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How employees' dynamic capabilities influence job performance across different stages of a crisis?

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ABSTRACT

The article investigates the impact of employees' dynamic capabilities (EDC) on job performance during various stages of a crisis in an organisation caused by a Black Swan event, mediated by job-related attitudes, such as person-job fit, work motivation, job satisfaction, and work engagement, based on EDC model of job performance. The article includes a critical literature review of the role of EDC and each job-related attitude in shaping employee job performance during a crisis caused by a Black Swan event as the basis for hypothesis development. The proposed hypotheses are verified by empirical studies conducted in 2021 on a sample of 1200 organisations from Poland, the USA, and Italy operating during the active wave of COVID-19. Statistical reasoning was made based on multigroup path analysis performed in IBM SPSS AMOS. The results confirmed the significant role of EDC in enhancing job performance during a crisis and revealed that work motivation is the most influential job-related attitude through which EDC impacts job performance across all stages of the crisis. The article contributes to the theory of human resource management and crisis management, presenting a comprehensive model of job performance based on EDC for various stages of a crisis caused by a Black Swan event. It also contributes to practice, showing entrepreneurs which work-related attitudes are crucial for obtaining the most benefit from EDC, enabling its proper translation into job performance growth. The article shows that work-related attitudes have a different value for shaping job performance, depending on the stage of crisis (caused by a Black Swan event) in which the organisation operates. Moreover, it confirms that EDC enables the possibility to obtain and maintain satisfactory job performance during a crisis, which suggests that EDC should be considered one of the new competitive advantages of contemporary organisations operating in the post-COVID-19 reality.

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INTRODUCTION

The mechanisms governing employee job performance represent a focal area of interest for contemporary researchers in management. The literature encompasses diverse models illustrating the influence of various job performance factors within organisations, including traditional job-related attitudes (e.g., Hackman & Oldham, 1976; Herzberg, 1987; Judge et al., 2001; Rich et al., 2010). However, the evolving and often turbulent environmental conditions in which organisations operate necessitate the consideration of factors beyond those traditionally associated with job

performance, thus underscoring the significance of exploring Employees' Dynamic Capabilities (EDC).

In this context, the Job Performance model based on Employees' Dynamic Capabilities (JP-EDC) by Bieńkowska and Tworek (2020) is noteworthy. This model incorporates EDC as a key determinant in addition to encompassing classical job performance-related factors, such as work motivation, job satisfaction, and person-job fit. EDC is intricately linked to the concept of an organisation's dynamic capabilities, encapsulating employee skills in accurately predicting and assessing changes within the organisation and its environment, as well as efficiently adapting and taking pre-emptive actions in response to evolving organisational conditions.

Notably, classical, universally recognised and empirically validated management models, theories, and paradigms, even those adapted to dynamic environmental influences, may prove inadequate for organisations grappling with the distinctive challenges posed by deep crises triggered by various Black Swan phenomena, which often occur in the contemporary world. Such phenomena, characterised by extreme unpredictability and severe negative repercussions, have materialised as a reality for contemporary organisations, as exemplified by the onset of the COVID-19 pandemic and current global uncertainties. Extensive empirical research conducted during the COVID-19 pandemic and similar crises has illuminated new strategies for influencing job performance (Meunier et al., 2022; Tworek et al., 2023; Narayanamurthy & Tortorella, 2021; Wiradendi Wolor et al., 2020). Consequently, established models must be adapted to these novel operating conditions shaped by crises. According to the crisis theory, in such scenarios, the very survival and endurance of the organisation take precedence and should serve as the lens through which organisational operations are analysed (Ancillo et al., 2021; Bieńkowska et al., 2021).

As job performance is particularly sensitive to changes resulting from highly unpredictable and turbulent phenomena in the organisational environment (Arifin et al., 2019; Tworek et al., 2023; Bieńkowska et al., 2021), models explicating its role in the organisation are especially susceptible to the need for adaptation. Moreover, job performance is a critical factor in ensuring organisational continuity during crises precipitated by Black Swan phenomena, further accentuating the necessity for reevaluating current models (Ferreira et al., 2020; Tworek et al., 2023; Bieńkowska et al., 2021). Despite the extensive research on job

performance models, a notable research gap remains regarding models based on EDC during various crisis stages, presenting an opportunity for empirical exploration.

