in the European market offer. Visually differentiated packaging was chosen for the research (bottles varied in shape, glass colour, colour and layout of the labels, graphics, size, font type, ergonomic solutions, and different warning signs). The research subject is presented in Fig. 2. The eye-tracking method was used to research the warning signs on the beer packaging.

The study involved 25 participants from different age groups, women and men. The research was conducted in 2022. It was designed and conducted following widely accepted research guidelines (Carter & Luke, 2020; Duchowski, 2007).

The research used the eye-tracker Tobii X2-30 Tobii Studio, which consists of a camera and infrared projector embedded into a standalone display monitor. Participants look at an image projected on the monitor; the infrared projector creates a pattern of the viewer's eyes, with the camera taking images of the users' eyes and patterns. The research sessions were held in peace and quiet, without any distractions for the respondent. After calibration of the eye tracker for each participant, they were instructed to look at a series of bottle images. The research scenario provided for free viewing of the whole packaging. Each image was shown individually to the participant for 30 seconds before the poster was automatically changed. Each eye-tracking session ran for approx. 5 min. After finishing the experiment, participants were asked to fill out a four-question demographic survey.

This study recorded variables with the eye tracker:

- fixation count;
- first fixation duration;
- fixation count on the packaging;
- fixation count on the warning sign;
- time to the first fixation on the packaging;
- time to the first fixation on the sign.

Fixation count is the number of times a participant looks at a particular area of interest. Fixations are relatively constant positions of an eyeball involving small vibrations. It is assumed that a cognitive process (when information reaches the brain and is consciously processed) takes place during the fixa-

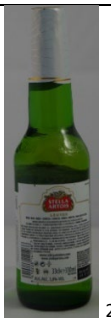
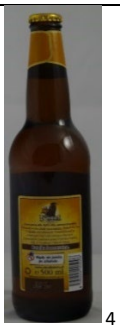
 1 It is safest not to drink while pregnant	 2 It is safest not to drink while pregnant Don't drink and drive	 3 Never drink and drive	 4 Never drink and drive
 5 Alcohol only for adults	 6 Never drink and drive	 7 It is safest not to drink while pregnant Don't drink and drive	 8 Don't drink and drive
 9 Don't drink and drive It is safest not to drink while pregnant	 10 Alcohol only for adults	 11 It is safest not to drink while pregnant Don't drink and drive	 12 It is safest not to drink while pregnant Alcohol only for adults Don't drink and drive
 13 It is safest not to drink while pregnant	 14 It is safest not to drink while pregnant	 15 It is safest not to drink while pregnant Don't drink and drive Alcohol only for adults	 16 It is safest not to drink while pregnant Alcohol only for adults

Fig. 2. Analysed beer packaging

Source: photographed by A. Kawecka.

tion. Fixation duration is the length of time in which the viewer looks at an area of interest, and time to the first fixation is the length of time it takes for a viewer to first look at an area of interest. Data for the variables are expressed in seconds. During data analysis, the area of interest was defined around the warning signs within the label for the eye tracker to determine if a participant looked at the warning labels.

The presented studies used an eye-tracking method as a technique allowing to obtain quantitative data. Measuring and physiological tests, based on the work of sight, allow for obtaining representative quantitative data and determining how certain visual layer elements of the packaging, such as warning signs, are perceived by potential consumers. The techniques used in this study focused on:

- perception speed of warning signs on beer labels;
- determining the difference in perception of only graphic signs and graphic signs with text;
- determining the relationship between the size of the sign and the time needed to find the sign;
- influence of sign colour on consumer perception.

Eye tracking helps understand the complete user experience, even if users cannot describe it. Eye tracking data helped explain the noted increase in attention during visual search tasks over the newly redesigned labels: lowered search demands or lowered information-processing demands posed by the new design.

Basic eye-tracking measures were used, such as scanning path, the number of fixations, or the total time of fixation. The achieved research results were presented in the form of heat maps, which are a dispersion of attention directed at the researched area of interest, with the possibility to distinguish noticed and omitted elements while scanning the sight. Heat map colours were used to show the average image of the packaging areas to which the respondents paid attention. Areas marked red received the most focus, and green was used for areas with the least focus. It shows the order of the sight activity of the respondents within the delineated area of interest (AOI) (Bergstromm & Schall, 2014).

3. Research results and discussion

Free looking of the respondents was analysed to identify the perception of health warning signs on alcoholic beverage packaging. The results of the sight perception analysis using eye-tracking measures is presented Table 1.

Tab. 1. Results of the sight perception analysis with the use of the chosen eye-tracking measures

Packaging	Eye-tracking measures								
	First fixation duration [s]			The time to the first fixation [s]			Fixation count		
	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
1	0.27	0.73	0.02	0.30	3.9	0.0	18.88	104	6
2	0.3	0.68	0.04	0.25	5.03	0.0	13.62	34	5
3	0.3	1.32	0.01	0.45	5.02	0.0	12.12	28	2
4	0.37	1.54	0.01	0.45	5.29	0.0	10.84	19	1
5	0.42	1.14	0.07	0.35	5.03	0.0	14.56	29	6
6	0.32	0.66	0.01	0.29	5.01	0.0	12.56	32	1
7	0.32	1.00	0.02	0.30	5.25	0.0	13.08	34	4
8	0.21	0.76	0.01	0.38	5.01	0.0	17.04	31	5
9	0.34	0.93	0.03	0.38	5.02	0.0	12.16	20	2
10	0.33	0.75	0.01	0.34	5.29	0.0	15.36	35	5
11	0.28	0.58	0.01	0.25	5.01	0.0	13.92	29	5
12	0.32	1.20	0.07	0.23	5.02	0.0	11.96	21	2
13	0.31	0.99	0.04	0.35	5.03	0.0	15.04	47	1
14	0.31	1.31	0.04	0.26	2.3	0.0	12.50	34	5
15	0.32	0.70	0.00	0.06	0.45	0.0	12.08	22	6
16	0.58	5.02	0.04	0.08	1.18	0.0	9.24	14	3

The analysis of the free-looking test results showed that all the researched beer packaging attracted potential consumers' attention. The sum of all fixations was in the range of 9.24 to 18.88. The fixation count depends on the number of graphic and textual elements on the packaging which attract attention (the largest number of graphic and lettering elements is the largest fixation count). In the case of the analysed beer packaging, bottle No. 1 received the most interest. This packaging had a lot of information and some graphic elements. The bottle also had embossed decorations. It had the biggest fixation count (18.88). This packaging was characterised as having great importance and was the most noticeable in the process of sight scanning for the respondents. The lowest number of fixations was noted for bottle No. 16, with a mean fixation count of 9.24. This packaging was much clearer. The form of the bottle is simpler, the label is more legible and easier to read, and the quantity of information is smaller than on bottle No. 1. A large difference was noticed in the easiness to read between those two labels because of the label background colour and font colour contrast. Also, legibility was influenced by the font size and the interline size.

The study confirmed the results by Mackey and Metz (2007). The research results showed a low time to the first fixation, which is from 0.06 to 0.45 s. Time to the first fixation depends on specific, distinctive elements that appear on the packaging, which attract sight in the first place (the more attractive element, the shorter time to the first fixation). The lowest time to the first fixation was noted for bottles No. 15 (0.06 s) and No. 16 (0.08 s). On both bottles, distinctive elements were areas with graphic sign clusters. Attention was attracted by labels with less text. The results of eye-tracking descriptive statistics confirmed that this packaging not only attracted the most attention of the respondents but was also noticed the fastest.

The interpretation of the first fixation duration supplemented the analyses of packaging perception. The first fixation duration is the time when respondents are looking at the first element that attracts their attention to the packaging. In the analysed case, the first fixation duration was in the range of 0.21 to 0.58 s. Bottle No. 16 was viewed the longest. The long viewing was due to the diversity of information (graphic and textual), different sign sizes, and the use of different colours. The shortest time was given to bottle No. 8. This packaging contained little text, and the shape and size of the signs were the same.

The perception was analysed to distinguish the packaging that attracts the most attention from potential consumers. It was based on the heat map analysis. The eye-tracking results are presented in Fig. 3.

The total variety analysis of the intensity of attention by using colour allowed for defining the level of concentration on the packaging from the highest degree of attention concentration (marked in red) to medium (marked in yellow) and small (marked in green). Explication of the respondents' sight activity based on the average areas of the packaging's image showed that in the case of all analysed beer packaging, the survey participants focused their sight mainly on the packaging elements which were highly persuasive. These elements may significantly influence a potential buyer by making certain impressions, which can be confirmed by the research results (Cholewa-Wójcik & Kawecka, 2015; Wright & Ward, 2008).

To check if warning signs are catching the attention of consumers in the first place, a comparison of descriptive statistics was done. Time to the first fixation on the whole packaging and on the area with signs was compared. If the time of the first fixation on the packaging is equal to the time of the first fixation on the area with the sign, it means that the sign was the first element of packaging that consumers looked at. The comparison is presented in Table 2.

On average, the time to the first fixation on the packaging was shorter than 0.5 seconds. The time to the first fixation on the area of signs varied. The measure was in the range of 1.60 s to 8.16 s. In the area of signs, the first fixation was always recorded much later than in other packaging areas. The fastest was noticed sign on bottle No. 7. Signs on this packaging were easily noticeable because the signs were white on the black label, and the glass was also very dark. The only white elements on the packaging besides signs were the brand name and the bare code. After 2.2 seconds, the sign on bottle No. 9 was also visible to respondents. The sign was easily noticeable because the field of view had very few elements, and the sign was in red, which is a very visible colour. This sign is a connection between the graphic and textual information. The signs on bottles No. 1 and No. 10 took the longest to be noticed. On both bottles, the signs were very small.

The results clearly showed that the time to the first fixation on the packaging is much shorter than the time to the first fixation on the area where signs

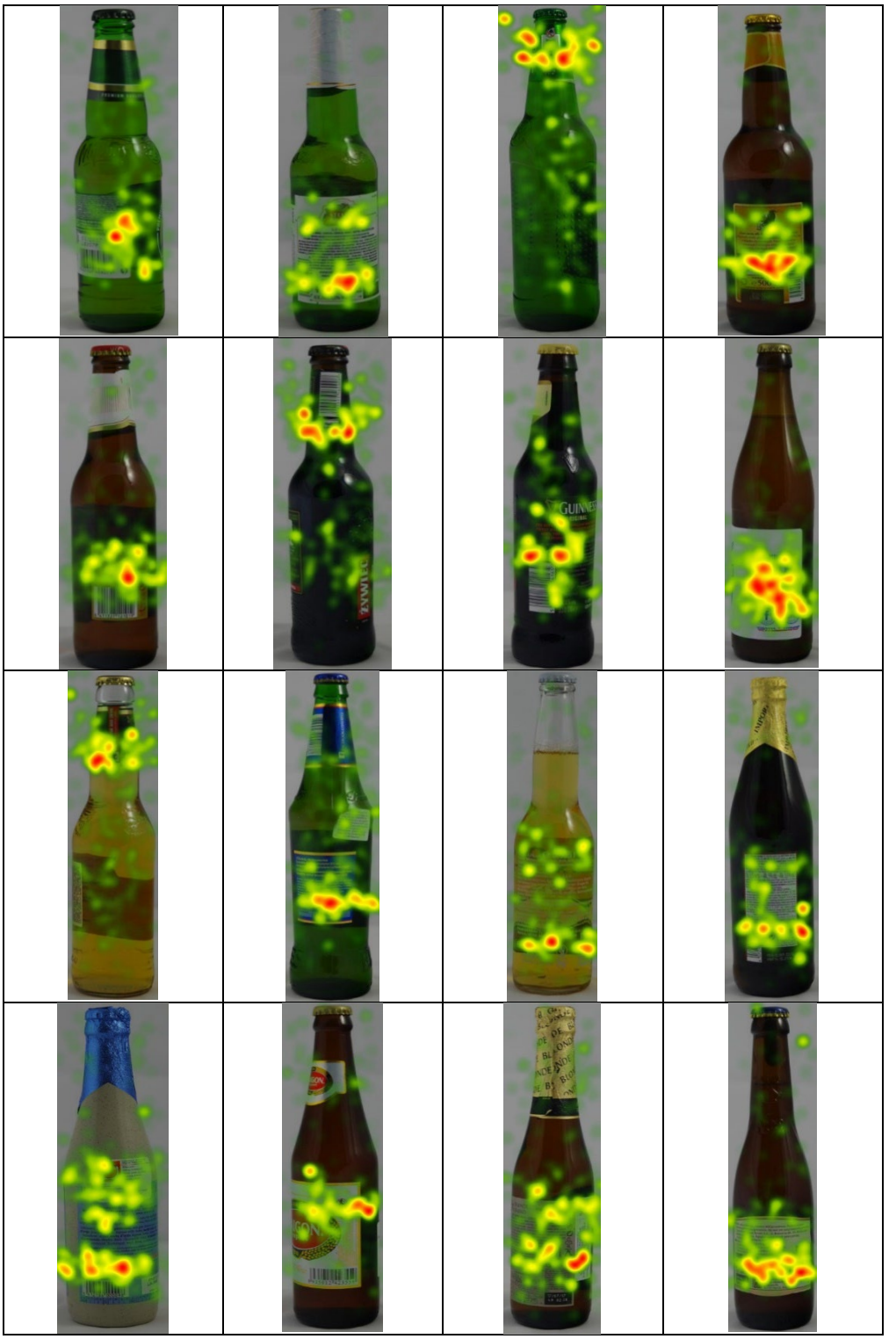


Fig. 3. Heat maps of the analysed beer packaging

are located. That means that signs do not grab consumer attention in the first place. To compare the overall rate of interest in a designated area of the AOI, the numbers of fixations recorded for the whole package and for the area with the sign were compared.

There is a strong relationship between the number of fixations and the length of time spent watching the area. The number of fixations is, therefore, an important indicator of viewing (both across the whole surface and its parts). The obtained results are presented in Table 3.

Analysis of the results showed that the packaging and the signs on it received diverse interest from the respondents. The fixation counts on packaging ranged from 9.24 to 18.88. However, signs on the packaging had fixation counts from 1 to 3. The sign on bottle No. 1 received the most interest, while the signs on packaging No. 10 received the least interest. The low number of registered fixations on packaging signs shows that consumers do not read the labels and do not pay or pay very little attention to the warnings. This may result from low consumer awareness and a lack of the ability to interpret graphic signs. Properly displaying the sign on the label in conjunction with the text and selection of appropriate contrasting colours can help to focus attention on it. The research results were the basis for the proposal concerning object perception and warning signs placed on the packaging. Perception understood as a process of sensory information identification, is hindered by difficulties defined as distractors.

Element perception is influenced by the object's ability to attract attention and distractors that may be internal or external to the packaging. External distractors are environmental factors independent of the packaging, such as consumers' personal attention deficits. However, other distractors are internal to the packaging, e.g.:

- Unsuitable packaging materials, which make it difficult to read the information (bottle No. 11 —the total time of fixations was short, as demonstrated by the heat map. This shows that weak legibility diverts the attention away from packaging).
- Very complex packaging, with a lot of different features and elements (bottle No. 1 — the fixation count was very high due to multiplicity of different elements such as more than one label, colour diversity of labels, lots of information in small font, ornaments, etc.).
- Unsuitable contrast between packaging, label background, font, and graphic information (bottle No. 4 — low fixations count of 10.84 is proof of little attention paid to this element).
- Unsuitable proportion of packaging, label, and information signs (bottle No. 10 — the biggest

Tab. 2. Perception results using the chosen eye-tracking measures

Packaging	Time to the first fixation on the packaging [S]	Time to the first fixation on sign or signs [S]
	Mean	Mean
1	0.30	8.16
2	0.25	6.72
3	0.45	4.85
4	0.45	2.65
5	0.35	3.79
6	0.29	3.61
7	0.30	1.60
8	0.38	4.08
9	0.38	2.20
10	0.34	8.27
11	0.25	4.46
12	0.23	4.18
13	0.35	5.07
14	0.26	3.59
15	0.06	3.47
16	0.08	3.15

Tab. 3. Fixation counts on packaging and sign areas

Packaging	Fixation count on packaging	Fixation count on signs
	Mean	Mean
1	18.88	3.00
2	13.62	1.75
3	12.12	1.83
4	10.84	2.19
5	14.56	1.83
6	12.56	2.62
7	13.08	2.11
8	17.04	1.58
9	12.16	2.04
10	15.36	1.00
11	13.92	1.11
12	11.96	1.25
13	15.04	1.57
14	12.50	1.25
15	12.08	1.33
16	9.24	1.56

subtraction between the total count of fixations on packaging and fixations on warning signs due to the small size of warning signs)
- Unsuitable placing of textual and graphics information (bottle No. 1 — the biggest difference between the time to the first fixation on packaging and the time to the first fixation on warning sign due to difficulty in finding a sign).

Conclusions

Warnings are an important element of the visual layer of product packaging. Their task is to warn about the threat, the source of which may be the product. From the point of view of public health, one group of extremely important warnings of consequences are placed on the packaging of alcoholic beverages, including beer.

Warning signs are the elements of social marketing. So far, they have been investigated using questionnaires or focus groups and eye-tracking methods in the analysis of perceptions. An eye-tracking method allows for supplementing research with objective knowledge obtained based on the analysis of the actual reception of the tested products, including packaging and their marking, not only the subjective opinions of the respondents, which was proven by Kersbergen and Field (2017), Monk et al. (2017), and Pham et al. (2018). This method makes it possible to determine the way consumers perceive particular elements of the visual layer of packaging (warning signs), as shown by Keyser et al. (2021) and Escandon-Barbosa and Rialp-Criado (2019). In addition, it allows for learning the perception patterns of potential consumers. The results of eye-tracking research indicate that poor visibility of a sign and its bad location on the packaging fail the intended function of communicating the warning content and, thus, cannot affect the actual behaviour of consumers. It is important to ensure the effectiveness of the warnings placed on packaging; therefore, research should be conducted on the perception and acceptance. The conducted study showed that the presence of pictograms (graphic symbols) does not guarantee the focus of potential buyers' attention. The analysis of obtained results clearly indicated that efficiency of perception is the result of many elements, including the placement of the sign, its size and colours, a link between graphic and textual information, and the colour of the packaging material and the label, as proved by Gold at al. (2021).

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Assessment of the occupational health and safety management system by qualimetric methods

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ABSTRACT

Requirements of the international standard ISO 45001:2018 were analysed to identify the need for monitoring, measuring and analysing the functioning of the occupational health and safety management system. This analysis has made it clear that the effectiveness of the development and implementation of the occupational health and safety management system depends on the assessment methodology. The study focused on existing studies and publications on the assessment of processes, including those related to occupational safety, assessment methods or qualitative methods, and statistical methods used for assessment. As a result, the topic has been proven relevant, and the goal of the article was determined: to study the possibility of using qualimetric methods for evaluating the labour safety management system. A survey was conducted among workers at a machine-building enterprise to evaluate the occupational health and safety management system. Verbal scales were proposed to process the study results as they allow quantitative ratings to be obtained on the coded scale of the desirability function. The study result is a technique for obtaining a quantitative assessment of the occupational health and safety management system. This technique is universal and can be applied to any enterprise. It can also be used to make managerial decisions regarding the improvement of the occupational health and safety management system.

KEY WORDS

management system, assessment of the system, occupational health and safety, risk, qualimetric methods

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Introduction

Despite the growth of technology and industrial development that has led to increased productivity and economic prosperity, new challenges have arisen in occupational safety. Various accidents are possible in production that can lead to the death, injury or illness of workers, and production and financial losses.

To avoid accidents, occupational safety management systems that consider the processes of identification, control, assessment and management are

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implemented. In accordance with international standards, effective management becomes a key prerequisite for the successful functioning of any organisation.

An effective occupational safety management system is the implementation of occupational safety policies, procedures and practical measures aimed at preventing accidents and protecting employee health. This includes identification of the existing risks, assessment of risks, development of preventive measures, training of workers in safety, and the systematic monitoring and evaluation of the occupational safety system's effectiveness.

The availability of an effective occupational safety management system not only ensures the safety and health of employees but also has a positive impact on the organisation as a whole. It will help avoid possible costs related to accidents, lost work time and lawsuits. In addition, it can increase employee motivation and productivity, reduce employee attrition, and improve the organisation's reputation in the eyes of customers and the public.

Therefore, it is necessary to have a scientifically based methodology for quantitative assessment of the occupational safety management system. Qualimetry methods are used to obtain quantitative indicators of the quality of various objects, including the occupational safety management system. Qualimetry science studies the quantitative assessment methodology of the quality of various objects and processes. The occupational health and safety management system was considered an object of qualimetry.

Thus, the purpose of the article is to develop a methodology for assessing the occupational health and safety management system by qualimetric methods considering health risk factors.

The theoretical value of the article is the possibility of using qualimetric methods to assess the labour safety management system. The practical value is the developed technique for assessing the labour safety management system that can be applied at various enterprises.

The article presents the literature review results related to the justification of the need to assess the labour safety management system considering health risk factors and the assessment technique. It describes the study's methodology and presents and discusses its results. Also, the results are generalised, study limitations are explained, and directions for further research are indicated. The last section presents conclusions and directions for future research.

1. Literature review

The standard ISO 45001:2018 "Occupational Health and Safety Management Systems. Requirements with Guidance for Use" establishes requirements for the occupational health and safety (OH&S) management system and contains guidelines for their use to enable organisations to create safe and healthy conditions at the workplace, preventing injuries and deterioration of health related to production and actively improving its performance indicators in the field of occupational health and safety.

To effectively solve labour safety issues at an enterprise, it is necessary to develop and scientifically substantiate methods and procedures for assessing labour safety. They should be unified and have the status of a regulatory document. The analysis of ISO 45001:2018 requirements confirmed the need for assessing the state of occupational safety, for example:

6.1.2.2. Methods and criteria for OH&S risk assessment should be determined by the organisation considering their scope, nature and timeliness. Documented information related to these methods and criteria should be managed and maintained;

9.1.1. To ensure the achievement of the expected results of the OSH management system, processes should be monitored, measured and analysed. The organisation should evaluate OH&S indicators and determine the effectiveness of the OH&S management system. The organisation should determine the methods of monitoring, measurement, analysis and evaluation of indicators, as far as applicable, to ensure suitable results and criteria, according to which the organisation will evaluate indicators in the field of OH&S (ISO 45001, 2018).

Monitoring, measurement and analysis can relate to either production events or the effectiveness of supervisory measures. Monitoring can be defined as supervision of working conditions. Measurements are a key part of quantifying data (e.g., measurement of indoor air temperature). In turn, the analysis refers to the study of data for identifying relationships.

More advanced and economical methods of collecting and processing information are needed for effective management. However, the assessment methods are not regulated in the standard, and each enterprise independently faces the problem of determining the mechanism for assessing the occupational health and safety management system.

The methodology for assessing processes of the quality management system following the requirements of the ISO 9001 standard is sufficiently fundamentally, completely and reasonably presented in the scientific work (Ginevičius et al., 2015), which regulates methods and techniques of quantitative quality assessment of technological, assurance and management processes.

In qualimetry, mathematical dependence is an integral part of many processes of assessment and comparison of various indicators. For example, Trishch et al. (2023) used mathematical dependencies to assess the quality of investments, considering the real values of investments and their assessments on a dimensionless scale. Similarly, Ginevičius et al. (2022a) underlined that mathematical dependencies are needed to compare the economic development of the European Union countries. In another work, Ginevicius et al. (2021) stressed the need to study the economic indicators of the country's development. Cherniak et al. (2020) used various functional dependencies between the measured indicators of dangerous factors and their assessment on a dimensionless scale to evaluate indicators of occupational health and safety. Therefore, techniques that apply mathematical dependencies are useful tools for evaluating, comparing, and solving complex problems in various science and research fields. They have a more accurate application of the values of various indicators and ensure objectivity and scientific accuracy in the conducted studies.

Tazim et al. (2023) applied a fuzzy analytical hierarchy approach to identify and rank occupational safety risk factors and a fuzzy inference system (FIS) to develop a risk assessment model. Yazdi et al. (2020) improved the DEMATEL method for effective decision-making in occupational safety management by introducing the best-worst method (BWM) and the Bayesian network (BN).

Yazdani et al. (2020), Stefanovića et al. (2019), and Stojčić et al. (2019) used multi-criteria decision-making (MCDM) methods. The most common of them is TOPSIS, a method of multi-criteria decision analysis that is used to determine the optimal option among alternatives (Divya et al., 2020; Chakraborty, 2022). EDAS is popular in various fuzzy cases. The best solution is selected by calculating the distance of each alternative from the optimal value. In calculations, attributes are independent, and all qualitative attributes are converted into quantitative ones (Ozgur et al., 2020). To evaluate the processes of social and economic systems, the following methods are used: PROMETHEE (a method for organising the preference ranking that is used to rank alternatives based on their independent importance against a set of criteria), MOORA (a method of multi-objective optimisation that uses ratio analysis to arrange alternatives), WASPAS (a method used for weighted assessment of quality indicators) (Abdullah et al., 2019; Manurung et al., 2019; Mishra & Rani, 2021).

2. Research methods

To achieve this goal, it is proposed that function-dependent statistics from the theory of extreme statistics be used as a mathematical apparatus. Mathematician Gnedenko proved that the class of limit distributions for the largest sample value contains only three types of laws, where the first type for the largest sample term x(n) is:

$$F_1(x) = exp(-exp(-x)) \quad (- < x <) \tag{1}$$

where x — numerical value of a variable; $F_1(x)$ — estimate of a variable on a dimensionless scale.

To obtain the asymptotic distribution of the smallest value, it is sufficient to use the symmetry principle and the asymptotic distribution of the largest values (1). Hence, the asymptotic distribution of the smallest value of the first type has the form:

$$F_2(x) = 1 - exp(-exp(x)) \tag{2}$$

Notice that the same distribution function in the region of the smallest values can belong to one type of asymptotic distributions, and in the region of the largest values — to another type. But, nevertheless, there is a class of functions that have extreme values whose asymptotic distribution is of the first type.

The important fact is that the first limiting distribution of extreme values can be linearly transformed into an expression containing no parameters. Since the normalised asymptotic distribution of the first type (1) has no parameters, it can be applied to the evaluation of any objects of qualimetry.

Taking the fact that the estimation of any object obeys such a distribution law that has the asymptotic distribution of the largest and smallest values of the first type, overestimated and underestimated values will be obtain, i.e., the estimation interval. The mean distribution is suggested to obtain a point estimate.

Thus, the lower and upper interval estimator is calculated by formulas (1) and (2), respectively, and

the point estimator, F(x), is of the form (Ginevičius et al., 2022b):

$$F_3(x) = \frac{\left(exp\left(-exp\left(-x\right)\right)+\left(1-exp\left(-exp\left(x\right)\right)\right)\right)}{2} \qquad (3)$$

Note that the function F(x) is the distribution function of the random variable x.

Fig. 1 presents functions $F_1(x)$, $F_2(x)$, and $F_3(x)$ in graphic form.

Based on Fig. 1, the OX scale should vary from -3 to 3 to obtain indicator estimates for qualimetry objects when using dependencies (1), (2), and (3). In the case when indicators are measurable and have different scales of measurement, the known method of dividing a segment in given proportion is applied. In the case when indicators of qualimetry objects are evaluated by experts or participants of survey or testing, then it is suggested to apply verbal scales.

The studied case used a quantitative-verbal matrix that allows for translating various options of verbal assessments into a coded scale to perform one of the assessment stages on the state of the system, i.e., the selection of the scale and measurement limits. The matrix involves the use of verbal scales with the number of assessment options (from 2 to 7). The coded scale varies from -3 to 3 in 0.5 steps and is functionally dependent on a score on a dimensionless scale due to nonlinear dependence (Fig. 2).

The experts choose the necessary dependence (1), (2), and (3) to assess the indicator and the value within the defined ranges on the coded scale. On the scale, there are "2 assessment options": "Bad" corresponds to the range from "-3" to "0"; "Good" corresponds to the range from "0" to "3". On the scale, there are "3 assessment options": "Bad" corresponds to the range from "-3" to "-0.5"; "Satisfactory" — from "-0.5" to "0.5"; "Good" — from "0.5" to "3". On the scale, there are "4 assessment options": "Very bad" corresponds to a range from "-3" to "-1"; "Bad" — from "-1" to "0"; "Good" — from "0" to "1"; "Very good" — from "1" to "3". On the scale, there are "5 assessment options": "Very bad" corresponds to a range from "-3" to "-1.5"; "Bad" — from "-1.5" to "-0.5"; "Satisfactory" — from "-0.5" to "0.5"; "Good" — from "0.5" to "1.5"; "Very good" — from "1.5" to "3". On the scale, there are "6 assessment options": "Very bad" corresponds to a range from "-3" to "-1.5"; "Bad" — from "-1.5" to "-0.5"; "More bad than good" — from "-0.5" to "0"; "More good than bad" — from "0" to "0.5"; "Good" — from "0.5" to "1.5"; "Very good" — from "1.5" to "3". On the scale, there are "7 assessment options": "Very bad" corresponds to the range from "-3" to "-1.5"; "Bad" – from "-1.5" to "-1"; "More bad than good" — from "-1" to "-0.5"; "Satisfactory" — from "-0.5" to "0.5"; "More good than bad" — from "0.5" to "1"; "Good" — from "1" to "1,5", "Very good" — from "1.5" to "3".

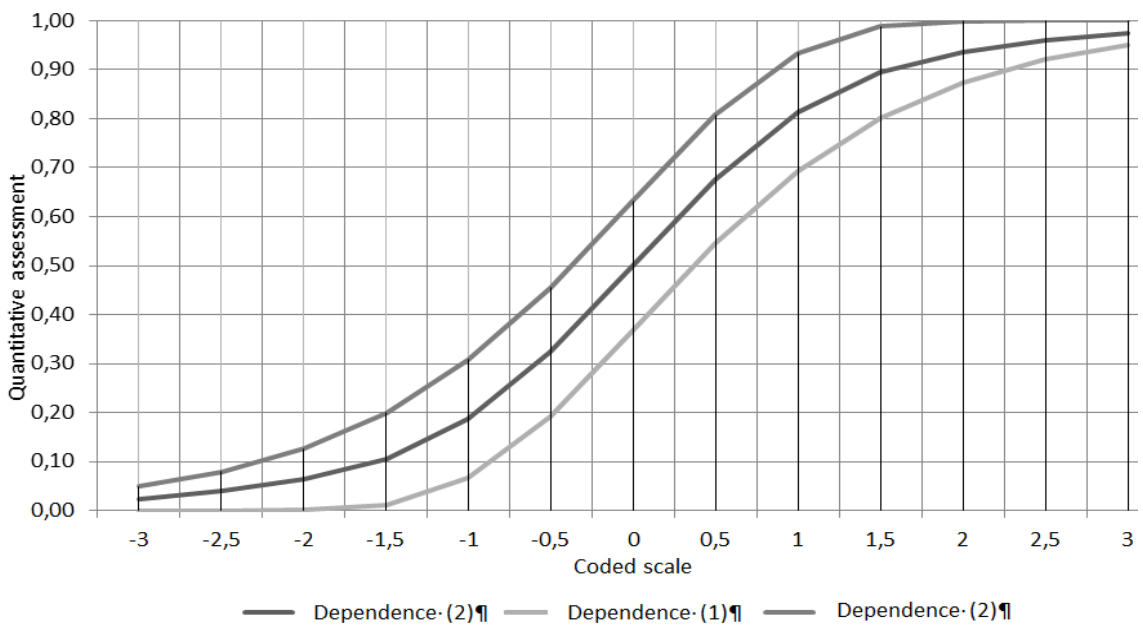

Fig. 1. Dependencies (1), (2), and (3) and their estimates on a dimensionless scale

Source: Ginevičius et al., 2022b.

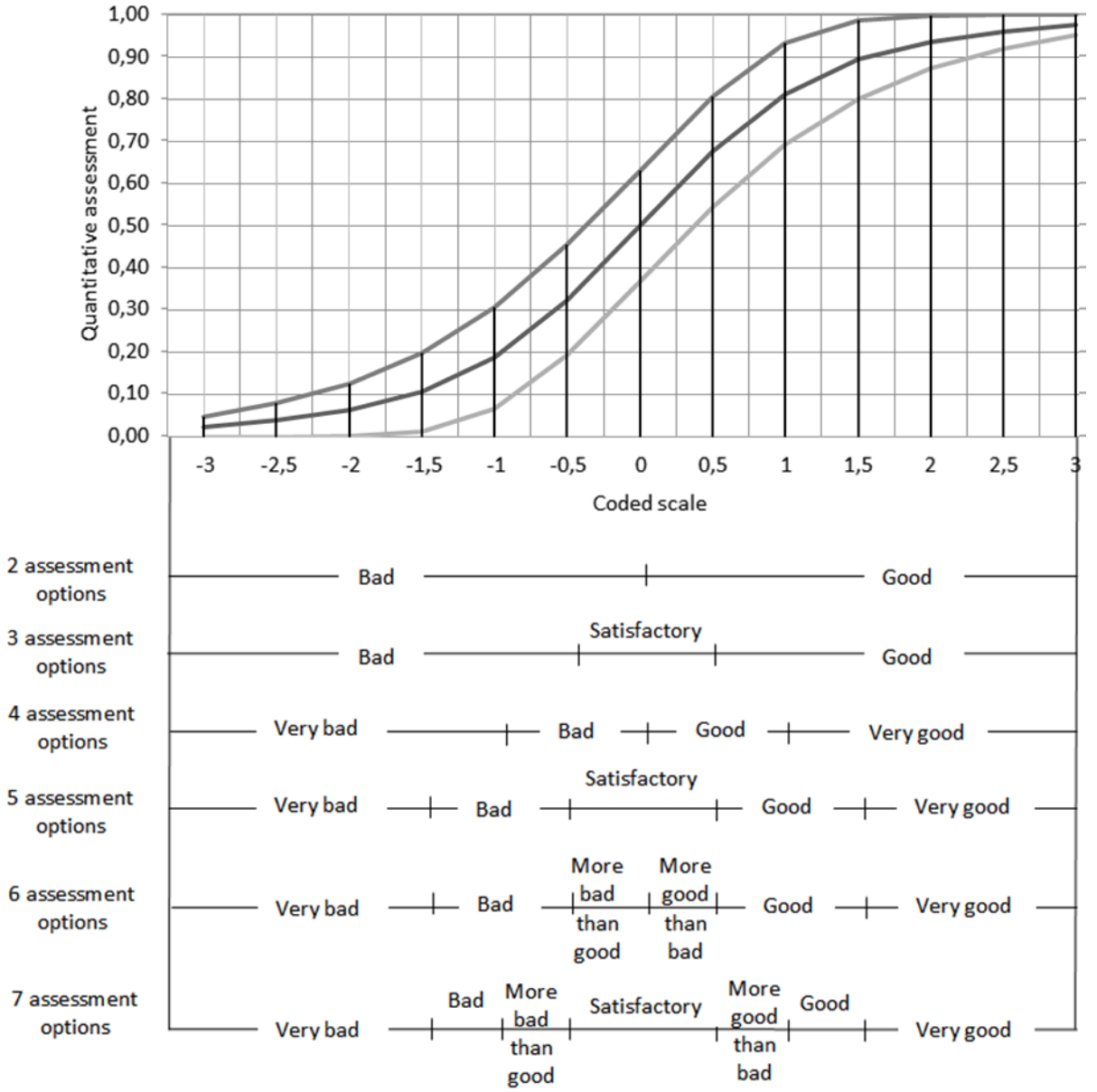

Fig. 2. Functional dependence of the verbal-numerical scale

Since the assessments of unit indicators have the same measurement scale (0 — 1), it is possible to find a comprehensive assessment by applying one of the average values. In this case, the arithmetic mean is used.

$$Q = \frac{1}{n}\sum_{i=1}^{n} F_i \qquad (4)$$

where n — is the number of unit indicators; F_i — is the value of the i-th unit indicator on the dimensionless scale.

A step-by-step methodology for assessing the occupational safety management system consists of the following stages:

Step 1. Determining the list of questions for assessing the occupational health and safety management system.

Step 2. Choosing scales and limits of measurement using the quantitative-verbal matrix (Fig. 2). This matrix is not the only possible option, but it is quite universal and practical. It is necessary to select the number of assessment options and determine the numerical values that correspond to them on the coded scale.

Step 3. Determining the scores of the indicators on a dimensionless scale. With the help of experts, select the necessary dependence (1), (2), and (3) to estimate the indicator.

Step 4. Using the coded value x in formula (1) if the indicator is not very important, in formula (2) if the indicator is important, and in formula (3) if the indicator is very important.

Step 5. Determining with the use of formula (4) of the comprehensive assessment of the labour safety system, considering all individual indicators.

3. Results and discussion

Studies were conducted at a machine-building enterprise to confirm the efficiency of the developed technique for assessing occupational health and safety management systems. A questionnaire with tests was developed for the assessment, and a survey of the enterprise's employees was conducted.