Consequently, the primary objective of this paper is to address this research gap by proposing the Multivariant Job Performance model based on EDC during crises (JP-EDC-C). This model will elucidate the mediating factors through which EDC influences job performance at different stages of crises induced by Black Swan phenomena, thus advancing our understanding of the role of EDC in shaping job performance during crises. It is important to acknowledge that the structure and relations within the Job Performance model, akin to other models in organisational theory, may exhibit variability contingent upon the prevailing organisational conditions, aligning with situational theory (Donaldson, 2001). Understanding these alterations within the Job Performance model at each crisis stage is a valuable contribution to the management field.

This endeavour bridges a critical research gap and holds promise for theory by verifying the paradigm of job performance within organisations navigating exogenic crises prompted by the Black Swan phenomena and for practice by identifying mechanisms that may enhance the prospects of survival for such organisations. The primary aim of this paper is to verify the JP-EDC model across four stages of crisis: prodromal, acute, chronic, and resolution crises, with a focus on the role of work motivation, job satisfaction, and work engagement in bolstering job performance through EDC during crises.

This aim will be pursued through an extensive literature review, serving as the foundation for hypothesis formulation and subsequent empirical research aimed at hypothesis testing. The empirical research will encompass organisations operating in various stages of crises induced by Black Swan events, facilitating an exploration of the roles of the elements within the JP-EDC model during each crisis stage.

1. THEORETICAL BACKGROUND

1.1. JOB PERFORMANCE

The literature provides various definitions of job performance (June & Mahmood, 2011), but it is generally regarded as the behaviour of employees that contributes to the expected organisational value (Motowidlo & Kell, 2012). This study adopts this

understanding, considering both the behavioural and outcome aspects of job performance (Sonnentag & Frese, 2002; Griffin et al., 2017), and conceptualises job performance as a combination of four aspects: task proficiency, task meticulousness, work discipline, and work improvement (with readiness for innovation) (Ali-Hassan et al., 2015; Kwahk & Park, 2018; Yuen et al., 2018).

The literature identifies numerous factors that influence job performance, which are often included in job performance models as specific sets of factors (e.g., hygiene factors and motivators in Herzberg's model (1987)). As previously noted by Bieńkowska et al. (2021), various classical and contemporary literature authors propose similar job performance models featuring personality traits (e.g., Barrick & Mount, 1991; Motowidlo et al., 1997; Salgado, 1997; Tett & Burnett, 2003), job-related attitudes, such as work motivation, job satisfaction, employees commitment, work engagement (e.g., Hackman & Oldham, 1976; Herzberg, 1987; Judge et al., 2001; Rich et al., 2010; Ilczuk et al., 2023; Widyanti et al., 2021; Suifan et al., 2019), and alternative predictors (e.g., Hunter & Hunter, 1984). The diverse range of job performance models in the literature allows for a multifaceted analysis of employee job performance, considering factors related to the employee–organisation relationship and ignoring psychological, social, or demographic factors that are expressed in job-related attitudes or other employee-based predictors.

1.2. INFLUENCE OF EMPLOYEES' DYNAMIC CAPABILITIES ON JOB PERFORMANCE

In recent years, the construction of job performance models has shifted to include non-traditional factors responsive to challenges arising within the organisation and its environment. However, a gap in the literature was identified due to the lack of factors related to employee abilities to react to changes within their environment in job performance models. This led to the emergence of adaptive performance, a concept aimed at highlighting the importance of employee ability to adapt (Ferreira et al., 2020; Pulakos et al., 2000; Marques-Quinteiro et al., 2019). The importance of adaptive performance has been recognised due to the dynamic nature of contemporary organisations, which operate in an increasingly dynamic environment. As a result, the nature of work and the workplace has also become dynamic, necessitating a redefinition of the expectations for modern employees, who are the primary organisational