The results of the tests that are presented in a qualitative format allow for assessing the dimensions of a particular problem, but this is usually not sufficient for making management decisions. The resulting data contain a limited amount of information and, in addition, are subjected to a grouping process that further reduces their value.

A questionnaire was drawn up, and interviews were conducted with 83 employees of the machine-building enterprise. Test questions in the questionnaire were divided into three test groups.

The first group of tests concerned working conditions at the workplace and their impact on workers' health. They were divided into four questions: (1.1) health status of employees in relation to existing labour safety requirements, (1.2) impact of working conditions on future employment at the enterprise, (1.3) assessment of labour conditions at the workplace, and (1.4) whether the employees of the company are provided with special clothing, footwear and other personal protective equipment. The results are presented in Table 1.

Tab. 1. Results of the survey on working conditions and their impact on workers' health

Test No.	Answers	Quantity of responses
1.1	Significantly deteriorated	9
	Somewhat deteriorated	10
	Depends on the season	20
	Remained unchanged	24
	Improved	7
	Significantly improved	13
1.2	Had to quit	62
	Did not have to quit	21
1.3	Satisfies	43
	Hard to say	31
	Not satisfied	9
1.4	Yes, I am provided with	32
	No, I am not provided with	3
	I am provided with, but it could be better	46
	I am not sufficiently provided with	2

Tab. 2. Results of the assessment of the occupational health and safety management system at the enterprise

Test No.	Answers	Quantity of responses
2.1	Excellent	21
	Good	20
	Satisfactory	8
	Unsatisfactorily	7
2.2	All issues are resolved	37
	Some issues are resolved	21
	No issues unresolved	25
2.3	Familiarised	67
	Not familiarised	16
2.4	Not satisfactory at all	3
	Rather unsatisfactory than not	4
	Satisfactory	15
	Rather satisfactory than not	17
	Quite satisfactory	44

Tab. 3. Ability of employees to protect their rights in the field of occupational health and safety

Test No.	Answers	Quantity of responses
3.1	Yes, I know	41
	No, I do not know	25
	I think it is useless to do so	17
3.2	Yes, I have enough information about it	19
	Yes, I have information about it, but I would like to have more of it	26
	Yes, I have information about it, but it is not enough	27
	No, I do not have any information about it	11
3.3	Yes, it provides	71
	No, it does not provide	12

Tab. 4. Quantitative and verbal assessments

TEST NO.	EVALUATION SCALES												
	-3	-2,5	-2	-1,5	-1	-0,5	0	0,5	1	1,5	2	2,5	3
1.1	Significantly deteriorated		Somewhat deteriorated		Depends on the season				Remained unchanged		Improved		Significantly improved
1.2		Had to quit										Did not have to quit	
1.3	Not satisfies						Hard to say						Satisfies
1.4	No, I am not provided with				I am not sufficiently provided with				I am provided with, but it could be better				Yes, I am provided with
2.1	Unsatisfactorily				Satisfactory				Good				Excellent
2.2	No issues unresolved						Some issues are resolved						All issues are resolved
2.3		Not familiarised										Familiarised	
2.4	Not satisfactory at all			Rather unsatisfactory than not			Satisfactory			Rather satisfactory than not			Quite satisfactory
3.1	No, I do not know						I think it is useless to do so						Yes, I know
3.2	No, I do not have any information about it				Yes, I have information about it, but it is not enough				Yes, I have information about it, but I would like to have more of it				Yes, I have enough information about it
3.3		No, it does not provide										Yes, it provides	

The second group of tests referred to the assessment of the occupational health and safety management system and compliance with safety standards.

It also had four questions: (2.1) assessment by employees of the state of labour safety at the enterprise, (2.2) readiness of the company to improve working conditions, (2.3) procedures familiarising employees with enforced internal acts on labour safety, etc., (2.4) effectiveness of in-service information on occupational safety at the enterprise (informative content of labour safety posters, ensuring awareness of employees by showing a series of videos on labour safety, effectiveness of visual study of safe methods and techniques of work performance (posters), and introduction of labour safety instructions). The results are presented in Table 2.

The third group of tests referred to questions regarding employee satisfaction with the legal system of occupational safety. The group was subdivided into three questions: (3.1) the possibility of recourse in case of violation of your rights in the field of occupational safety, (3.2) sufficient information about their rights in the field of occupational health and safety, (3.3) the extent to which the legislation provides for the possibility of defending the interests of employees in relation to occupational safety. The results are presented in Table 3.

In the second stage of the research, a quantitative-verbal matrix was used to transform the qualitative assessment of the state of the enterprise's occupational safety and health management system into a quantitative one. The results are presented in Table 4.

By equating the test results in a qualitative form to the scale of normalised numerical values of the factors (from -3 to 3 with a step of 0.5), numerical values of the test results were obtained. An assessment of the factor on the dimensionless scale is achieved by using the values in the formula of functional dependence.

Thus, all indicators were assessed using a single (dimensionless) assessment scale. After that, a generalised multi-criteria assessment of the occupational safety management system can be obtained using the arithmetic mean formula (4).

The results of applying the proposed methodology in quantitative terms will be presented using the example of a machine-building enterprise when 83 employees were interviewed. Tables 1–3 present 11 questions and the number of answers to each of them. Using the proposed methodology and Table 4, the answers to questions presented in (Table 1–3) were converted into a verbal scale with a range of (-3;3). In this way, we convert the answers to the questions into numerical values.

Having the values on the verbal scale (OX) and applying dependencies (1–3), we obtain numerical values on the dimensionless scale for each answer to the question. Knowing the number of answers and their numerical values on a dimensionless scale, we obtain a complex indicator using the formula:

$$q_i = \frac{1}{n}\sum_{i=1}^{n} F_i k_i \qquad (5)$$

where q_i — is the value of the complex indicator on a dimensionless scale; F_i — is the assessment of the i-th question on a scale without dimensions, k_i — is the number of answers to the i-th question; n — is the number of indicators, in our example n=11.

Thus, we obtain complex indicators for all (11) questions. The results are presented in Table 5.

A comprehensive assessment of the occupational safety management system at a machine-building enterprise using the arithmetic mean of all q_i can be found using the results of the surveys.

The complex indicators presented in Table 5 provide information for making management decisions within the enterprise. The company's management can make decisions on preventive and corrective actions in relation to a particular indicator.

The obtained value of the complex indicator of the occupational safety and health management system shows its level, which can serve as a criterion for assessing the enterprise at the state level and taking appropriate measures to improve the state of occupational safety at this enterprise.

Thus, the entire occupational safety management system in production can be assessed with the help of functional dependence and experts. The proposed technique can make management decisions that lead to the minimisation of risks and accidents. The technique is universal and can be applied to assessment of

$$Q = \frac{0{,}61 + 0{,}31 + 0{,}76 + 0{,}91 + 0{,}51 + 0{,}62 + 0{,}82 + 0{,}87 + 0{,}64 + 0{,}63 + 0{,}87}{11} = 0{,}69 \qquad (6)$$

Tab. 5. Complex indicators for 11 questions

Test No	questions	complex indicator q_i
1.1	Health status of employees in relation to existing labour safety requirements	0.61
1.2	Impact of working conditions on future employment at the enterprise	0.31
1.3	Assessment of labour conditions at the workplace	0.76
1.4	Whether the employees of the company are provided with special clothing, footwear and other personal protective equipment	0.91
2.1	Assessment by employees of the state of labour safety at the enterprise	0.51
2.2	Whether the company addresses the issue of improving working conditions	0.62
2.3	Whether employees are familiarised with internal acts on labour safety	0.82
2.4	Effectiveness of in-service information on occupational safety at the enterprise	0.87
3.1	The possibility of recourse in case of violation of your rights in the field of occupational safety	0.64
3.2	Sufficient information about their rights in the field of occupational health and safety	0.63
3.3	The extent to which the legislation provides for the possibility of defending the interests of employees in relation to occupational safety	0.87

the occupational health and safety management system in various organisations.

Discussion

The results obtained in the article open up a new direction for research in terms of quantitative assessment of the labour safety management system using qualimetric methods. The proposed methodology allows for obtaining quantitative values of occupational safety indicators using survey results. In this case, mathematical statistics methods were used, making the methodology universal. In addition, this methodology can be applied to management decisions at the enterprise and higher levels.

In the existing scientific literature (Trishch et al., 2023; Ginevičius et al., 2022a), nonlinear functional dependencies are used to assess socio-economic systems, but unlike the proposed methodology, it is not clear why the scales are divided into three groups. There is also no justification for the choice of such an uneven scale.

In contrast to the methodology (Ginevičius et al., 2022b) that also uses qualimetric methods, the proposed methodology proposes to use the functional dependence of the verbal-numerical scale. This allows it to be universally applicable.

For the further development of scientific research, it is possible to apply other mathematical dependencies between the measured indicators of working conditions and their assessment on the dimensionless scale that would consider various features of the qualimetry object. Based on the proposed technique, it is desirable to develop a computer program that will allow the assessment process to be automated.

Conclusions

The result of the article is a technique of obtaining quantitative assessments of the occupational health and safety management system with a large number of indicators. This technique allows using a wide range of mathematical tools for assessment and management decision-making.

At the same time, several scientific tasks were solved:

- a quantitative-verbal matrix that allows converting various options of verbal assessments into the coded numerical scale has been developed. The matrix involves the use of verbal scales with several assessment options (from 2 to 7) that make it universal;
- the numerical values of the generalised multicriteria assessments of the tests of the employees of the machine-building enterprise and the system of ensuring safe working conditions at the enterprise within the limits of a representative sample (83 persons) have been obtained;
- a comprehensive assessment of the occupational health and safety management system at the machine-building enterprise has been found.

The scientific value of the proposed technique lies in its universality. It can be used to assess working conditions at production facilities of various industries with a different number of harmful factors and

with a different range of measurements. In addition, the indicators may have different measurement scales, which may be determined by legal or corporate requirements. They can also be reviewed and changed to manage the occupational safety system effectively.

The limitation of this methodology is that it does not use quantitative indicators. It refers to the impact of physical, chemical and biological factors on health. In addition, it uses verbal scales with a limited number of answers, namely seven options. Also, questions that use scoring are not used in the employee survey.

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Towards a taxonomy of design options for augmented reality-based remote service business models

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ABSTRACT
The aim of this paper is to develop design options for Augmented Reality (AR)-based remote service business models to support the implementation of AR technology for remote services currently taking place in the manufacturing industry. The design options were developed using a qualitative content analysis based on the results of a systematic literature review and on focus group discussions with 19 service-responsible industry experts from 12 German manufacturing companies. The application of a conceptual approach to taxonomy development resulted in a novel morphological framework with a total of 18 dimensions, each with two to six distinct characteristics representing the targeted design options of AR-based remote service business models. Since previous research on AR for remote services has largely neglected the business model perspective, this work makes a significant contribution to this scarcely explored research field by providing a systematic basis for describing and classifying such business models in terms of their design. The results provide industrial practice with the most important aspects to consider when designing AR-based remote service business models.

KEY WORDS
augmented reality, remote service, business model, taxonomy

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Introduction

The use of augmented reality (AR) technology for industrial maintenance purposes has received growing interest in science and practice. Numerous AR applications have been identified (Dini & Mura, 2015; Nee et al., 2012; Palmarini et al., 2018), including remote maintenance services (Egger & Masood, 2020; Fernández del Amo et al., 2018; Fraga-Lamas et al., 2018) as one of the most prominent.

For some time now, the scientific community has been pointing out the advantages of using AR tech-

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nology for remote maintenance (for example, Aschenbrenner et al., 2019; Mourtzis et al., 2017; Obermair et al., 2020; Porter & Heppelmann, 2017; Rapaccini et al., 2014). Essentially, this involves an increase in the speed of troubleshooting and a reduction in field service deployments. Accordingly, manufacturing companies increasingly intend to use AR technology to provide AR-based remote services (Hadar et al., 2017; Si2 Partners, 2018).

However, very few companies have successfully integrated AR into their business models (BMs) (Röltgen et al., 2019; van Kleef et al., 2010) and most research activities in this area tend to be related to technical issues (Breitkreuz et al., 2022; Marques et al., 2021; Röltgen et al., 2019). Thus, there is little scientifically sound knowledge on AR-based remote service BMs in terms of their classification or design. This is not only a practical problem for service managers, who are responsible for developing such BMs. The classification of objects in general is essential for other studies within the related field of research (Lambert, 2015b). Therefore, missing classification is also a problem for research into AR-based remote service business models.

The development of a taxonomy—as an empirical classification scheme—can address these problems. Taxonomies, due to their ability to structure and organize the knowledge of a specific field (Glass & Vessey, 1995), help to understand and analyze complex domains (Nickerson et al., 2013). Since BMs are abstract and complex concepts, taxonomies are often a subject of study in BM research. Their relevance and importance have been discussed and shown by numerous scholars (Groth & Christian, 2015; Lambert, 2015a). However, the literature lacks a taxonomy for AR-based remote service BMs.

Existing taxonomies in the field of AR, such as those of Marques et al. (2023) or Brockmann et al., (2013), do not take into account the BM perspective. They deal only with technological characteristics or aspects of collaborative work and have a completely different purpose, which clearly deviates from the aim of this work. A taxonomy of AR-based remote service BMs would improve the general understanding of such BMs, provide a foundation for systematic research on this topic, and support practitioners in the development, evaluation, and management of AR-based remote service BMs.

Since a taxonomy is an empirically derived classification of objects based on the totality of their observable characteristics (Baden-Fuller & Morgan, 2010; Lambert, 2015a), empirical data are essential to develop a taxonomy. However, because few companies are operating AR-based remote service BMs, empirical data are not yet available. Accordingly, this paper aims to provide a sound conceptual basis for the future empirical development of a taxonomy of AR-based remote service BMs.

One goal in developing a BM taxonomy is to develop dimensions and characteristics in which the BMs under consideration differ. In addition to differentiating the BMs, the dimensions also specify what must be considered when designing them. Therefore, this paper focuses on dimensions and characteristics that distinguish AR-based remote service BMs and can be used to design them. The research question is as follows: What dimensions and characteristics can be used to differentiate and design AR-based remote service business models?

The rest of the paper is structured as follows: The next chapter presents the theoretical background of this paper by elucidating the concept of AR-based remote services and highlighting the significance of studies on business model taxonomy. Chapter two details the methodology employed to develop the taxonomy, including the process for conducting a systematic literature review, focus group discussions, and qualitative content analysis. The dimensions and characteristics of AR-based remote service business models, developed through this approach, are showcased in the results chapter via a morphological box. The derivation of design options is illustrated through selected quotations. The contribution of focus group discussions to the development of these design options is also highlighted. To ensure the results are appropriately utilized for subsequent empirical iterations in the taxonomy development process, Chapter four discusses these results in light of certain conditions for taxonomy development. The final chapter summarizes the findings, outlines the contributions of this paper as well as the applicability of the results in both academic research and industrial practice. Additionally, it addresses the limitations of the study and proposes avenues for future research in the domain of AR-based remote service business models.

1. Theoretical background

1.1. AR-based remote services

Industrial maintenance tasks are often complex and knowledge intense (Aromaa et al., 2015), and

thus they often require remote support from distant people (Porcelli et al., 2013). The use of AR technology is helpful when technicians need to obtain information on how, for example, a specific maintenance or repair task should be carried out (Palmarini et al., 2023; Porcelli et al., 2013; Rapaccini et al., 2014; Wang et al., 2021).

AR-based remote services in general are services that are provided using mobile AR devices that involve interacting with a so-called remote expert. Mobile AR devices (that is, AR smart glasses or AR-enabled smartphones or tablets) support the interaction between, for example, a technician at the customer's site and the remote expert. The integrated camera in the mobile AR device allows the expert to see what the technician sees on-site. In turn, the display of the mobile AR device allows the remote expert to display instructions in the form of virtual overlays directly in the field of vision of the technician on-site. Although AR smart glasses have the advantage of allowing the technician to work hands-free, both Marques et al. (2022) and our own experience from working with industry partners show that technicians in the field prefer smartphones or tablets to AR smart glasses. However, when AR smart glasses are used in industrial practice for remote service purposes, they are usually the RealWear HMT-1 (or its successor models).

Manufacturing companies can use AR technology for providing remote services in different business cases, such as inspection, diagnosis, and repair; training; system installation; system acceptance tests; or even application support (Müller et al., 2018). Unlike other AR applications (for example, AR-guided step-by-step instructions), AR-based remote services always involve a second person—the remote expert. AR-based remote services can therefore be seen as a specific form or subset of AR applications, with the central aspect of human collaboration being the main differentiator from other AR applications. However, although academia argues that companies need to adapt their BMs to implement AR (Gruia et al., 2020; Röltgen et al., 2019), little attention has been paid to the application of AR from a BM perspective (Grothus et al., 2021; Soh et al., 2018).

1.2. Business model taxonomies

"[…] the general idea of business models is intimately linked with notions of taxonomies and 'kinds.'" (Baden-Fuller & Morgan, 2010, p. 157)

The BM is a distinct concept that is worthy of academic study and relevant in practice (Zott et al., 2011). Although the term business model has gained considerable attention in research and practice over the past decades, there is no accepted definition of the term[1]. In addition to the multitude of definitions, there are also many BM frameworks that describe BMs in terms of their dimensions[2]. However, while some of these frameworks are very generic and intended to describe any BM, they are less suitable for describing specific BMs. Therefore, studies on the classifications of specific BMs are a relevant part of BM research and often the result of BM taxonomy studies. Tab. 1 shows some examples.

Tab. 1. Examples of BM taxonomy studies

Author (Year)	Business Model
Labes et al. (2013)	Cloud business models
Hartmann et al. (2014)	Data-driven business models used by start-up firms
Haas et al. (2014)	Crowdfunding business models
Bock & Wiener (2017)	Digital business models
Eickhoff et al. (2017)	FinTech business models
Nickerson et al. (2017)	Carsharing business models
Urbinati et al. (2017)	Circular economy business models
Beinke et al. (2018)	Start-ups in the finance sector using blockchain
Weking et al. (2019)	Blockchain business models
Mengelkamp et al. (2019)	Local energy market business models
Möller et al. (2019)	Digital business models in logistic start-ups
Ertz et al. (2019)	Product lifetime extension business models
Möller et al. (2020)	Data-driven business models in logistics
Tönnissen et al. (2020)	Blockchain-based business models of start-ups
Perscheid et al. (2020)	Decentralized platform-based business models

[1] Overviews of various definitions of the term business model can be found in El Sawy & Pereira (2013), Zott et al. (2011), and Baden-Fuller & Morgan (2010).
[2] Groth & Christian (2015), Zott et al. (2011), Morris et al. (2005), and El Sawy & Pereira (2013) provide an overview of a number of different BM frameworks by several authors, with a specific examination of the dimensions of each framework.