resource (Wolf, 2013). Organisations no longer consider employees existing resources only but are creating mechanisms to shape and utilise new competencies that are necessary for efficiently performing tasks and flexibly adapting to changes taking place in the environment (Sony & Mekoth, 2016; Marques-Quinteiro et al., 2019). It is, therefore, essential to include factors related to adaptive performance in job performance models to reflect the changing nature of the workplace and the demands placed on employees. Such models must consider the dynamic nature of the work environment, the changing expectations for employees, and the need to develop new competencies to respond to these changes. By doing so, organisations can create a workforce equipped to handle the challenges of the modern workplace and maintain high levels of job performance.

The research gap was filled by the Employees' Dynamic Capabilities concept, which was a basis for a new model of job performance. EDC was defined as "abilities to integrate, build, and reconfigure employee competencies to address the rapidly changing environment, which is directly influencing the performance of tasks in the workplace" (Bieńkowska & Tworek, 2020). Accordingly, Bieńkowska and Tworek (2020) elucidated the concept of Employees' Dynamic Capabilities (EDC), which pertain to employee proficiency in the following dimensions: the ability to perceive environmental changes, encompassing the capacity to discern alterations, identify potential opportunities, and recognise risks that could impact workplace performance; adaptability to environmental shifts, comprising the aptitude for proactive preventive actions aimed at averting workplace problems; proactive problem-solving, including the ability to resolve workplace issues if they arise and introduce innovations into the work environment; and the generation of innovative ideas, original problem solutions, continuous competence development, and qualification enhancement through work. This multifaceted definition of EDC underscores its critical role in shaping employee job performance.

Bieńkowska and Tworek (2020) conducted a study, depicted in Fig. 1, to establish a mediation model of Job Performance predicated on EDC (EDC-JP). This model was initially validated based on data collected from 550 organisations in Poland and the USA during normal operating conditions in 2019. The model integrated several job-related attitudes as mediators in elucidating the relationship between EDC and job performance. These mediating job-related attitudes encompassed:

Person–Job Fit (PJ-fit) — characterised as the alignment or compatibility between job requisites and individual knowledge, skills, and abilities. PJ-fit predominantly relates to the concordance between employee characteristics and the job tasks and their characteristics that are expected to be executed in return for employment. This concept is consistent with the work of O'Reilly and Chatman (1986), Edwards (1991), Kristof (1996), and Chilton et al. (2005).

Work Motivation, which denotes the extent to which employees are driven to perform effectively in their job positions, as defined by Hackman and Oldham (1974).

Job Satisfaction — defined as the degree to which employees derive contentment and happiness from their job. This concept is in accordance with Hackman and Oldham (1974), Rich et al. (2010), and Locke (1976).

Work Engagement — the voluntary dedication of employees to their job roles, encompassing physical, cognitive, and emotional involvement in their work. This construct aligns with Kahn's (1992) definition of employee engagement as a positive and fulfilling state of mind related to work, characterised by vigour, dedication, and absorption, as elaborated by Schaufeli and Bakker (2004).

As illustrated in Fig. 1, the EDC-JP model positions PJ-fit as the primary mediator. PJ-fit functions as an intermediary mechanism bridging the relationship between EDC and other factors that influence job performance within the model, including work motivation, job satisfaction, and work engagement. Therefore, the model's development has confirmed the intricate nature of the mechanisms that shape employee job performance, which are contingent upon multiple interconnected factors. Importantly, this research underscores the significance of EDC as a crucial element within this multifaceted framework.

1.3. EMPLOYEES' DYNAMIC CAPABILITIES INDIRECT INFLUENCE ON JOB PERFORMANCE

As stated above, EDC plays a crucial role in influencing job performance through various job-related attitudes, including work motivation, job satisfaction, and work engagement (Ferreira et al., 2020). EDCs involve an employee's capacity to set and pursue challenging goals, especially when faced with evolving tasks and changing circumstances. Employees with strong dynamic capabilities are more likely to be motivated by a sense of purpose and a desire for continuous improvement (Paais & Pattiruhu, 2020). This motivation is rooted in their ability to adapt to new challenges and leverage their skills to overcome obstacles (Andreas, 2022). Motivated employees tend to put in extra effort, strive for excellence, and remain committed to their tasks. Their motivation increases their job performance and positively influences team dynamics and the overall work environment. Work motivation is usually closely related to job satisfaction (Paais & Pattiruhu, 2020). EDCs can also enhance job satisfaction by enabling employees to match their evolving skills and competencies with the demands of their jobs (Davidescu et al., 2020; Andreas, 2022). When employees see their work as a meaningful contribution and believe that they can adapt to new challenges successfully, they experience higher levels of job satisfaction. Job satisfaction, in turn, has a direct impact on job performance. Satisfied employees are more likely to be proactive, productive, and committed to their organisations, which contributes to improved job performance. EDCs also contribute to work engagement by helping employees effectively handle novel situations and problem-solving challenges. Engaged employees are more likely to immerse themselves in their work, apply their skills, and find satisfaction in their achievements, which is confirmed by the works of Arifin et al. (2019), stating that work
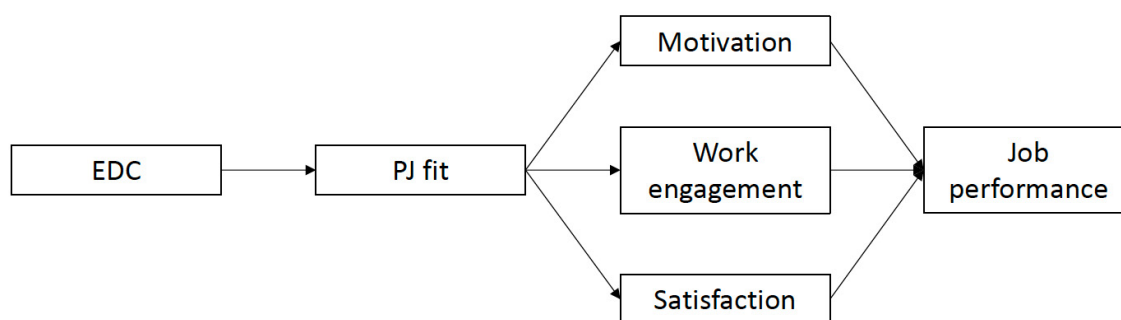

Fig. 1. Structure of the Job Performance model founded on EDC — the initial pilot study

engagement is closely connected with job satisfaction in this regard. It is also closely tied to job performance, as engaged employees tend to be more productive and contribute positively to their teams and organisations (Helmi & Abunar, 2021).

In summary, EDC drives job performance through a chain of interconnected factors. Their ability to adapt, learn, and innovate promotes work motivation by fostering a sense of purpose and the pursuit of challenging goals. This, in turn, leads to greater job satisfaction as employees find meaning in their work and feel capable of dealing with the evolving demands of their roles (Davidescu et al., 2020; Helmi & Abunar, 2021; Andreas, 2022). Additionally, dynamic capabilities facilitate work engagement by enabling employees to address new challenges effectively and experience a state of deep focus and high performance. Collectively, these factors create a positive feedback loop, enhancing job performance and contributing to a more dynamic, adaptable, and successful workforce.

1.4. JOB PERFORMANCE AND EDC UNDER CRISIS

Based on the introduction, the models concerning the functioning of the organisation as a whole and its individual areas mostly concern the normal condition of the organisation's functioning and, therefore, rarely assume not only moderate or even turbulent variability of the environment but also the dynamic impact of this environment on the functioning of the organisation's interior. Unfortunately, the models constructed for organisations operating in the conditions of deep crisis, especially those caused by the Black Swan phenomenon, often do not fit into the normal operating conditions of the organisation (e.g., Tworek et al., 2023; Bieńkowska et al., 2020; Ahmed et al., 2020; Wanasida et al., 2021; Durant et al., 2006; Taleb, 2007). Therefore, it is necessary to verify not only traditional but also modern models explaining the phenomena accompanying contemporary organisations. As stated before, according to the crisis theory, they must be adapted to the new operating conditions defined by the crisis, in which the goal itself is to survive and ensure the existence of the organisation as a whole.