Since it is the BM dimensions that constitute BMs (Al-Debei & Avison, 2010), the results of such BM taxonomy studies are BM-specific dimensions. Examples include destination or vehicle access in the case of carsharing BMs (Nickerson et al., 2017), blockchain sourcing or token system in the case of blockchain BMs (Weking et al., 2019), or data source or data interface in the case of data-driven BMs (Möller et al., 2020).

However, to the best of the authors' knowledge, no taxonomy studies of AR-based remote service BMs have been conducted to date. Accordingly, the specific BM dimensions that can be used to design AR-based remote service BMs are yet unknown.

2. Research methodology

To develop design options for AR-based remote service BMs, we followed the conceptual approach of taxonomy development by Nickerson et al. (2013). For data collection, we conducted a systematic literature review to identify publications on AR-based remote services from a BM perspective. We also conducted focus group discussions with 19 service-responsible industry experts from 12 German manufacturing companies on the topic of AR-based remote services BMs (Ohlig et al. 2020). From two identified publications as well as the transcripts of the focus group discussions, the targeted design options for AR-based remote service BMs were derived using a qualitative content analysis according to Mayring (2015).

2.1. Taxonomy development

In general, a taxonomy consists of several dimensions, each consisting of at least two characteristics. Therefore, one goal in developing a taxonomy is to develop the dimensions in which the object under consideration differs. There are a few other terms used for dimensions and characteristics, such as variables and values, attributes and values, or categories and capabilities (Nickerson et al., 2013). We decided to use the terms dimensions and characteristics, following the taxonomy definition of Nickerson et al. (2013, p. 340):

"A taxonomy T is a set of it n dimensions D_i (i=1, …,n) each consisting of k_i ($k_i \geq 2$) mutually exclusive and collectively exhaustive characteristics C_{ij} (j=1, …, k_i) such that each object under consideration has one and only one C_{ij} for each D_i."

According to Nickerson et al. (2013) the development of a taxonomy is an iterative process (Fig. 1). Even though it is fundamentally an empirical classification, one can follow either an empirical or conceptual approach during each iteration (Fig. 1, step 3). In

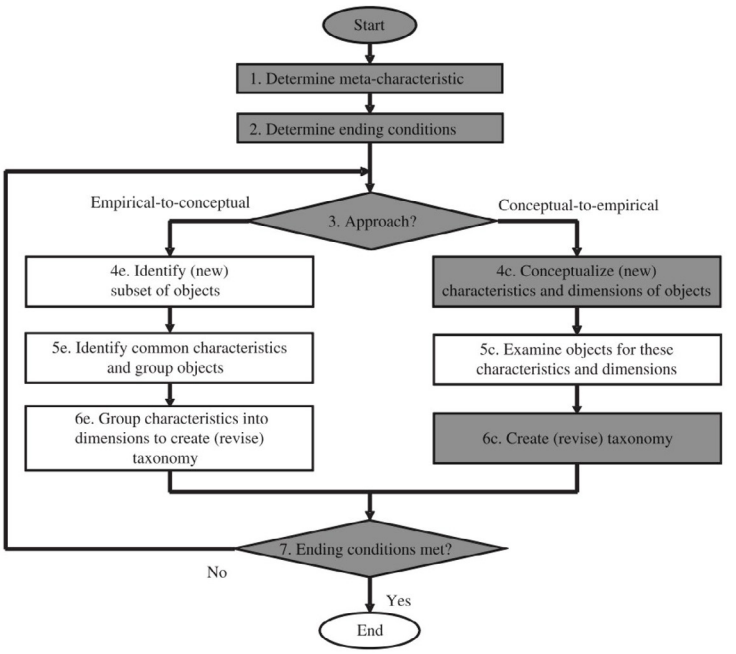

Fig. 1. Iterative taxonomy development process; gray colored elements represent the steps performed in this paper

Source: (Nickerson et al., 2013, p. 345).

each iteration, the researcher has to decide which approach to use. The choice depends on the availability of data and the researcher's knowledge about the object under investigation. Since only a few companies operate AR-based remote service BMs and thus empirical data is not yet available, we take the conceptual approach. This approach starts with the conceptualization of dimensions and characteristics (Fig. 1, step 4c), which is the first essential step towards a taxonomy when little data are available. The outcome is therefore a set of conceptually developed dimensions and characteristics, while empirical iterations will be the subject of further research to establish a final taxonomy of AR-based remote service BMs.

Regardless of the approach chosen, a meta-characteristic (Fig. 1, step 1) as well as ending conditions (Fig. 1, step 2) must be defined first. The meta-characteristic serves as the basis for the selection of characteristics in the taxonomy. That is, each characteristic should be a logical consequence of the meta-characteristic. The meta-characteristic should therefore be based on the purpose of the taxonomy (Nickerson et al. 2013). The purpose of our taxonomy is to classify AR-based remote service BMs based on their design options, which is why we define design options for AR-based remote service BMs as the meta-characteristic. All dimensions and characteristics must be a consequence of this meta-characteristic.

The ending conditions determine the point in time when no further iterations are necessary, and the taxonomy development is completed. Here we adopt the objective and subjective ending conditions proposed by Nickerson et al. (2013), which we will use later to discuss the results.

2.2. Systematic literature review

A systematic literature review was conducted with the aim of identifying publications on AR-based remote service from a BM perspective. Various terms related to augmented reality, such as mixed reality or extended reality, as well as hardware-related terms, such as smart glasses OR head mounted, were identified as key terms relevant to the topic of interest. We conducted a keyword search with these terms in combination with the term business model. To search as comprehensive as possible, we 1) used a total of eight different search engines, 2) searched for the title, abstract and keywords, 3) did not limit the search results to a specific time period, and 4) considered all types of scientific publications such as journal articles, conference papers, books and so on. The literature search is documented in Tab. 2. In total, the keyword search yielded 134 accessible full-text publications (reduced by duplicates and false entries) from all databases.

Prior to a backward and forward search, the number of publications was reduced to those relevant to the topic of interest based on an analysis of their titles, abstracts, and full texts. This was done in three sequential steps, each considering a different inclusion criterion (Tab. 3).

Step 1 aimed at identifying publications with a focus on AR (or other similar technology concepts, such as mixed reality, but no virtual reality). Some publications were excluded in this step because their focus was not on AR. Often, AR was merely listed along with other emerging technologies, such as the internet of things, digital twins, blockchain, or artificial intelligence. Consequently, the focus of these publications was mostly not on AR itself but on Industry 4.0-related technologies in general. In some other cases, the focus was on virtual reality, which is different from AR in many aspects. These publications were therefore also excluded.

Step 2 aimed at identifying publications whose focus—in addition to AR—was on the BM concept. In about half of the AR-related publications screened, the term BM was used in some way, but it was not the publication's focus. For example, it was not uncommon for the term to be used in rather general statements, for example, Industry 4.0 and its related technologies (of which AR is one) will change the BMs in the manufacturing industry.

Step 3 then aimed to identify the relevant publications for analysis that addressed AR in the specific remote service context. However, this was only the case for two publications. The first of those two was that of Niemöller et al. (2018). They investigated the impact of the use of smart glasses for remote services on the BM of a hybrid value creator and how new BMs could be created by using smart glasses. While this study provides interesting insights on the impact of AR technology use on the BM, it is based on anecdotal evidence with a limited focus on smart glasses as an AR technology.

The second publication was that of Röltgen et al. (2019). They presented a step-by-step approach for developing BMs for AR that was successfully validated by applying it to an industrial case study from a research project. While there are many established approaches for BM design in general, this approach considers specific AR-related challenges. However, the approach is general, that is, intended for multiple

Tab. 2. Search fields, filter, and number of hits per search engine/database (search conducted in September 2022)

Search Engine	Database	Search Fields	Filter	Hits
ProQuest	ABI/INFORM Collection; Publicly Available Content Database; Ebook Central	Title, Abstract	Source Type = Scholarly Journals, Working Paper, Conference paper, Books; Language = English, German	28
Scopus	-	Title, Abstract, Keyword	Language = English, German; Exclude Document type = Conference Review	120
Web of Science	Web of Science Core Collection	Title, Abstract, Keyword	No filter	38
EBSCOhost	Business Source Premier; Library, Information Science & Technology Abstracts, eBook Collection	Title, Abstract, Keyword	Language = English, German	28
Science Direct	-	Title, Abstract, Keyword	No filter	19
IEEE Explore	-	Title, Abstract, Keyword	Source Type = Conferences, Journals, Books	26
ACM Digital Library	ACM Guide to Computing Literature	Title, Abstract, Keyword	No filter	7
Google Scholar	-	Title	No filter	30
Total (only accessible full-text publications; excluding duplicates and false entries)				134
Search term: ("augmented reality" OR "extended reality" OR "mixed reality" OR "smart glasses" OR "head mounted") AND ("business model*")				

Tab. 3. Three-step literature screening process

Step	Step 1: Augmented Reality	Step 2: Business Models	Step 3: Remote Service
Inclusion criterion	Publications with a focus on augmented reality	Publications with a focus on business models	Publications in a specific remote service context
Included for the next step	89 of 134	48 of 89	2 of 48

and not exclusively remote service-related AR applications.

Since a backward and forward search also did not reveal any other publications relevant to the topic, only these two studies were used to derive the targeted design options.

2.3. Focus group discussions with industry experts

To derive more insightful design options of AR-based remote service BMs, we also drew on focus group discussions we conducted with service-responsible industry experts on the topic of AR-based remote service BMs. The discussions took place in January 2019 and included a total of 19 industry experts from 12 internationally operating German capital goods manufacturing companies from various industries (Ohlig et al. 2020).

Due to the focus on the service business and to ensure the validity of the results, participating industry experts were required to be strategically and/or operationally responsible for the implementation of remote AR technology in their company. However, as most companies have not yet developed an AR-based remote service BM, only those that had already tested or were currently testing AR technology for remote service purposes were selected. This ensured that the participating industry experts had a comprehensive understanding of the technical, user and customer-related aspects of remote AR technology. Thus, the assessment of expert knowledge focused on a comprehensive understanding of the impact of using remote AR technology on their company's service

business rather than simply on their years of professional experience. Nevertheless, all participating industry experts had several years of professional experience in the industrial services context. Tab. 4 lists the participants of the focus group discussions.

Participants were divided into four separate focus groups and asked to discuss possible AR-based remote service BMs. Two groups discussed the case in which an AR device is used by the companies' own technician or service partner to receive remote guidance from an original equipment manufacturer (OEM) expert (case A). The other two groups discussed the case in which an AR device is used by a customer to receive remote guidance from an OEM expert (case B).

To facilitate structured discussions within the focus groups, we used the Business Model Canvas (BMC) by Osterwalder & Pigneur (2013). The BMC serves as a common language for describing, visualizing, evaluating and managing BMs. It is a widely used tool and well known among practitioners. The participants were asked to address all nine elements of the BMC and to record their results on a pinboard. The discussions were conducted in German and facilitated by a professional moderator, who had no influence on the content. Each focus group discussion lasted one hour and was audio recorded. The audio files were transcribed verbatim. Written informed consent was obtained from legally authorized representatives before the study.

Tab. 4. Focus group participants

#	Industry	OEM Information (2018)	Position of Participant within the Company	Group Nr.	Discussed Use Case
1	Bagging Systems	< 250 employees < 25 million € turnover	Head of R&D (construction)	3	Case A
			Head of Service Department	1	Case B
2	Clamping Technology for Production Technology	< 1,000 employees < 250 million € turnover	Head of Service Department (current)	2	Case B
			Head of Service Department (former)	1	Case B
			Product Manager Service	4	Case A
3	Coating Systems	< 500 employees < 250 million € turnover	Head of Service Sales & Repair	2	Case B
4	Control Valve Technology	< 5,000 employees < 1 billion € turnover	Digital Service Consultant	2	Case B
			Head of Service Support	3	Case A
5	Dry Grinding Systems	< 250 employees < 25 million € turnover	Product Manager Service	3	Case A
6	Finishing Machine Tools	< 500 employees < 100 million € turnover	Head of Service & Tool Sales	2	Case B
			Head of Electrical Assembly	3	Case A
7	Food Processing Plant Engineering	< 10,000 employees < 10 billion € turnover	Head of Customer Service	3	Case A
8	Gearing Machine Tools	< 500 employees < 100 million € turnover	Service Technician	1	Case B
			Head of Service Department	4	Case A
9	Grinding Machine Tools	< 500 employees < 100 million € turnover	Head of Service Department	4	Case A
10	Micro Milling Machine Tools	< 250 employees < 50 million € turnover	Head of Service Department	1	Case B
			Head of Service Department (deputy)	4	Case A
11	Packing Systems	< 250 employees < 25 million € turnover	Member of the Advisory Board	1	Case B
12	Vacuum Technology	< 500 employees < 250 million € turnover	Manager After Sales Service Business Development	2	Case B

Source: (Ohlig et al. 2020, p. 477).

2.4. Qualitative content analysis

In order to develop design options of AR-based remote service BMs, the two publications identified as well as the resulting transcripts of the focus group discussions were systematically analyzed following the qualitative content analysis approach of Mayring (2015). This method aims to shorten the material to be analyzed to a manageable size and to preserve the essential content. The result is a system of codes, which is an essential tool for ensuring the comprehensibility and intersubjectivity of the procedure.

To create the codes, the publications and transcripts were manually worked through line by line using NVivo software. A selection criterion that specifies which material is to be coded must first be defined. The selection criterion applied was derived from the research question and reads as follows:

Selection criterion: The text passage (single or multiple sentences) provides information about dimensions and/or characteristics that represent design options of AR-based remote service BMs.

Codes were formulated as short sentences as closely as possible to the text (that is, in-vivo-coding). Text components with little or no content, such as embellishments, repetitions, or clarifying phrases, were omitted. Text passages with relevant content were translated to a uniform language level, transformed to a grammatical short form, and translated into English if necessary. Additions by the authors that contribute to a better understanding of the respective code are placed in [brackets]. Tab. 6-23 contain examples of in-vivo-codes for each dimension and characteristic developed.

2.5. Initial business model dimensions

Groth & Christian (2015) argue that existing BM frameworks should be used when creating a BM taxonomy. Using such an overarching framework supports the derivation of the targeted BM-specific dimensions and characteristics. There seems to be a consensus here, as many authors initially draw on BM dimensions of generic BM frameworks in the development of specific BM taxonomies (for example, El Sawy & Pereira, 2013; Hartmann et al., 2014; Möller et al., 2020; Nickerson et al., 2017). This both avoids developing dimensions that are not suitable for describing BMs and ensures that relevant dimensions are not disregarded (Groth & Christian, 2015).

We also used such initial BM dimensions to guide the coding process and to develop the specific dimensions and characteristics of AR-based remote service BMs. Specifically, we used the nine BM dimensions of the BMC by Osterwalder & Pigneur (2013) as well as the BM dimension Mission of Alt & Zimmermann (2001).

3. Results

Based on a total of 199 in-vivo-codes, we developed 18 dimensions with a total of 61 characteristics that represent the targeted design options of AR-based remote service BMs. Since only about 14% of all in-vivo-codes came from the two publications analyzed (Tab. 5), most of the design options were developed on the basis of the in-vivo-codes from the focus group discussions. Thus, without the focus group discussions, we would have been able to develop only 5 of the 18 dimensions with a total of only 15 instead of 61 characteristics. This again underlines the necessity of the focus group discussions and also shows the extent to which they contributed to the development of the design options for AR-based remote service BMs described in this paper.

The dimensions with their respective characteristics are shown as a morphological box in Tab. 6 and described below. Tab. 7-24 contain examples of in-vivo-codes used to develop each dimension.

In the following and for the rest of the paper, manufacturing companies that intend to operate AR-based remote service BMs will be referred to as BM operators for short.

Type of use case: What type of use case does the BM pursue? AR-based remote service BMs can pursue different use cases (for example, remote support in troubleshooting or machine commissioning). However, instead of listing all possible use cases, this dimension distinguishes AR-based remote service BMs according to the nature of their use case, which can be differentiated as follows: Field service support: Use cases in which a field service technician is supported remotely in on-site service activities (for example, a field service technician employed by the BM operator is supported remotely in on-site troubleshooting, or a service partner's field service technician is supported remotely in commissioning a machine of the BM operator). Customer support: Use cases in which the customer's personnel are

Tab. 5. Assignment of the in-vivo-codes to the initial business model dimensions

Initial BM Dimension	Description (Reference)	Nr. of In-vivo-codes		
		Focus Groups	Literature	Total
Mission	"[…] a highlevel understanding of the overall vision, strategic goals and the value proposition including the basic product or service features." (Alt & Zimmermann, 2001, p. 7)	45	3	48
Customer segments	"[…] the different groups of people or organizations an enterprise aims to reach and serve" (Osterwalder & Pigneur, 2013, p. 20)	13	1	14
Value proposition	"[…] the bundle of products and services that create value for a specific customer segment" (Osterwalder & Pigneur, 2013, p. 22)	36	7	43
Channels	"[…] how a company communicates with and reaches its customer segments to deliver a value proposition" (Osterwalder & Pigneur, 2013, p. 26)	9	1	10
Customer relationships	"[…] the types of relationships a company establishes with specific customer segments." (Osterwalder & Pigneur, 2013, p. 28)	0	1	1
Revenue streams	"[…] the cash a company generates from each customer segment." (Osterwalder & Pigneur, 2013, p. 30)	25	2	27
Key resources	"[…] the most important assets required to make a business model work" (Osterwalder & Pigneur, 2013, p. 34)	20	5	25
Key activities	"[…] the most important things a company must do to make the business model work" (Osterwalder & Pigneur, 2013, p. 36)	7	4	11
Key partnerships	"[…] the network of suppliers and partners that make the business model work." (Osterwalder & Pigneur, 2013, p. 38)	8	2	10
Cost structure	"[…] all costs incurred to operate a business model" (Osterwalder & Pigneur, 2013, p. 40)	8	2	10
	Total	**171**	**28**	**199**

Tab. 6. Design options of AR-based remote service BMs

Dimension	Characteristics				
Type of use case[1]	Field service support[1]			Customer support[1]	
Affiliation of the AR device user[3]	Internal AR device user[1]			External AR device user[3]	
Strategic goal[3]	Cost savings[1]		Improving corporate image[1]		Improving customer relations[3]
	Increase in new machine sales[1]		Increase in service quality[3]		Increase in service sales[3]
Target customer group[1]	Existing service customers[1]		New service customers[1]		Third-party service providers[1]
Customer's key value proposition[1]	Cost benefits[1]	Reduction of machine downtime[1]		Fast response[1]	Maintenance and repair know-how[1]
Service offering[3]	24/7 remote service hours[1]	Remote connection to the machine[1]		Sale of AR devices[3]	Warranty extension[1]
Sales channel[1]	After-sales department[1]	Specialized business unit[1]	Service technicians[1]	Helpdesk staff[1]	Training sessions[1]
AR device pricing[3]	Free of charge[1]	Free during warranty[1]	Usage fee[2]	Fixed price[1]	No AR device pricing[4]
Remote service pricing[1]	Free during warranty [1]	Pay per minute[1]	Monthly fees[1]	Technician hourly rate[1]	No remote service pricing[1]
Contractual commitment[1]	Separate contract[1]		Part of maintenance contract[1]		No contractual commitment[1]
Type of AR device[3]	Head-worn AR device[3]			Handheld AR device[3]	
AR device connection[1]	Provided by the customer[1]			Provided by the BM operator[4]	
Remote software[1]	Commercially available software[1]			In-house software development[1]	
Remote expert skills[1]	Service technician skills[1]			Subject matter expert skills[1]	
Additional key resources[3]	3D models for AR visualizations[2]		Visual marker for AR tracking[2]		Remote connection to the machine[1]
Additional key activities[3]	AR data preparation[3]		Smart glasses management[1]		In-house training[1]
Key partner[3]	Remote software provider[3]	Service partner[1]		AR data supplier[2]	No key partner[1]
Key cost driver[3]	Remote experts[1]	AR devices[3]		Remote software[1]	AR content creation[2]

Note on the origin of the dimension/characteristic: 1 = developed exclusively on the basis of the focus group discussions; 2 = developed exclusively on the basis of the literature; 3 = developed on the basis of both; 4 = addition by the authors considering the conditions of taxonomy development (see chapter 4.1)

directly remote supported by a remote expert (for example, the customer's machine operator is remotely guided to solve a machine problem).