The examined EDC-JP model has been scrutinised under specific operational circumstances typical of contemporary organisations. This model already acknowledges the pivotal role of Employees' Developmental Competencies (EDC) in enabling employees to respond and adapt to changes, ultimately influencing their job performance. However, it is imperative to recognise that in cases of extraordinary conditions brought about by the Black Swan phenomena, the significance of EDC is further accentuated. A more comprehensive iteration of the EDC-JP model designed for crisis situations has been posited by Tworek et al. (2023), thereby highlighting the critical relevance of EDCs for organisations operating under exigent conditions.

It is essential to distinguish between challenging conditions engendered by the highly unpredictable Black Swan phenomena and those arising from even the most turbulent environmental circumstances. Black Swan phenomena give rise to exogenic crises, characterised by their intrinsic unpredictability and the impossibility of anticipation and preparedness by organisations (Nafday, 2009). These exogenic crises are typified by the conditions that challenge an organisation's viability, characterised by ambiguity concerning their root causes, repercussions, and requisite resolutions, as well as a compelling need for swift decision-making, as delineated in the realm of management theory (Pearson & Clair, 2008).

Nevertheless, crises of an exogenic nature incited by the Black Swan phenomena transcend conventional definitions. The concept of a Black Swan, as elucidated by Nafday (2009), characterises an unanticipated, infrequent, though not implausible, cataclysm devoid of proactive preparedness. Such unforeseeable occurrences exceed the boundaries of reasonable expectations within a given context, inflicting a spectrum of potentially severe consequences. Consequently, these scenarios culminate in exogenic crises within organisations, characterised by exceedingly critical operational conditions, heightened turbulence, and unparalleled unpredictability, as delineated by Pearson and Clair (2008).

While it is imperative for managers to focus on stimulating employee job performance under all circumstances, regardless of the organisational context, due to its profound impact on overall organisational performance (Sriviboon, 2020), it becomes particularly critical during dire and unpredictable situations brought about by the Black Swan phenomena. In such scenarios, job performance takes on heightened importance, given that these situations trigger exogenic crises within organisations, necessitating a fundamental reshaping of operational strategies. Such conditions have the potential to disrupt organisational sustainability and even imperil its survival by precipitating an escalating cycle of adverse events. Further-

more, the attributes of such crises evolve dynamically across different stages. Numerous crisis models, such as those proposed by Pearson and Mitroff (1993) and Fink (1996), delineate these stages. Nevertheless, considering that crises resulting from Black Swan-type events may not encompass stages pertaining to an organisation's ability to detect them, the four-stage crisis management model outlined by Fink (1996) seems particularly relevant in this context. This model posits four crisis stages: the prodromal stage (where the crisis-inducing event has occurred but the full-blown crisis has not yet commenced), the acute crisis stage (marked by sudden and turbulent changes), the chronic crisis stage (during which the organisation endeavours to respond to the ongoing crisis), and the resolution stage (entailing a return to pre-crisis functioning). Consequently, preserving and upholding employee job performance necessitates distinct approaches throughout these stages and becomes a prerequisite for organisations seeking to surmount the crisis and reestablish sustainability and equilibrium (Marques-Quinteiro, 2019; Sahho & Abbas, 2019).

The EDC-JP model already incorporates a factor emphasising the necessity for employees to adapt to changing conditions, rendering it well-suited as a foundational framework for elucidating the mechanisms governing job performance throughout each stage of crises induced by Black Swan phenomena, consistent with the adaptive performance theory of Pulakos et al. (2000). It appears that the mechanisms delineated in the model validated for normal conditions will undergo transformation during various crisis stages, further underscoring the role of EDC and potentially necessitating the reconfiguration of other factors within the model, or the introduction of new factors that may be pivotal for organisational survival.

The literature clearly states that job performance itself and all characteristics connected to job performance are highly impacted by any crisis occurring within the organisation (Markovits et al., 2014; 2017), and this statement will be all the truer in a crisis caused by a Black Swan phenomenon. Various research emerged in this area during the COVID-19 pandemic, showing the importance of a crisis as a factor in decreasing job performance (Kumar et al., 2021; Aguiar-Quintana et al., 2021). Scholars from the field of crisis management and human resources engage in debate rooted in some shared theoretical perspectives, determining the role of human resources in crisis management (e.g., Hutchins & Wang, 2008; Bieńkowska et al., 2022). However, specific studies concerning job performance in each stage of crisis

have not been performed and those connected to the overall crisis conditions are usually based on the sample limited to a specific country (many studies on Spain by, e.g., Markovits et al. (2014) and Sánchez et al. (2017), Turkey by, e.g., Meyer et al. (2018), and Greece by, e.g., Papavasili et al. (2019)), a specific sector (e.g., manufacturing by Voulgaris et al. (2015) or financial by David et al. (2016) and Elsafty and Shafik (2022)) and almost all of them exclusively cover the financial crisis (e.g., Markovits et al., 2014; Meyer et al., 2018; Papavasili et al., 2019; Elsafty & Shafik, 2022). They all offer conclusions which may suggest that factors included in the job performance model and the job performance itself are highly susceptible to changes during each stage of crisis occurring in the organisation and may be shaped differently in each one of them, but they do not offer comprehensive studies in this regard. Moreover, they are not connected directly to the crisis caused by the Black Swan phenomena but rather the crisis overall.

In this context, it is obvious that EDC itself will remain an important factor influencing job performance during a crisis occurring in an organisation. Employee adaptability is verified by many studies as a prerequisite for allowing employees to keep working during a crisis and achieve any job performance (e.g., Pearson & Clair, 1988; Pulakos et al., 2000; Marques-Quinteiro et al., 2019), and it will be treated as such for the purpose of this study. The most recent approaches to the issue of EDC influence on job performance (also indirect) during a crisis cover the COVID-19 pandemic and reveal that EDC became one of the key aspects determining business continuity (Tworek et al., 2023; Bieńkowska et al., 2022; Mercedes & Burell, 2022). EDCs are a vital determinant of job performance during a crisis for several compelling reasons, and that is why they are chosen as key drivers of job performance here. In times of crisis, such as natural disasters, economic downturns, or pandemics, the ability to adapt and learn quickly becomes paramount (Mercedes & Burell, 2022). Employees with strong dynamic capabilities excel in these situations, as they possess the skills and mindset to navigate unforeseen challenges effectively. They embrace change, innovate, and exhibit exceptional problem-solving abilities, all of which directly enhance their job performance (Al-Jubari, 2022; Tworek et al., 2023). Furthermore, EDC fosters resilience and stress management, essential attributes during a crisis (Fischer et al., 2023). In high-stress scenarios, employees with dynamic capabilities remain composed and focused, mitigating the risk of burnout and ensuring consistent job performance.

Their commitment to continuous learning and skill development equips them to rapidly acquire the expertise needed to address emerging crisis-related issues (Bieńkowska et al., 2022). This agility empowers employees to contribute proactively, uphold resource-fulness, and take the initiative in finding solutions. By cultivating a collaborative spirit and emphasising teamwork, employees with EDC foster an environment where collective efforts lead to effective crisis resolution (Klonek et al., 2022). This long-term perspective on organisational resilience makes EDC a critical factor in enhancing job performance during a crisis, and it ensures the groundwork for sustained success in the face of future challenges. However, it is crucial to consider also the indirect influence of EDC on job performance during a crisis.