Affiliation of the AR device user: What is the affiliation of the person using the AR device to be supported remotely? As described in the use case examples mentioned above, different people can use the AR device to be supported remotely. Again, instead of listing all possible AR device users, this dimension distinguishes AR-based remote service BMs according to the affiliation of the person using the AR device as follows: Internal AR device user: The person using the AR device belongs to the BM operator (for example, a field service technician employed by the BM operator). External AR device user: The person using the AR device belongs to another organization outside the BM operator (for example, a technician of a service partner or a machine operator of the customer).

Strategic goal: What is the strategic goal for the operator of the BM? This dimension differentiates AR-based remote service BMs based on the strategic goal associated with the operation of the BM. The following goals, which appear to be of strategic importance, have been identified and represent the characteristics of this dimension. Cost savings: Savings, for example, in travel costs, such as unpaid travels of service technicians within the warranty period. Improving corporate image: Improvement of the corporate image through customers' increased perception of the BM operator as an innovative up-to-date company. Improving customer relations: Improvement of the customer relationship through personal and stronger customer integration. Increase in new machine sales: Increasing sales of new machines or equipment (for example, by expanding into markets not previously served due to a lack of local service infrastructure). Increase in service qual-

Tab. 7. Examples of in-vivo-codes used to develop the dimension type of use case

Characteristic	Examples of in-vivo-codes
Field service support	"We want to support our technicians when they are out [*at the customer's*], and send them drawings, for example, or provide software support." (FG3, P3)
Customer support	"It would be interesting for us to equip the customer with them [*smart glasses*] and give them support and help them more quickly." (FG3, P1)

Tab. 8. Examples of in-vivo-codes used to develop the dimension affiliation of the AR device user

Characteristic	Examples of in-vivo-codes
Internal AR device user	"My technician is at the customer's and wears the smart glasses." (FG3, P2).
External AR device user	"One can also give smart glasses to subcontractors or externals" (FG4, P2)

ity: Improvement of the service quality (for example, through improved error detection or improved service know-how of service partners). Increase in service sales: Increasing the sales of services (for example, through new revenue streams with service partners, who in turn can expand their customer base).

Target customer group: What is the target customer group of the BM? The characteristics of this dimension describe the different customer groups that the BM is designed to reach. Existing service customers: Customers who already use services provided by the BM operator. New service customers: Customers who are already part of the customer base but have not yet used services provided by the BM operator. Third-party service providers: Competing third-party service providers offering services to the installed base of the BM operator.

Customer's key value proposition: What is the customer's key value proposition? AR-based remote service BMs appear to differ in the key value proposition offered to the customer. The following characteristics representing different value propositions indicate this. Cost benefits: Cost savings compared to the previous non-remote service provision (for example, by reducing travel costs for service technicians). Reduction of machine downtime: Reduced machine downtime (for example, through AR-based remote troubleshooting of simple errors by the customer himself). Fast response: Fast response to the customer's service request (for example, through faster and improved situational awareness of the remote experts of the situation at the customer's site). Maintenance and repair know-how: Access to and acquisition of knowledge on the maintenance and repair of the machinery and equipment sold by the BM operator.

Service offering: What are the additional components of the service offer? This dimension distinguishes AR-based remote service BMs according to their service offering. The following components of the service offer represent the characteristics of this dimension: 24/7 remote service hours: The AR-based remote service is offered around the clock. Remote connection to the machine: A remote connection to the machine is part of the service offer. Sale of AR devices: The BM operator offers AR devices, such as AR smart glasses, to its customers. Warranty extension: The customer will get a warranty extension for his machines and equipment when he signs an AR-based remote service contract.

Sales channel: What channels are used to sell AR-based remote services? This dimension captures the various channels identified for selling AR-based remote services. After-sales department: Employees in the after-sales department are a sales channel. They use their contact with the customer to offer them AR-based remote services. Specialized business unit: Employees who are specialized in the sale of, for example, digital service products are a sales channel. They also use their contact with the customer to offer them AR-based remote service. Service technicians: The service technician at the customer's site serves as a sales channel (for example, by using AR smart glasses himself and describing the benefits of being supported remotely to the customer). Helpdesk staff: Helpdesk staff with direct customer contact serve as a sales channel. If they handle a service request that could be solved remotely, they offer the AR-based remote service to the customer. Training sessions: Training sessions, such as in-house training for customers or service partners, serve as a sales channel (for example, the use of AR smart glasses can be demonstrated, and the advantages of remote service explained).

AR device pricing: What does the pricing model of the AR device look like? This dimension refers to the pricing model of AR devices (for example, AR smart glasses) if they are sold to the customer. Free of charge: AR devices are provided to the customer free

Tab. 9. Examples of in-vivo-codes used to develop the dimension strategic goal

Characteristic	Examples of in-vivo-codes
Cost savings	"In this case, the business plan is not to earn additional money but only to cover costs" (FG3, P4)
Improving corporate image	"One [*the customer*] has a more positive image of the company's competences" (FG3, P4)
Improving customer relations	"The use of smart glasses can strengthen the current level of [*customer*] integration." (Niemöller et al. 2018, p. 176)
Increase in new machine sales	"The new machinery business can also go hand in hand with this." (FG1, P5)
Increase in service quality	"The quality of the partner companies [*service partners*] increases when they have the smart glasses." (FG3, P2)
Increase in service sales	"I could imagine [*that my company is*] being considered for service requests more often." (FG2, P5)

Tab. 10. Examples of in-vivo-codes used to develop the dimension target customer group

Characteristic	Examples of in-vivo-codes
Existing service customers	"Customers who already use teleservice and are familiar with the issue of being supported by external parties have been identified as potential A-customers." (FG2, P2)
New service customers	"New customers. Actually, we have supplied them with a plant. In this respect, they are not new customers. But they are new customers for service." (FG1, P1)
Third-party service providers	"Targeting third-party providers as new customers so that they in turn can expand their customer base." (FG1, P1)

Tab. 11. Examples of in-vivo-codes used to develop the dimension customer's key value proposition

Characteristic	Examples of in-vivo-codes
Cost benefits	"Cost benefits because he [*the customer*] does not have to pay for the service technician's travel." (FG2, P5)
Reduction of machine downtime	"The added value would be shortened downtimes because they [*the customers*] can help themselves more quickly." (FG2, P1)
Fast response	"Faster response time as an aspect of the value proposition." (FG4, P3); "The added value is that we have a very fast response." (FG4, P2)
Maintenance and repair know-how	"Learning by doing for the customer. Maybe he can do it [*fix the error*] himself in the future." (FG1, P3)

Tab. 12. Examples of in-vivo-codes used to develop the dimension service offering

Characteristic	Examples of in-vivo-codes
24/7 service hours	"If we have someone in the US, in Germany, and in Singapore, I have all time zones covered and I don't have to worry about 24-7." (FG3, P2)
Remote connection to the machine	"I see the connection [*to the machine*] as a basis and these smart glasses as an addition." (FG1, P5)
Sale of AR devices	"I would sell the smart glasses to the customer with the machine." (FG4, P2)
Warranty extension	"Combine a [*AR*] remote service contract with a warranty extension as an incentive." (FG1, P1)

Tab. 13. Examples of in-vivo-codes used to develop the dimension sales channel

Characteristic	Examples of in-vivo-codes
After-sales service department	"That [*sales*] has to be with after-sales, because if new equipment sales do that, it goes in as a rebate somewhere." (FG1, P5)
Specialized business unit	"For us, this [*sales*] will run through the IoT service sales channel, a special sales department that only deals with digital products." (FG2, P1)
Service technicians	"The technicians, who are at the customer's site anyway, are an indirect sales channel because they recommend this to the customer." (FG1, P5)
Help desk staff	"Our employees on the phone will ask [*the customer*] if you have a contract. If not, the contract costs 3.000 Euros and will be emailed to you."
Training sessions	"Use trainings as a sales channel and show the customer how to do it even better." (FG2, P1)

of charge. Free during warranty: AR devices are provided to the customer free of charge only during the warranty period. Usage fee: The customer pays a usage fee for the AR device provided to him for use. However, from a legal point of view, the AR device belongs to the BM operator. Fixed price: The customer buys the AR device at a certain price. No AR device pricing: There is no pricing for AR devices, as no AR devices are offered to the customer for purchase.

Remote service pricing: What does the pricing model of the AR-based remote service look like? This dimension refers to the pricing model of the AR-based remote service. The following characteristics could be identified: Free during warranty: The customer receives certain AR-based remote services free of charge during the warranty period. Pay per minute: The customer pays for the period he is supported remotely. The service is charged at a fixed price per unit of time. Monthly fees: The customer pays a monthly fee. In return, the customer receives remote support for a certain number of minutes/hours or for a certain number of calls. Technician hourly rate: The customer pays for the AR-based remote service indirectly via the service technician hourly rate (for example, increase in the technician hourly rate). No remote service pricing: There is no pricing, as no AR-based remote service is directly offered to the customer (for example, a new inexperienced field service technician employed by the BM operator is supported remotely in on-site troubleshooting).

Contractual commitment: How is the contractual commitment designed? This dimension distinguishes AR-based remote service BMs according to their contractual commitment. Separate contract: The customer can get AR-based remote services as a separate service contract, independent of a maintenance contract. Part of maintenance contract: The customer can get AR-based remote services only in conjunction with a maintenance contract. No contractual commitment: The customer can get AR-based remote services without having to contractually commit for an extended period of time.

Type of AR device: What type of AR device is used by the person who is being remotely supported? This dimension describes the different types of AR devices that can be used by the person receiving remote support. Head-worn AR device: The person being remotely supported is using a head-worn AR device, such as AR smart glasses. Handheld AR device: The person being remotely supported is using a handheld AR device, such as a smartphone or tablet.

AR device connection: Who provides the internet connection for the AR device? The AR device requires an internet connection. This dimension describes who provides that connection. Provided by the customer: The internet connection for the AR device is provided by the customer (for example, use of customer's Wi-Fi on site). Provided by the BM operator: The internet connection for the AR device is provided by the BM operator (for example, through mobile hotspots).

Remote software solution: What type of remote software solution is used? The remote software is the key software component of the BM. The following distinguishing characteristics of remote software could be identified: Commercially available software: The BM operator uses one of the numerous ready-made software solutions (with white labelling, if applicable) available on the market today. In-house software development: The BM operator develops his own remote software solution.

Remote expert skills: What kind of skills are required of the remote expert? Another key resource of the BM is remote experts. The following distinguishing characteristics could be identified with regard to their skills: Service technician skills: The remote experts are former service technicians or at least have the skills of a service technician. Subject matter expert skills: The remote experts are subject matter experts for a specific topic (for example, mechanics, electrics, commissioning, application engineering, or software).

Additional key resources: What additional resources are required to operate the BM? In addition to the actual key resources of the BM, further additional key resources were identified that could be used to differentiate AR-based remote service BMs: 3D models for AR visualizations: Construction drawings in a three-dimensional (3D) format as a basis for creating AR content for visualization purposes. Visual marker for AR tracking: Visual markers (for example, QR code stickers on the machine or equipment) to align AR visualizations relative to specific machine components. Remote connection to the machine: Remote connection to the machine control (for example, to detect or correct software errors remotely).

Additional key activities: What additional activities play a key role in the BM? Besides the actual key activity—remote support of the AR device user by a remote expert—the following additional activities could be identified: AR data preparation: Activities to prepare and create AR content that is used for visu-

Tab. 14. Examples of in-vivo-codes used to develop the dimension AR device pricing

Characteristic	Examples of in-vivo-codes
Free of charge	"The hardware [*the smart glasses*] would be provided free of charge." (FG1, P5)
Free during warranty	"During the warranty period you [*the customer*] get the smart glasses free of charge, outside the warranty period it [*the smart glasses*] costs something." (FG4, P4)
Usage fee	"Providing AR devices for a monthly usage fee." (Röltgen et al. 2019, p.634)
No AR device pricing	*Addition by the authors considering the condition of collective exhaustiveness*

Tab. 15. Examples of in-vivo-codes used to develop the dimension remote service pricing

Characteristic	Examples of in-vivo-codes
Free during warranty	"During the warranty it is free of charge." (FG2, P4)
Pay per minute	"As a source of revenue, one can do pay-per-minute, i.e., charge according to performance." (FG2, P1)
Monthly fees	"We can offer a technician on site with these smart glasses for a fixed monthly amount and thus guarantee all the know-how from the factory." (FG4, P2)
Technician hourly rate	"No longer charge a service locksmith, but a service expert for x euros instead of much less before." (FG3, P2)
No pricing	"I do not see a revenue source in this case." (FG3, P3)

Tab. 16. Examples of in-vivo-codes used to develop the dimension contractual commitment

Characteristic	Examples of in-vivo-codes
Separate contract	"We have a so-called flat rate, which he [*the customer*] can buy in separate form as an annual contract with an hourly package." (FG2, P2)
Part of maintenance contract	"Or we have it [*AR remote services*] included in maintenance contracts." (FG2, P2)
No contractual commitment	"The customer is not bound by a contract, so only incurs costs if he uses our services." (FG1, P2)

Tab. 17. Examples of in-vivo-codes used to develop the dimension type of AR device

Characteristic	Examples of in-vivo-codes
Head-worn AR device	"Smart glasses are necessary for customers to enable AR visualizations; however, most customers lack them." (Röltgen et al. 2019, pp. 633-634)
Handheld AR device	"Instead of using smart glasses, it can also be done with a smartphone." (FG1, P2)

Tab. 18. Examples of in-vivo-codes used to develop the dimension AR device connection

Characteristic	Examples of in-vivo-codes
Provided by the customer	"We need internet access, which the customer must provide." (FG2, P2)
Provided by the BM operator	*Addition by the authors considering the condition of at least two characteristics per dimension*

Tab. 19. Examples of in-vivo-codes used to develop the dimension remote software solution

Characteristic	Examples of in-vivo-codes
Commercially available software	"You certainly buy the software at the beginning." (FG2, P4)
In-house software development	"You can also do it [*the software development*] yourself." (FG3, P4)

Tab. 20. Examples of in-vivo-codes used to develop the dimension remote expert skills

Characteristic	Examples of in-vivo-codes
Service technician skills	"You need former service technicians." (FG3, P2)
Subject matter expert skills	"For us, that means five people. Mechanic, electrician, commissioning engineer, application engineer and software." (FG4, P2)

Tab. 21. Examples of in-vivo-codes used to develop the dimension additional resources

Characteristic	Examples of in-vivo-codes
3D models for AR visualizations	"AR use cases usually require 3D models specially prepared for visualization by AR." (Röltgen et al. 2019, p. 642)
Visual marker for AR tracking	"It might be necessary to add new components to the product such as visual marker for tracking." (Röltgen et al. 2019, p. 633)
Remote connection to the machine	"It must still be possible to look into the control system via a connection to the Programmable Logic Controller." (FG1, P5)

Tab. 22. Examples of in-vivo-codes used to develop the dimension additional activities

Characteristic	Examples of in-vivo-codes
AR data preparation	"Considerable effort is required to prepare the data for transmission via smart glasses." (FG2, P5)
Smart glasses management	"Deliveries and repairs of smart glasses must also be managed." (FG2, P4)
In-house training	"In-house training is a required activity." (FG4, P2)

Tab. 23. Examples of in-vivo-codes used to develop the dimension key partner

Characteristic	Examples of in-vivo-codes
Remote software provider	"With the partners, I see the software producer, depending on whether I make the app [*AR remote service app*] myself or buy it." (FG3, P2)
Service partner	"I would consider external service technicians or service companies, who then stand between the customer and us as partners." (FG1, P3)
AR data supplier	"3D models are often held by the supplier." (Röltgen et al. 2019, p. 642)
No key partner	"I have not written anything down for partners." (FG1, P5)

Tab. 24. Examples of in-vivo-codes used to develop the dimension key cost driver

Characteristic	Examples of in-vivo-codes
Remote experts	"I have also added employees [*remote experts*] as a cost structure." (FG1, P3)
AR devices	"Costs for procurement and maintenance of the smart glasses." (Niemöller et al. 2018, p. 179)
Remote software	"We pay the fees [*remote software license fees*] even if the customer does not use it." (FG1, P5)
AR content creation	"Costs for AR content creation." (Niemöller et al. 2018, p. 179)

alization purposes. Smart glasses management: Activities related to the management of AR smart glasses, such as replacement deliveries in the event of defects or firmware updates. In-house training: In-house training on the use of the AR smart glasses and the remote software.