1.4.1. P-J FIT AS A MEDIATOR BETWEEN EDC AND JOB PERFORMANCE DURING A CRISIS

One critical aspect that should be underscored pertains to the notion of person–job fit (P-J fit), which serves as a pivotal bridge connecting Employees' Dynamic Capabilities (EDC) with job performance. It is imperative to recognise that P-J fit is particularly vulnerable to shifts occurring within an organisation, especially during times of crisis. P-J fit comprises two fundamental components: the alignment between job demands and employee capabilities, signifying the extent to which job requirements correspond to employee competencies, and the alignment between employee needs and organisational provisions, reflecting the degree to which the work undertaken by employees caters to their individual requirements encompassing values, objectives, interests, compensation, benefits, and competency development (Muchinsky & Monahan, 1987; Edwards, 1991; Cable & DeRue, 2002). Amid a crisis, the organisation may undergo operational transformations that are incongruent with the individual needs of its employees, resulting in a sense of diminished control, heightened job insecurity, and increased stress among the workforce (Theorell et al., 1988; Bolino et al., 2010). The disruptive perturbations induced by organisational changes can compel employees to transition from a state of equilibrium, characterised by high P-J fit, to a state of disequilibrium (Lee & Mitchell, 1994; Chilton et al., 2010).

However, it is important to note that reestablishing a state of balance or high P-J fit among employees is possible, but the mechanisms for doing so during a crisis will differ from those used when employees are not forced out of their balance. This underscores the importance of considering factors that influence job performance during times of crisis, such as adaptive performance and Employees' Dynamic Capabilities (EDC). By doing so, organisations can better support their employees and help them adapt to changing circumstances, ultimately improving their job performance.

There are also some literature reports confirming the fact that job-related attitudes — a group of factors influencing job performance — may also be highly conducive to changes occurring in the organisation, but their role in various stages of crisis may differ significantly. The study will cover three job-related attitudes: work motivation, job satisfaction and work engagement, which appeared in the original model and have been verified as statistically significant elements of the JP-EDC model.

1.4.2. WORK MOTIVATION AS A MEDIATOR BETWEEN EDC AND JOB PERFORMANCE DURING A CRISIS

The functioning of an organisation during times of crisis is a challenging task for both employees and managers, as it greatly impacts the overall working atmosphere and work motivation (Závadský et al., 2015). Nevertheless, work motivation is a crucial factor in ensuring the organisation's survival (Wiradendi Wolor, 2020). During the initial stages of the crisis, employees need to remain vigilant and act appropriately in response to any early warning signs. As the crisis deepens, employees must continue to perform their work to the best of their ability despite the changing circumstances that may be increasingly detrimental to their work environment. Eventually, work motivation becomes the key factor in driving the recovery process, as employees need to make an extra effort to complete all the necessary tasks that ensure the continuity of the organisation's operations.

During times of crisis, there is a pronounced propensity for work motivation to diminish, presenting a formidable challenge for managers seeking to reignite it (Závadský et al., 2015). It is imperative to acknowledge that this holds true for both intrinsic and extrinsic motivation, two pivotal categories of work motivation (Tovmasyan & Minasyan, 2020). Intrinsic motivation originates from within oneself, often stemming from the sheer enjoyment of the work itself, while extrinsic motivation is externally driven, arising from factors such as compensation, recognition, and various rewards. In crisis contexts, both forms of motivation can be adversely affected, resulting in

a decline in employee work motivation. This decline in motivation is notably prevalent when employees are grappling with heightened stress levels associated with the fear of job loss and the challenges posed by performing their roles under altered conditions, thereby impacting their sense of security within the organisation (Závadský et al., 2015). Job insecurity is delineated as the "perceived powerlessness to maintain desired continuity in a threatened job situation" (Greenhalgh & Rosenblatt, 1984, p. 438), and it has been observed to be precipitated by exogenic crises occurring within the organisation (Adkins et al., 2001). Notably, such a conceptualisation of job insecurity elicits a profound sense of powerlessness and loss of control, which exerts a diminishing effect on work motivation (De Spiegelaere, 2014). This observation aligns with the enduring tenets of the Active Events Theory, which expounds that in organisations affected by crises, employee motivation experiences a decline due to the influence of negative events that have the potential to evoke negative emotions (Hobfoll, 1989; Weiss & Cropanzano, 1996).