Key partner: Which partner plays a key role in the BM? This dimension captures various key partners that make the BM work. Remote software provider: Manufacturer of the remote software, which is the main software component of the BM. Service partner: Cooperating service companies or independent service technicians who perform services on behalf of the BM operators at its installed base while being supported remotely. AR data supplier: Suppliers of data, such as 3D models, that are necessary to generate AR content for visualization purposes. No key partner: No partner is required to operate the BM.

Key cost driver: What is the key cost driver of the BM? In the case of AR-based remote service BMs, the following cost drivers were identified that represent the characteristics of this dimension: Remote experts: Personnel and workplace costs for the remote experts. AR devices: Costs for AR devices, such as AR smart glasses, especially if the BM operator's own technicians are equipped with them. Remote software: Acquisition or development as well as operation and maintenance costs for the remote software. AR content creation: Costs incurred to generate AR content for visualization purposes.

4. Discussion

Although we have explicitly not developed a final taxonomy here–which would have required empirical data–the results are discussed in terms of the conditions for taxonomy development proposed by Nickerson et al. (2013). This ensures a better understanding

Tab. 25. Assessment of taxonomy-related conditions for the conceptually developed dimensions and characteristics

Taxonomy-related conditions		Assessment
Conditions derived from taxonomy definition	At least two characteristics	Fulfilled
	Mutual exclusiveness	Considered but not verifiable (empirical data required)
	Collective exhaustiveness	Considered but not verifiable (empirical data required)
Subjective ending conditions	Explanatory	Fulfilled
	Concise and robust	Not considered
	Comprehensive	Considered but not verifiable (empirical data required)
	Extendable	Fulfilled
Objective ending conditions	All or a representative sample of objects have been examined	Not verifiable (empirical data required)
	At least one object is classified under every characteristic of every dimension	Not verifiable (empirical data required)
	No object was merged/split in the last iteration	Not verifiable without iterations
	No new dimension/characteristic was added/merged/split in the last iteration	Not verifiable without iterations
	Every dimension/characteristic is unique and not repeated	Fulfilled

Source: (Nickerson et al., 2013, p. 344).

of the results and ensures a proper use for the subsequent empirical iterations in the taxonomy development process.

However, some of the conditions cannot be verified because they must be viewed from the perspective of an empirically and iteratively developed taxonomy. Even though these conditions are marked as "not verifiable" (Tab. 25), they have still been considered at this conceptual stage of taxonomy development.

4.1. Conditions derived from taxonomy definition

At least two characteristics per dimension: This condition results from the taxonomy definition. According to this, each dimension should comprise at least two characteristics. For the dimension AR device connection, however, only the characteristic Provided by the customer could be derived from the data (Tab. 18). However, in order to fulfill the condition of at least two characteristics per dimension, the dimension was supplemented in this case by the characteristic Provided by the BM operator.

Mutual exclusiveness and collective exhaustiveness: Two further conditions, also derived from the taxonomy definition, are that the characteristics in each dimension must be mutually exclusive and collectively exhaustive. In other words, each BM must have one of the characteristics in each dimension and no BM can have two different characteristics in a dimension. To consider the collective exhaustiveness condition, we added the characteristic No AR device pricing to the dimension AR device pricing (Tab. 14) because according to the dimension Service offering, the sale of AR devices is only one possible characteristic of AR-based remote service BMs. Thus, BMs that do not involve the sale of AR devices do not require any AR device pricing. While these conditions can be considered in the conceptualization of the dimensions, since no real BMs were studied, the conditions are not verifiable. Therefore, no claim is made for mutual exclusivity or collective exhaustiveness of the dimensions.

4.2. Subjective ending conditions

Explanatory: Dimensions and characteristics should provide useful explanations, rather than only descriptions of every detail of the objects. Without taking this condition into account, some dimensions would have much more characteristics, but without explaining the objects' nature. For example, dimension AR device user could have been developed with the characteristics own service technician, third-party service provider's service technician, sub-contractor's service technician, and customer's staff. Instead, considering the explanatory condition, the

dimension Affiliation of AR device user was developed with the characteristics Internal AR device user and External AR device user, expressing the AR device user's affiliation as the nature of these objects.

Concise and robust: These two subjective ending conditions refer to the number of dimensions and characteristics. It should not be too large, making the final taxonomy difficult to understand and apply, and simultaneously, the number of dimensions should not be too small to be able to differentiate among the BMs adequately. However, an ideal number of dimensions was not sought. Instead, each dimension representing design options of AR-based remote service BMs was included.

Comprehensive: A useful taxonomy should be able to classify all known objects within the domain under consideration. We addressed this condition by using initial BM dimensions from established BM frameworks in the coding process. This ensured that no relevant dimension was disregarded and only dimensions useful for describing BM were developed. Nevertheless, this condition is not verifiable as no real AR-based remote service BMs were investigated.

Extendable: This condition refers to a taxonomy's ability to include further dimensions and characteristics easily when new objects appear. The results can be considered extensible, as other dimensions and characteristics can be easily added, which of course could be the result of further empirical investigation.

4.3. Objective ending conditions

With one exception, the objective ending conditions cannot be evaluated at this conceptual stage of taxonomy development. To satisfy these conditions, the taxonomy would need to be developed in iterative steps based on real AR-based remote service BMs. Therefore, the results only fulfill the last of these objective ending conditions, namely that each dimension/characteristic is unique and not repeated.

5. Conclusion

Based on the aim of this paper–to develop design options for AR-based remote service BMs–we developed a novel morphological framework with a total of 18 dimensions and 61 characteristics that represent the targeted design options of AR-based remote service BMs. To this end, we followed a conceptual approach to taxonomy development. We chose this conceptual approach because very few companies currently operate an AR-based remote service BM and thus no empirical data is yet available.

The results were derived using qualitative content analysis from two sources. First, from the only two existing publications on the topic of AR-remote service BMs which were the result of a systematic literature search. And second, from transcripts of focus group discussions conducted with 19 service-responsible industry experts from 12 German manufacturing companies. However, most of the design options were developed solely on the basis of the focus group discussions.

Depicted in the form of a morphological box, the BM dimensions and their respective characteristics provide a novel framework that addresses the lack of a structured framework for classifying AR-based remote service BMs in the literature. In contrast to existing AR taxonomies, whether in the broader field of AR (for example, Hugues et al., 2011) or in collaborative AR specifically (for example, Brockmann et al., 2013; Marques et al., 2021), our approach includes the largely unexplored BM perspective for the first time. We also address the demand for methodological support for the design of AR-based BMs (Röltgen et al., 2019), as the dimensions and characteristics described in the framework enable the systematic description, differentiation, and design of AR-based remote service BMs.

With regard to the development of AR-based remote service BMs in industrial practice, companies will benefit from using the framework developed in this paper. It serves as a guide for identifying key aspects of AR-based remote service BMs and provides a selection of different design options. It can also be used to compare their own AR-based remote service BMs with those of other companies and identify similarities and differences between them.

It should be noted that the BM dimensions and their respective characteristics were developed on a solid, but merely conceptual basis, as both the literature and the focus group discussions describe scenarios of possible future BMs rather than real existing ones. Hence, the results need to be validated by further empirical studies.

Nevertheless, the present work represents an essential step towards the systematic description and classification of AR-based remote service BMs in terms of their design options and the creation of a taxonomy of such BMs. Further empirical studies, such as the survey of configurations of AR-based

remote service BMs, should be conducted along the dimensions conceptually developed here.

In addition to empirical validation, future work could explore the identification of business model archetypes through cluster analysis. Moreover, individual dimensions of these business models could further be investigated. For example, research could delve into which pricing models for AR-based remote services are most effective and identify the underlying reasons for their success. Further studies could aim to evaluate AR-based remote service business models, focusing on economic aspects such as the comparison of costs on the one hand and profits or cost savings due to AR-based remote service on the other.

In any case, the framework developed in this paper will serve a systematic foundation for future research into AR-based remote service business models.

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Process security methods and measurement in the context of standard management systems

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ABSTRACT

The main purpose of the paper is to identify ways to establish process security in the constantly changing risk and control environment and to introduce a new model. The research is based on a literature review of process security components. Qualitative content analysis was used to establish a linkage between the certified management systems and the level of process security. Elaborations have been conducted based on the survey data of the International Standards Organisation (ISO) and served as a basis for analysis of certification types and their sectoral division in the European Union (EU) member states. A new Balanced Scorecard has been developed to cover the security pillars in the context of standard management systems and serve as a framework for process security measurement. The research paper processes the state-of-the-art issue of process security, introduces components that help to establish process security, and establishes a linkage between the level of process security and certified management systems. An analysis was based on the ISO certification information related to different management system standards. Management systems were analysed in the context of process security and corresponding process performance measures. A brief walkthrough has been prepared to demonstrate the processes behind the underlying performance measures. A new Balanced Scorecard approach has been developed that maps and covers different security aspects retrieved from and linked to different management system standards. The new Balanced Scorecard based on different security aspects of entities can be leveraged by any organisation, regardless of its size or business profile.

KEY WORDS

process security, safety, security, ISO, standard management systems, Balanced Scorecard

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Introduction

As a key component of resilience, process security is crucial in the changing risk and control environment of businesses and even state-owned entities. The publication primarily uses the term "process security" instead of the term "process safety". The term "security" is preferred due to the intense role of information and communication technology in business processes and the significance of information security; though, the article covers both safety and security aspects, and the authors use the terms

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"safety" and "security" interchangeably (Wolter et al., 2009; Badreddine et al., 2009; Swuste et al., 2016). The objective of process security can be met using various methods, standards and recommendations. The research identifies ways to establish, maintain and monitor process security in compliance with corporate objectives. Management systems have become widespread, and entities tend to have more than one system selected based on professional judgment with the intention to best serve the organisation's interest. Standard management systems, such as ISO, serve to meet corporate objectives in different fields of operation, such as product or service quality, environmental performance, health and safety in the workplace, etc. The ISO's approach envisages the concept of integrated management systems. The goal of the standardisation organisation is an integrated management system composed of arbitrary components. The similar structures of process-oriented management systems enable their relatively easy integration. The integrated use of management system standards makes room for effective management of applied management systems and facilitates transparency, hands-on alignment to strategy, and handy reporting.

In the research, the authors introduce components that help to establish process security and the use of management systems, including the use of standard management systems. In this research, out of the introduced security components, the Balanced Scorecard (BSC) approach is used as a methodological background for further development. The authors analyse different management system standards and establish a new, security-focused Balanced Scorecard framework using different security aspects linked to management system standards. Several studies in the research area focus on Balanced Scorecard and standard management systems. The combination of the two research areas is yet to be explored and is a new approach that leverages their benefits in support of process security measurement. This approach helps organisations achieve their objectives and gives visibility, thus underpinning the necessity for security processes.

The literature review section explores the relevant literature in support of the research and formulates the hypothesis. It is followed by the research method, the results with the outcome of the research, the discussion, and conclusions.

1. Literature review

Since the eighties of the last century, process-oriented corporate operations have become widespread. Efficiency, quality, and the controlled execution of business and technological processes have become equally important with the previous profit- and/or sales revenue-centricity. The global economic crisis of 2008, the COVID-19 pandemic, and the current war situation in Ukraine are testing companies repeatedly.

IT reliability is crucial for the survival and sustainability of organisations. It is recommended that IT reliability is promoted and considered a source of organisations' sustainability in mitigating the negative effects of the COVID-19 pandemic (Tworek, 2023). Furthermore, digitalisation has set new directions and brought opportunities, risks, and obligations, such as privacy protection. The shift to data-driven decision-making, for example, puts reliance on sensitive data about identifiable persons (Bakthina et al., 2023). Digital systems are exposed to the risk of a cyberattack (Daubner et al., 2023). In addition, the structures of organisations, as well as their IT infrastructures in modern companies, are in constant change (Kern et al., 2022).

Corporate goals are differentiated in various ways, even in undisturbed external conditions. One definite strategic goal is long-term profit maximisation. Continuous product and technology innovation can ensure the company's long-term "survival", while the daily routine operative management tasks, such as production management, fixed asset, workforce and working capital management, ensure the going concern. On top of this, compliance with legal requirements, environmental protection and the operation of management systems are generally expected by external partners.

The marketing goal is to satisfy the consumer needs. The mindset of continuous improvement and delivering value to customers are key principles in the lean methodology as well, which in parallel promotes the elimination of waste, i.e., non-value-adding process steps (Kilpatrick, 2003). However, the implementation of the lean concept often faces some difficulties, e.g., some small- and middle-sized enterprises (Ule-

wicz & Kucęba, 2016). A successful adaptation of lean principles requires certain preconditions for all sizes and types of businesses and state-owned entities.

The safe operation of process-centric companies can be supported by several theoretical foundations, tools, methods, standards, and recommendations. It is the duty of business entities to create a governed and controlled operation that increases their resilience even under turbulent environmental changes and gives them and their partners a sense of security. "Process security can be defined as a state in which, with all required inputs (or resources necessary for execution of the process) given, the organisational units responsible for fulfilling process-related tasks will produce outputs (such as products, services, or information) in adequate quantity and quality in due time, and, upon any disturbance, normal operation of the process can be restored with the lowest possible use of resources within the shortest possible time" (Michelberger, 2014, p. 402).

The following components support process security:

- Porter's value chain model (Porter, 1985),
- Transaction management information systems (e.g., ERP systems),
- Business process reengineering (BPR),
- Information systems supporting process management (e.g., Aris),
- Prescribing and monitoring KPIs,
- Business continuity management and corporate flexibility (resilience),
- Standard management systems and their integrated implementation,
- Controlling systems (e.g., Balanced Scorecard).

Michael Porter's value chain concept — published in his book Competitive Advantage — differentiates primary (inbound logistics, operations, outbound logistics, marketing and sales, and service) and support activities (firm infrastructure, human resources management, technology, and procurement), and can be used as a basic tool in diagnosing competitive advantage, i.e., its two basic types: low cost or differentiation (Porter, 1985). The product goes through the chain of discrete activities and gains certain value in the value chain where technology pervades and culture is an important element (Porter, 1985). Porter's value chain concept identifies how inputs are transformed into outputs and is a process-oriented approach that uses an activity-based analysis in support of gaining market advantage.

Transaction management information systems, e.g., Enterprise Resource Planning (ERP), can achieve effective forecasting, planning and scheduling in support of productivity. Proper ERP implementation focuses on people besides computers and software and can provide a competitive advantage (Wallace et al., 2001). An ERP can treat the in-scope business processes in a single integrated system that enables proper information flow and smooth reporting, such as financials, payroll, customer orders, etc.

According to Hammer and Champy, business process reengineering (BPR) means "the fundamental rethinking and redesign of business processes to achieve dramatic improvements in critical, contemporary measures of performance, such as cost, quality, service and speed" (1993). The work focuses on the process of how work gets done rather than on specialisation, i.e., the division of labour promoted by Adam Smith in the Wealth of Nations in 1776 (Hammer & Champy, 1993). BPR tools and techniques include process visualisation, process mapping/operational method study, change management, benchmarking, process and customer focus (O'neill & Sohal, 1999). Organisations face the technical risk that the process changes will not work and the organisational risk that the corporate culture is against the changes related to the implementation of BPR.

Information systems (e.g., Aris) support business processes. Business processes can be modelled using process modelling and planning software capable of capturing AS-IS and TO-BE modelling. For example, ARIS can be used as a powerful tool for process modelling (Davis, 2008). The availability of quality enterprise process models ensures the skeleton of well-structured process documentation that helps to meet quality objectives set by customers. Customer satisfaction is the key objective of the ISO 9001 Quality Management Standard, and the processes of an organisation serve to meet this objective. Process approach and continuous improvement are inherent to quality management as well. Process maps present the process steps visually and strengthen the enterprise's safety and security by serving as a basis for process documents and highlighting the most critical points in the processes that are a subset of related control process documents. Process maps capture the control points and control activities built into the processes, which are the fundamental elements of the corporate safety network (Kemendi, 2022).

Key performance indicators (KPIs, aka process performance measures) should comply with the strategic objectives of the organisation and must be associated with target values. Process improvements

are required to meet the KPIs, i.e., the strategic objectives. A better process contributes to meeting strategic objectives better, and KPIs can measure the level of improvement. Some KPIs are easy to gather, and others are more difficult and time-consuming (van der Aalst et al., 2016). Performance indicators serve to reflect process performance, and the design of the KPI set is a prerequisite for proper process performance measurement. The captured data should be accurate and reliable, top and line management should monitor the KPIs regularly and define actions as and when needed.

Business continuity management (BCM), covered in the ISO 22301 standard, helps corporations to be prepared for possible business disruptions with its elements of Business Continuity Planning (BCP) and Disaster Recovery Planning (DRP). BCP provides alternative solutions in the event of downtime in the support processes to make business processes possible. DRP provides the required resources for the processes involved in the business operation — to replace and restore — in the event of an emergency (Michelberger & Kemendi, 2020). Organisational resilience capabilities increase organisational performance during unexpected events. They have an established relationship with organisational sustainability, and both relate to BCM through crisis management (Corrales-Estrada et al., 2021).

1.1. Standard management systems and process security

Management systems serve to support organisations to achieve their objectives related to different aspects. These systems are process-oriented and can be integrated due to their similar structure, which permits the avoidance of multiple process controls and excessively frequent external audits. In recent years and decades, the International Organisation for Standardisation has created and continuously developed several auditable and certifiable management systems, e.g., for quality, environment, information security, food safety, supply chain operation, business continuity, and in the field of occupational health protection. Certificates issued by external, independent certification bodies prove the company's well-organised and controllable operations. These certificates can strengthen business confidence.

In many cases, the existence of a management system is a precondition for establishing a business relationship. Establishing and maintaining the management system means additional work for the organisation. It is important to choose standard packages that correspond to the external (market) expectations and the internal organisational culture. The pressure of over-regulation and excessive expectations set by the owners/management (e.g., irrational profit or turnover, market expansion, and technology change) can break a company down.

The number of certified organisations/companies is constantly increasing worldwide (ISO.org), and it is not only the ISO that recommends standard management systems and methodologies supporting process-based company operations. The application and design of different management systems vary greatly depending on the country, continent, and industry. In many cases, their design and operation are invisible to the world outside. New entrants and those who lose their certificates are constantly changing these numbers. However, the numbers in the ISO survey do not include all management systems. For example, there are companies that do not boast about their existing information security management system, as it indicates the presence of protected information that may be valuable/interesting for others. The ISO Survey of Certifications is an annual survey of the number of valid certificates to ISO management system standards worldwide. The providers of data are the certification bodies accredited by the IAF MLA Members (ISO Explanatory note, 2021). Own elaborations have been conducted based on the survey data of the ISO and served as a basis for the analysis of certification types and their sectoral division in the European Union (EU) member states. The scope of covered ISO standards is listed in Section 3.1. Standard management systems and process security.

The analysis of ISO Certificates per certificate type in the European Union (EU) member states (EU-27), which is own elaboration based on "1. ISO Survey 2020 results — Number of certificates and sites per country and the number of sectors overall", shows that the dominating percentage of 68 % of all ISO certificates are related to the ISO 9001 Quality management standard. This comes as no surprise since this is the quality management system standard which supports an organisation in achieving its goals and objectives, document processes, policies, roles, and responsibilities to meet customer satisfaction and the necessary statutory and regulatory requirements. The ISO 9001:2015 standard is built on seven principles: customer focus, leadership, engagement of people, process approach, improvement, evidence-based decision-making, and relationship management (ISO, 2019). The second most frequent ISO standard

is the ISO 14001:2015 Environmental management systems standard, which helps organisations to fulfil compliance obligations and achieve environmental objectives, enhance environmental performance, and promote reduction in waste and emissions (Keen, 2022). The third most frequent standard is the ISO 45001:2018 Occupational health and safety management systems standard. The occupational health and safety (OH&S) standard is fundamental and important in any sector because it promotes safe and healthy workplaces. It is important to identify related risk factors (Erazo-Chamorro et al., 2022). OH&S management systems are adopted to control hazards (Čiutienė et al., 2022). The sectoral division shows almost equal distribution in the named sectors; the only outstanding sector was construction. The construction sector carries a number of critical safety hazards that justify the highest frequency of certifications in this sector. The top three standards cover 94.1 % of the reviewed population.

The sectoral division of ISO certifications per certificate type in EU-27 was done according to 39 economic sectors. The sectoral analysis is own elaboration based on "2. ISO Survey 2020 results — Number of sectors by country for each standard". The survey results for the number of sectors for each standard show that the distribution of certificates in relation to various standards was relatively even amongst the different sectors with some — typically sector-specific — concentrations. It is noted that "Sector unknown" was reported for approx. half of the number of certificates. This category could not be used to retrieve information for analysis purposes.

The ISO 9001 certificates mostly belong to wholesale and retail trade, repairs of motor vehicles, motorcycles and personal and household goods, metal products, construction, and other services (around 5 % per frequency per sector). The frequency of ISO 14001 certificates shows similar results to the results of ISO 9001 certificate frequencies, with the exception of the construction sector, which has a frequency of 9.5 % for ISO 14001 and shows an outstanding role of environment management systems in the sector. Moreover, 13 % of the ISO 45001 certificates belong to the construction sector, which is in line with the expectations and shows the significant role of OH&S in this sector. The distribution of ISO 45001 certificates follows a similar dynamic to the frequencies of the ISO 14001 certificate frequencies.

The information technology sector has the highest frequency of getting certified for the ISO/IEC 27001 (35.5 %), ISO/IEC 20000-1 (35.7 %), and ISO 22301 (12.7 %) standards. 33.5 % of the ISO/IEC 27001 certificates belong to the information technology sector, which shows the centric role of information security management systems and of the treatment of information security risks in the IT sector. 35.7 % of ISO IEC 20000-1 certificates and 12.7 % of ISO 22301 certificates are related to the IT sector. The mentioned standards focus on IT security, IT service management, and BCM, all of which are essentially important in the IT sector.

Regarding the actual numbers of ISO certificates in the information technology sector, the ISO/IEC 27001 and ISO 9001 standards show the highest numbers. This shows the fundamental role of quality management systems in this sector. ISO/IEC 27001:2013 Information technology — Security techniques — Information security management systems standard promotes Information Security Management Systems (ISMS), which serve to meet the goals of information security, i.e., confidentiality, integrity, and availability (Michelberger & Kemendi, 2020) and help the organisations to manage information security risk systematically. The role of information security in the ever-changing world is critical (Kemendi et al., 2021), which justifies the ranking of the related management system standards. The market participants set high expectations for businesses in the IT sector, and the outcome of the analysis confirms that IT sector participants adopt the related management systems and obtain certificates to prove their compliance.

Standard management systems increase the organisation's performance. Furthermore, the integration of separate management systems, such as quality, environment, and/or health and safety management systems, is found to be increasingly desirable and feasible (Labodová, 2004). The integration of a management system serves as a common platform for the applied management systems, consequently reducing redundancies, contributing to transparency and possibly reducing time spent on audits. Furthermore, processes are linked to each other, and the resulting duplications can be eliminated using an integrated management system. The benefits of integration can contribute to achieving higher quality standards and easier decision-making. This, however, is the prerequisite for proper project implementation beforehand. Organisations that are certified for management systems can face challenges when implementing a new management system; successful implementation requires the right competence and engagement (Fiore et al., 2023).

Certified management systems are beneficial for organisations because they help to improve their process performance. These systems are based on solid requirements, which make the system stable and transparent, and help to reduce the risk exposure. For this reason, the following hypothesis was formulated.

H1: Certified management systems increase the level of process security.

1.2. Controlling systems (e.g., Balanced Scorecard)

Controlling systems (e.g., Balanced Scorecard) enable the management and control of the organisation's activities in line with the organisational objectives. Anthony segmented organisational planning and control into strategic planning, management control and operational control (1965). These processes relate to the organisational hierarchy and to respective management levels (Strauss & Zecher, 2013). Anthony's work was a milestone in management control, but over time, it was criticised, e.g., for its narrow view due to its focus on financial and accounting-based controls and for the separation of management control from strategic and operational control (Strauss & Zecher, 2013). To meet the needs of the dynamic, constantly changing business environment, adequate dynamic controlling systems are required, e.g., the Balanced Scorecard (BSC), which is a management control and strategy communication device which offers a superior combination of financial and non-financial performance measures (Malina & Selto, 2001).

The Balanced Scorecard is a strategic performance assessment method that captures four perspectives, i.e., customer (How do customers see us?), internal (What must we excel at?), innovation and learning (Can we continue to improve and create value?), and financial (How do we look at shareholders?). The Balanced Scorecard focuses on the most critical measures and minimises information overload due to the limited number of measures (Kaplan & Norton, 1992).

The measurement of security process performance delivers essential information to the top management about the status quo of the security processes and serves as a basis for identifying areas of focus and the performance of the related action plans. Proper measurements are linked to strategic objectives.

The four perspectives of the balanced scorecard are interlinked and should be derived from the strategy. The four perspectives are related to each other and should be applied to capture these relationships. For instance, continuous improvement is a subset of innovation, and related projects are linked to the financial perspective on the input, processing and output side: CI projects usually require resources, such as time, cost, and expenses and may require investments, which will result in simpler processes that require less resources, including human. This means a direct financial benefit which should be measured, and, in turn, the resources can be used for other tasks and jobs. The changed process feeds the learning perspective. The improvement is also a feed into the internal process perspective, which generates value for the customers as defined in the customer perspective. The impacts of particular actions should be evaluated from all angles. The above example also illustrates the strive for balance in the Balanced Scorecard.

The four key categories of the Balanced Scorecard are financial, customer, internal process, and innovation and learning. As for the customer perspective, the key factors are time, quality, performance and service, and cost. The internal business perspective focuses on measures that have the greatest impact on customer satisfaction. The financial measures are associated with shareholder value. The financial consequences of a company's performance should be captured well to explicitly see the linkage between operations and finance. In the rapidly changing world, the company's ability to innovate, improve and learn has become a critical success factor that is directly linked to the company's value. Existing products, services, and processes should be subject to continual improvement and should be innovative to launch new products and services as needed. Companies should improve their ability to deliver value to customers and shareholders. Internal company processes, including the human resources associated with the processes, should embrace the innovative changes. The innovation and learning layer is inherently associated with a company that wants to continually deliver value to its stakeholders (Kaplan & Norton, 1992; Kaplan & Norton, 1993). The management systems also promote this attitude (reference in italics in Table 2). Performance objectives and measurements in line with ISO standards per Security groups). Each ISO standard has an innovation and learning layer. End-to-end processes, including inputs, processes and the resulting outputs, should be subject to continuous improvements. With reference to performance goals, people should be trained and

developed as needed and attend the required training.

Security management is a unique function. When security is present, no one notices its efforts. If there is, however, a process failure, the role of security comes into focus. The performance of information and process security requires a unique mindset to design and analyse the relevant figures in a way that shows the actual and potential gaps in the process and security efforts, which represent the achievement in the security field. Performance indicators show the process's health. This has, however, the prerequisite that they are designed properly and fit the organisational processes as well. Process security is linked to the underlying safe processes, which are based on relevant security policies and procedures. It is also linked to the security culture, which is supported by appropriate training with a proper learning loop and support from the top management.

The use of standard management systems and process measurement, e.g., the Balanced Scorecard, has demonstrated benefits for an organisation. The measurement of process security is beneficial for an organisation. It is worthwhile to leverage the benefits of the Balanced Scorecard and of the standard management systems in support of process security measurement. For this reason, the Security Balanced Scorecard linked to standard management systems should be developed as a new approach to managing the performance of security processes. The Balanced Scorecard approach is to be used to create a framework for process security measurement in the context of standard management systems. In this new framework, authors identify security groups that target different corporate strategic objectives and link the corresponding ISO standard(s) to that security group, which is a comprehensive approach to security process measurement.

2. Research method

The research is based on a literature review of the components of process security.

Qualitative content analysis is used to establish a linkage between the certified management systems and the level of process security (Graneheim et al., 2017; Lindgren et al., 2020). Content analysis is a systematic method for analysing data (Lindgren et al., 2020). The analysis focuses on the theme and the context and emphasises variation as similarities and differences between passages of text. It provides an opportunity to analyse not only clear, descriptive content but also latent, interpretive content (Graneheim et al., 2017).

A new Balanced Scorecard has been developed, covering the security pillars in the context of standard management systems. It serves as a framework for process security measurement. The Balanced Scorecard approach has been researched based on a literature review and has been developed further based on the review conducted about the standard management systems. The research has been accompanied by a thorough research on standard management systems. The new Balanced Scorecard cover different security aspects (controlling areas) linked to standard management systems.

3. Results

3.1. Standard management systems and process security

Research analysis is conducted to identify the linkage between process security and certified standard management systems. Qualitative content analysis on the related ISO standards has been selected as a research method (Graneheim et al., 2017; Lindgren et al., 2020). The ISO standards subject to review were identified based on the scope of the ISO survey (ISO, 2021). The in-scope ISO standards are listed in Table 1. Three ISO standards available in the ISO survey were descoped from the detailed analysis due to their unique sectorial nature, i.e., ISO 22000:2018 Food safety management system, ISO 13485:2016 Medical devices Quality management systems, and ISO 39001:2012 Road traffic safety management systems. It should be noted that the ISO 31000 Risk management standard is a management standard and not a management system standard (ISO, n.d.). It promotes the integration of risk management into the corporate governance system and, consequently, strengthens it. Also, it establishes adequate risk management processes, which is important from the process security perspective. The ISO 31000 standard cannot be certified for; hence, no certification data is available and is therefore out of the scope of this analysis.

The in-scope ISO standards define the requirements for the specific management systems and are security-oriented bold highlights in Table. Per defini-

tion, the operation of the management systems is based on the so-called Plan-DO-Check-Act (PDCA) cycle and has a process-oriented approach. There is a built-in component for a continuous improvement mindset in each standard, i.e., in the Act phase of the PDCA cycle, following the performance evaluation in the Check cycle. The training and development cycle is an important element of the standards ensuring the availability of the required skillset. Certified management systems are attested by an independent body that applies a standard, formal, and acknowledged process, which further increases the reliability of given management systems. These factors help to increase process performance and security (Table 1). Consequently, the hypothesis is proven that the certification of management systems increases the level of process security.

3.2. New Balanced Scorecard based on different security aspects

In this research, the Balanced Scorecard approach is used to create a framework for process security measurement in the context of standard management systems. Though performance indicators are expected to be tailored to the unique objectives of an organisation, the identified set of performance indicators can be commonly used in many cases.

The scopes of the standards used to create a new balance scorecard based on different security aspects (the so-called "Security Balanced Scorecard") overlap with the scope for the Analysis based on the ISO survey of certifications to management system standards (above and are described in Table 1). Due to its importance and relevance, the authors put in the

Tab. 1. Scope of ISO standards

Name of the ISO standard	Extract from scope
ISO 9001:2015 Quality management systems — Requirements	… to demonstrate its ability to consistently provide products and services that meet customer and applicable statutory and regulatory requirements; to enhance customer satisfaction through the effective application of the system, including processes for improvement of the system and the assurance of conformity to customer and applicable statutory and regulatory requirements
ISO 14001:2015 Environmental management systems — Requirements with guidance for use	… to enhance its environmental performance
ISO/IEC 27001:2013 Information technology — Security techniques — Information security management systems — Requirements; Technical Corrigendum in 2014 & 2015 *	... continually improving an information security management system within the context of the organisation; includes requirements for the assessment and treatment of information security risks tailored to the needs of the organisation
ISO 45001:2018 Occupational health and safety management systems — Requirements with guidance for use	… to enable organisations to provide safe and healthy workplaces by preventing work-related injury and ill health, as well as by proactively improving its OH&S performance
ISO 50001:2018 Energy management systems — Requirements with guidance for use	... to enable an organisation to follow a systematic approach in achieving continual improvement of energy performance and the Energy management systems (EnMS)
ISO 22301:2019 Security and resilience — Business continuity management systems — Requirements	... improve a management system to protect against, reduce the likelihood of the occurrence of, prepare for, respond to and recover from disruptions when they arise
ISO/IEC 20000-1:2018 Information technology — Service management — Part 1: Service management system requirements	... continually improve a service management system (SMS). The requirements specified in this document include the planning, design, transition, delivery and improvement of services to meet the service requirements and deliver value
ISO 28000:2022 Security and resilience — Security management systems — Requirements	… specifies requirements for a security management system, … which intend to establish, implement, maintain and improve a security management system
ISO 37001:2016 Anti-bribery management systems standard	… improving an anti-bribery management system. The system can be stand-alone or can be integrated into an overall management system

*Note that since the review date, the ISO/IEC 27001:2013 standard has been revised by the ISO/IEC 27001:2022 Information security, cybersecurity and privacy protection — Information security management systems — Requirements standard. The wording about the scope of the standards is identical.

Source: Extracted from the named ISO standards (ISO 9001, ISO 14001, ISO/IEC 27001, ISO 45001 ISO 50001, ISO 22301, ISO/IEC 20000-1, ISO 28000, ISO 37001).

scope the ISO/IEC 33001:2015 Information technology — Process assessment standard that provides a repository for key terminology relating to process assessment. It gives overall information on the concepts of process assessment, the application of process assessment for evaluating the achievement of process quality characteristics, and the application of the results of process assessment to the conduct of process management (ISO/IEC 33001, 2015). ISO/IEC 33xxx family of standards revises the ISO/IEC 15504 series, aka Software Process Improvement and Capability dEtermination (SPICE), which is an international framework for accessing software development processes.

The controlling areas of the new, security-focused Balanced Scorecard are based on management system standards, which cover the most important and critical controlling areas of different entities. These controlling areas are also referred to as Security groups in the publication and relate to different security aspects.

3.2.1. Security groups — key factors in determining the performance measures for the Security Balanced Scorecard

I. Quality management. In line with the ISO 9001 Quality management standard, organisations maintain, update and review the quality policy and standard operating procedures, including control activities available for in-scope business processes with clear roles and responsibilities, to have a document management system, up-to-date organisation chart and job descriptions for each job/role. These measures help organisations to maintain well-structured processes that are resilient to withstand the changes, e.g., if a key employee leaves the organisation. They are transparent and can be measured with process performance measures, which, in turn, can serve as a tool for identifying continuous improvement opportunities. The QMS aims to ensure customer satisfaction, which has to be measured to obtain the necessary feedback from the customers (external measure) and to be supported by regular QM audits performed (internal measure).

II. Process management (internal). Internal business processes are required to continually serve customer requests. They must ensure reliable and secure business operations. Businesses also must be maintained under unexpected circumstances. Internal processes should be subject to process assessments to achieve the required quality and identify improvements.

III. Information technology and information security. Information technology services and information security management systems (ISMS) ensure confidentiality, integrity and availability. Information technology is deeply embedded into corporate processes and is required for undisturbed business operations together with human resources. Information security is essentially important for organisations. Breach of information and ICT security can have serious consequences, including direct financial losses, business disruptions due to unavailability of systems, breach of confidentiality, fines related to violations of the General Data Protection Regulation, reputational issues, etc. Information and cybersecurity controls are needed to ensure confidentiality, availability, and integrity. Security is the result of adequate processes and procedures, which should be supported by technology (software solutions for security activities to handle various risks) and people (who should have adequate skills, knowledge, competences, e.g., to identify and withstand social engineering attacks).

IV. Human resources. Human resources are an integral part of business processes that require them. Occupational health and safety is an essential issue. Any safety hazard, related issues, injuries, and incidents should be taken seriously and followed up to prevent future reoccurrence. These incidents are not only a safety matter for people but can turn into an actual financial loss due to the lost time and production/value creation in the connected business processes. Consequently, such incidents directly impact the business results and cause reputational damage. The diligent follow-up on OH&S matters is essential.

V. Supply chain security. The security of the supply chain results in stable delivery of products and services to the customers, which is essential for short and long-term business success.

It is also advisable to establish business relationships with counterparts with proven quality management standards.

VI. Energy and other infrastructures. The most suitable performance measures for energy and other infrastructure primarily depend on the business profile. To determine the proper performance measures, the related processes need to be analysed in detail. The energy crisis of recent days emphasises the need for well-thought-out energy consumption. The efficient use of energy ultimately helps to reduce operating costs; thus, the price of products and services can remain lower, which is of decisive importance from the point of view of customer satisfaction. Further-

Tab. 2. Performance objectives and measurements in line with ISO standards per Security groups

SECURITY GROUP WITH ISO STANDARDS	OBJECTIVE	MEASUREMENT - PERFORMANCE INDICATORS
I. ISO 9001 Quality management systems	• Continuous improvement (CI) of processes in place, including proper documentation • KPIs, e.g., customer satisfaction measures, first pass yield, are in line with business processes, regularly monitored and actioned as needed • No overdue actions • No overdue audit actions • Employees aware of the Quality Policy, Quality objectives and their QMS obligations/ contributions • Promote quality culture	• Nr. of CI projects (open, completed) and gained efficiency • KPI reviews performed and actions defined after KPI reporting by management and top management • Nr. of open/overdue actions • Nr. of open/overdue audit actions • Regular QM training with exam testing per training schedule, training records retained; Attendance rate • Regular communication on quality management, e.g., email, floor- walk, quality sessions
II. Process management (internal) ISO 22301, & 33001 Business continuity management systems; & Information technology - Process assessment	• Business continuity maintained • Reliable ICT service delivery in line with Service Level Agreements (SLAs); ICT and information security policy defined, operated and reviewed regularly; process performance is monitored; • Identify gaps and improvement areas for the information security processes and procedures to ensure information-, and cybersecurity controls are in place and updated as needed to ensure confidentiality, availability and integrity. • Persons employed aware of their obligations regarding BCM-related issues	• Nr of BCM testing • Nr of efficient BCM testing • Nr. of ICT reviews/audits performed, Nr. of audit actions/actions related to gaps, Nr of CI actions defined and completed on time/overdue • Regular training with exam testing per training schedule, training records retained; Attendance rate
III. ISO/IEC 20000-1, & 27001 Information technology - Service management; & Information technology - Security techniques	• Enterprises do not experience any problems due to ICT and/or information security incidents, e.g., unavailability of ICT services, corruption of data, or disclosure of confidential data (Kemendi et al., 2021). • Persons employed aware of their obligations in ICT security-related issues (Kemendi et al., 2021)	• Nr. of ICT incidents (target: zero) and of ICT incidents actioned as per SLA (Compliance ratio) • Nr. of ICT requests and of requests actioned as per SLA • Average resolution time for incidents • Nr. of Segregation of duties conflicts (target: zero) • Nr. of training sessions regarding ICT security & of people attended; Attendance rate
IV. ISO 45001 Occupational health and safety management systems	• accident-free working days • work-related incidents/accidents/near misses • provide and ensure attendance at OH&S training	• Nr. of work-related incidents (target: zero); Lost time due to OH&S issues • Nr. of safe (i.e., free of accident, OH&S incidents, injuries) working days • Nr. of OH&S training provided, & of people attended; Attendance rate
V. ISO 28001 Security management systems for the supply chain	• Conduct supply chain security assessment and define actions for gaps and development opportunities	• Reduce lead time of delivery • Increase preferred supplier purchases
VI. ISO 50001 Energy management systems; Energy and other infrastructure	• Review energy-absorbing processes (e.g., production units or office buildings) and seek for energy optimalisation solutions • Energy performance measured, energy data tracked and analysed • Improve energy efficiency by v%	• Energy consumption metrics • Nr of identified optimalisation solutions • Financial amount of gained efficiency

Security group with ISO standards	Objective	Measurement - Performance indicators
VII. ISO 14001 Environmental management systems	• Minimise the environmental impact of the operation by: • Reducing emissions in the supply value chain by x% • Increase renewable energy/material consumption in favour of non-renewable by y% • Increase reused material consumption in favour of traditional materials by z% • Identify improvement areas • Persons employed aware of their obligations regarding environmental management	• Percentage of completion achieved compared to the target values (x;y;z) • Nr. of CI projects (open, completed) and gained efficiency • Nr. of training sessions regarding environment preservation & of people attended; Attendance rate
VIII. ISO 37001 Anti-bribery	• Combat bribery-, and terrorist financing	• Nr. of anti-bribery-, and terrorist-financing-related breaches, incidents (target: zero)

more, it helps to ensure environmentally conscious, sustainable operations. Below, the authors broadly outline a walkthrough of the key points to identify the proper performance measurements and targets for an organisation.

Walkthrough to identify energy performance objectives and targets. The basic value of the energy savings depends on the nature of the entity's facility, i.e., whether it is productive (production plant factory) or non-productive (office building).

In the case of a non-production enterprise facility, important factors are the energy demand of technological processes, previous assessments of efficiencies, their previous analysis, and the type of available historical data. Based on this analysis, it is advisable to examine the possibility of modernisation. It is advisable to investigate the possibility of reducing energy demand and costs, to consider investing in heat recovery equipment, which can be done based on the knowledge of technologies, and alternative energy replacement, which is also expensive. Therefore, an impact analysis is required. The solar system is reliable in the long term, and a solar collector is also very good in the case of a high demand for hot water. However, during the planning, care must be taken to ensure the safe removal of heat due to overheating (heating-up) during the shutdown period without heat consumption. The possibility of building a heat pump system should also be investigated.

In the case of a non-production enterprise facility, the heat demand and its heat supply, as well as the heat removal (cooling demand) of the building complex along with the production plants, must be considered. It is important to solve the energy demand of the energy consumers operating during operation, as well as the associated heat generation and the removal of excess heat. How does this happen? Is there a heat recovery device built into the ventilation system? Is it possible to use computer equipment with lower energy needs and to evaluate building properties by evaluating the energy consumption data of the previous period? The modernisation and transition to a more favourable energy source for non-production facilities is in many ways the same as for production plants, but it depends on the company's profile, strategic plans and available financial funds, and the resource needs also vary. For example, the domestic hot water demand will probably be lower, and the work schedule, the working hours, and the resulting distribution of the energy demand on the time axis will be different.

VII. Environment management. Minimising environmental impact of corporate operations has become more and more relevant. To have a clear view on environmental impact of the operation, to identify environmental risks and improvement areas are important steps in the successful environmental management process.

VIII. Anti-bribery. Combating bribery and terrorist financing is an important topic for companies. This demonstrates the need for robust anti-bribery controls. Management of anti-bribery controls should be present in all contexts where the risk can arise, e.g., employees, customers, vendors, and any counterparts.

Table 2 contains generic performance objectives and measurement indicators per Security groups

(I–VIII) together with the corresponding ISO standards. All this can serve as a good practice and is recommended as a model when implementing a comprehensive security management system as a whole or in part.

3.2.2. "Security Balanced Scorecard" — the new Balanced Scorecard based on security groups

Security objectives and goals are a subset of corporate strategy, and in the changing business and risk environment, their role has become increasingly important. The integrated risk management approach also promotes the treatment of security management processes as an inherent part of the corresponding business processes. The Balanced Scorecard is implemented based on strategic objectives, which should be linked to performance goals and measures related to the four perspectives of the Balanced Scorecard.

Fig. 1 lists strategic objectives related to the categories of the Security BSC. The categories are linked to relevant ISO standards.

Table 3 presents performance goals and measures with reference to Security groups. The structure of the Security Balanced Scorecard follows the structure of the original Balance Scorecard, i.e., the financial, customer, and internal process, as well as innovation and learning perspectives, together with performance goals and measures. The Security BSC adopts the structure of the original BSC and applies it from the security perspective. The Security groups of the Security BSC were defined in line with the related ISO standards. The Security BSC contains generic security performance goals and measures that can be tailored and leveraged by any organisation.

4. Discussion

The application of standard management systems helps organisations to achieve their objectives. These systems cover different objectives. Processes perform well when the underlying security objectives are met. The objectives of management system standards are security-oriented and contribute to the increase in process performance. Management systems are linked to the continuous improvement mindset. Furthermore, these systems pay sound attention to training and development. These factors also contribute to increased process security. The attestation of an independent certification body of the management system has sound requirements. In case these requirements are met, an organisation is able to demonstrate the performance of its management system, which increases the level of process security.

As for information security, the ISO/IEC 2700x family of information security management system standards and guidelines serve as a common language worldwide for engaging in business securely (Hum-

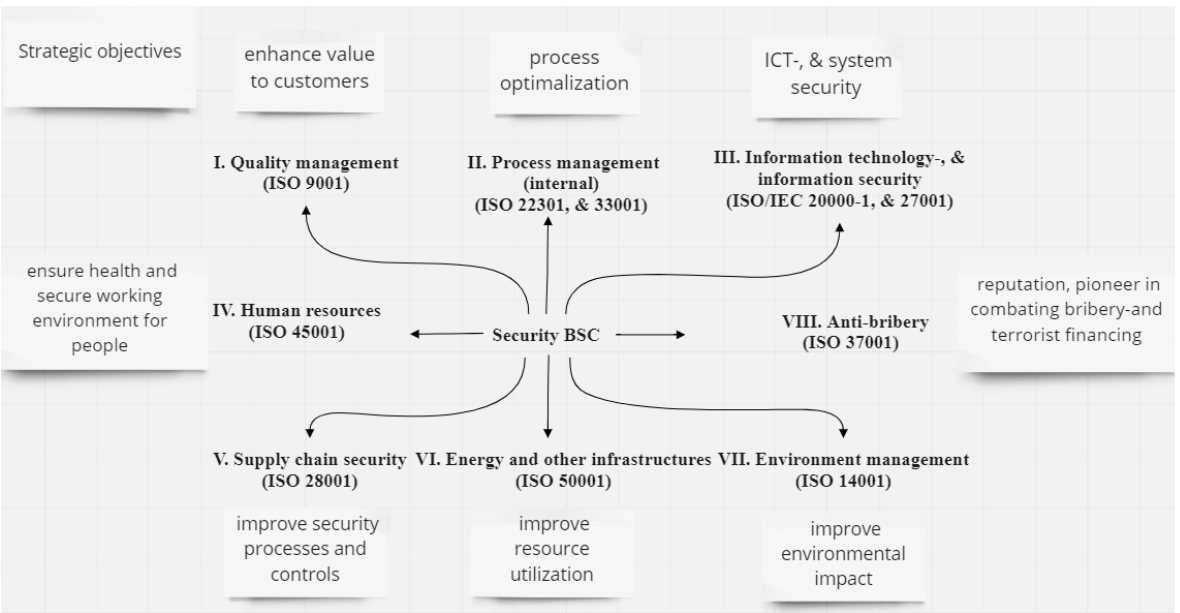

Fig. 1. Pillars and Strategic objectives related to the Security Balanced Scorecard

Tab. 3. Performance goals and measures related to the Security Balanced scorecard

Security Balanced Scorecard					
Reference to Security groups with ISO standards in Tab. 4.	**Financial perspective**		**Reference to Security groups with ISO standards in Tab. 4.**	**Customer perspective**	
	goals	**measures**		**goals**	**measures**
I. QMS	Profitability - going concern	Cash flow; Income; Expenses	I. QMS	Customer satisfaction	Customer satisfaction index (customer value: price, quality, reliability of products and services, availability-delivery time)
I. QMS	Reliability of financial reporting	Adequate internal processes; internal control reviews; audit findings (internal; external)	I. QMS	Market share	Key accounts; customer acquisition, retention
I. QMS; II. Process management; III. ICT security; IV. OH&S	Stable operation	Time spent due to lost time related to process failure, incident; returned product/complaints; customer orders processed on time			
III. ICT / data related compliance (Confidentiality, GDPR etc.); IV. OH&S; V. Supply chain; VII. Environment; VIII. Anti-bribery	Compliance with law, regulations	No fines due to non-compliance			
V. Supply chain; VI. Energy	Improve cost structure, optimalization solutions	Cost reduction, reduced expenses			
I. QMS; II. Process management; III. ICT security	Project management	Budgeting and results (end-to-end tracking)			
Reference to Security groups with ISO standards in Tab. 4.	**Internal business perspective**		**Reference to Security groups with ISO standards in Tab. 4.**	**Innovation & learning perspective**	
	goals	**measures**		**goals**	**measures**
II. Process management (BCM, IT service)	Provide fast response to unexpected events	Efficiency of BCM readiness; SLAs - service quality	I-VIII.	Improve ICT-, and system security level	Gap analysis; development projects/actions; Continuous improvement projects (open, closed)
II. Process management	Simplify processes, minimize potential problems	Security incidents, near misses	I-VIII.	Corporate security culture	Staff security attitude survey; development trainings (on-the-job; classroom; online)
I. QMS	First pass yield	Rework, complaint	I-VIII.	Employees' competences	Training
IV. OH&S	Preserve employee health and safety	Safe working days	I-VIII.	Employees' commitment	Employee satisfaction index; Employee retention index
V. Supply chain security	In-time delivery	Reduced lead time			

phreys, 2011). The ISO/IEC 2700x standard package, differently from other management system standards, contains a risk management standard dealing with information security (ISO/IEC 27005). This proves the importance of risk management in the field of information protection. An ISO/IEC 27001-certified business must have put in place all protection measures that were specified in the standard (Kitsios et al., 2023). The certification of the information security management system guarantees that the information security requirements are met through the implemented controls; the certification helps to build trust

in an organisation's capacity, as well as reduces the risks (incl. business loss, the risk of fines or compensation payments due to legal disputes) and helps to prevent security breaches (Disterer, 2013; Saint-Germain, 2005). Furthermore, successful implementation of ISO/IEC 27001 requires that employees provide their full support and contribution (Kitsios et al., 2023). Given the significant risk exposure that comes from inside the organisation (Arsenault, 2023; ENISA, 2006; van Zadelhoff, 2016), the information security management system contributes to reducing the risks related to the human factor.

The systematic approach to standard management systems, clear processes, and the list of steps defined as a part of management system are in support of process performance management as well.

The Balanced Scorecard approach is a sound approach to measuring process performance since it pays attention to financial, customer, internal business, and learning and development perspectives. These perspectives are interconnected. This interconnected nature represents the context of security matters as well and is found to be a good basis for the purposes of this research. For this reason, the new Balanced Scorecard leverages the benefits of the Balanced Scorecard methodology and that of standard management systems, which are well aligned with corporate objectives.

The BSC has been successfully used by many different organisations to measure and evaluate performance (Mendes Jr. & Alves, 2023). The BSC is regarded as one of the most influential strategy implementation and control tools, but data about its impact on performance is mixed (Tawse & Tabesh, 2023). The BSC can be viewed critically, e.g., as a new fashion in management or a consulting product. Its underlying assumption is that organisations implement a strategy in a rational top-down process or that this is built on notions of strong organisational control (Madsen & Stenheim, 2015).

Many studies show that the BSC can be successfully implemented in large-scale companies and organisations. The BSC appears to be suitable for all types and sizes of businesses, large and small. However, based on research data from 500 companies in the UK and Cyprus, very few small companies use the BSC, especially in the UK (Giannopoulos et al., 2013). There are good examples beyond the business sector as well, such as higher education (Mendes Jr. & Alves, 2023) or healthcare (Amer et al., 2022; Peters et al., 2007), where the BSC is proven to be an effective strategic management tool.

However, the concept of the BSC can be utilised as a meaningful tool in support of process performance measurement and in particular to develop it further for the purposes of security process measurement. Regardless the criticism, the implementation and operation of the BSC should happen in a way that it can well support organisational objectives.

There are studies that deal with the BSC in the context of safety such as adaptation of the BSC to measure organisational safety culture (Mohamed, 2003), occupational health and safety (Mearns & Håvold, 2003), health, safety and environment management systems (Beheshti et al., 2018; Azour et al., 2017), school safety performance (Alolah et al., 2014), to improve maritime safety through enhancing marine process management (Lin & Cheng, 2021), etc. There are studies on security matters, e.g., the BSC is researched from the perspective of information security (Fatkieva & Krupina, 2020; Herath et al., 2023) or information security investment decisions (Tallau et al., 2010).

As a subject of the current article, the BSC approach is applied to a number of security areas in the context of standard management systems. The outlined new concept of the Security BSC, i.e., the subject of this paper, offers a comprehensive approach that uses standard management systems and explores security groups linked to standard management systems (i.e., controlling areas, such as quality management, process management, information technology and information security, human resources, supply chain security, energy and other infrastructures, environmental management, or anti-bribery measures). This Security BSC presents an integrated approach to different security matters. It can serve as a best practice to address security process performance at the organisational level and is recommended as a model when implementing a comprehensive security management system in whole or in part.

Conclusions

Process security is crucial for businesses and state-owned entities. To establish, maintain and reinforce process security, it is recommended to use state-of-the-art methods and tools.

The results of the research show that the application of management system standards supports process security. It has been proven that the certification

of management systems increases the level of process security.

The analysis of the ISO standard certifications has shown the dominance of the ISO 9001 quality management standards. Building and maintaining a quality management system is a good basis for establishing further management systems. Quality management is also a mindset embedded in the possibility of continuous improvement initiatives. The delivery of quality products and services helps organisations to be resilient, maintain more transparent processes, operate processes with less "waste", and be more efficient and effective. This requires significant efforts when adopting a quality management system and continuous maintenance. The commitment to this way of working generates real value not only for the customers but for the organisation itself. Thus, it contributes to long-term corporate success. Obtained and maintained ISO management system certifications helps to demonstrate management efforts to stakeholders. Moreover, diligent audits help to improve the management system.

The analysis has shown that the top three ISO certificate types in the EU-27 cover 94.1 % of the reviewed population. The top three certified management system standards were the ISO 9001 Quality management (67.6 %), the ISO 14001 Environment management (19.3 %), and the ISO 45001 Occupational health and safety management (7.3 %). The distribution of certificates in relation to various standards was relatively even amongst the different economic sectors with some — typically sector-specific — concentrations. Mostly, the participants in the information technology sector had a certified information security management system, information technology service management, and business continuity management systems related to ISO standards.

Process performance measures, aka KPIs, should be tracked over time and compared to targets. This living process provides management with regular information on the state of the organisation and its specific units' performance and provides the framework for follow-ups when and where there is a discrepancy. Also, it helps to identify development opportunities. With respect to security performance indicators, it is advisable to find the right balance in proactively defining measures and focusing not only on what went wrong but also on the achievements and results of the security management process. It is advisable to find an optimal number of performance measures focusing on the most critical ones. The number of performance indicators should be just enough to give the proper status of the measured processes and should not be too much. Otherwise, information overload can occur, making it harder to focus on the most important items. The creation of a too-complex system is undesirable. Simplicity is a recommended direction. The focus should be on creating a simple system that contains the most important and critical items and that is easier to be managed. It is also advisable to consider starting from scratch when creating a system of performance measures that is simple and fit for purpose.

The Balanced Scorecard encompasses performance measures in financial, customer, internal process, and innovation and learning categories. These categories are closely interlinked, so the measures should be applied and interpreted comprehensively, looking at the cause-and-effect relationships. The goals and measures of the scorecard should be derived from the strategy. The authors have prepared a brief walkthrough to identify energy performance objectives and targets to illustrate the process behind each process performance measure. The research has led to the development of the Security Balanced Scorecard. The recommended set of process performance measures in the Security Balanced Scorecard helps the management to see the most important measures at a glance and view the effects of particular decisions. This promotes system thinking and better decision-making. The controlling areas of the new, security-focused Balanced Scorecard are based on management system standards, which cover the most important and critical controlling areas of different entities. The introduced list of recommended security process measures can be leveraged as good practices for any organisation and selected according to the organisation's goals.

The research is based on a thorough literature review related to the research area and standard management systems. It aimed to exhaust the research scope to offer a fair recommendation for the Security Balanced Scorecard. However, the recommendation should be reevaluated for possible changes in the future. The future direction of the research will be to integrate the research field with further research objectives.

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