Nailasari et al. (2021) underline that self-efficacy is key to obtaining intrinsic motivation in such conditions, and employees may be able to restore and sustain their motivation only by themselves, as it is the first step needed to translate it into their job performance. This proposition gains particular significance in light of the standard practice during crises, where many of the conventional motivators for employees are typically curtailed to minimise additional costs for the organisation, as elucidated by Závadský et al. (2015). In response to such constraints, managers endeavour to introduce motivational factors that do not necessitate supplementary financial investments, as emphasised by Hitka and Sirotiakova (2011). These measures may encompass alterations in internal communication, harnessing the latent knowledge resources within the organisation, and enhancing operational processes through a coaching framework (Hitka & Sirotiakova, 2011). Such actions underscore the increasing importance of intrinsic motivation and, consequently, exert an influence on the role that work motivation plays in shaping job performance. That is because maintaining intrinsic motivation and translating it into job performance may allow employees to use their various skills (including EDC, which is so important during a crisis). Hence, it seems that this job-related attitude should be treated as a key, allowing employees to actively use their EDC.

1.4.3. Job satisfaction as a mediator between EDC and job performance during a crisis

Crises caused by Black Swan events present a significant challenge due to their unpredictability and long-term uncertainty, as their duration is usually unknown. As a result, organisations often prioritise cost-minimisation strategies to survive in such conditions (Cao & Chen, 2016), making it challenging to meet employee expectations beyond financial compensation. This, in turn, adversely impacts their job-related attitudes, particularly job satisfaction. Since employee-centred actions that generate additional costs may not ensure the organisation's continuity and survival in the short term, they are often limited at the onset of the crisis. Consequently, several researchers (e.g., Markovits et al., 2014; Cahill et al., 2015; Green et al., 2016) contend that job satisfaction during a crisis is one of the most distorted job-related attitudes. There is a lot of coverage in the literature stating that job satisfaction is almost non-existent during various crisis stages, and, therefore, its potential role in allowing employees to use their EDC and translate it into job performance is debatable in every stage. The decrease in job satisfaction is caused not only by a negative assessment of the organisation by the employees who clearly see the negative effects of the recession (Markovits, 2014) but also by the uncertainty about the fact of whether it will ever change for the better. Some empirical research, e.g., conducted during the crisis in 2009, provided information that market conditions and the need to prevent job loss and resignation from promotions at work had the greatest impact on the reduction of job satisfaction (Markovits et al., 2014; Green et al., 2016). It is logical, as the increase in job insecurity as a factor reducing job satisfaction is often mentioned in the literature (Ashford et al., 1989; Sverke & Hellgren, 2002). However, contemporary literature shows that during a Black Swan phenomenon-driven crisis, not only job insecurity itself but even job instability, which is not necessarily translating into full job insecurity, may be a huge enough source of job satisfaction decline, disabling its ability to positively influence employee job performance (Nemteanu et al., 2021). It furthermore shows that a crisis may distort the level of job satisfaction and the relations of job satisfaction with other factors within the job performance model. It seems that this job-related attitude will lose its importance as a mediator between EDC and job performance, as

employees will be forced to fulfil their tasks despite its lack.

1.4.4. Work engagement as a mediator between EDC and job performance during a crisis

Numerous authors contend that the effects of a crisis on employee work engagement, particularly those brought about by a Black Swan event, are heterogeneous and not straightforwardly explicable (Sverke & Hellgren, 2002; Moshoeu & Geldenhuys, 2015) primarily because of the differing levels of employee identification with the organisation and their individual interpretation of the situation (Moshoeu & Geldenhuys, 2015). Furthermore, due to various factors affecting engagement (both positively and negatively), its impact on shaping job performance during different stages of a crisis may be the most volatile and visible. During the initial stage of the crisis, work engagement may diminish due to the first signs of crisis and the changing overall situation. Employees may be preoccupied with other aspects of their lives associated with the occurring Black Swan event and may not yet realise its effect on their work environment. However, during subsequent stages when the organisation faces the most turbulent and unpredictable changes and endeavours to respond to them, work engagement may be the key factor that enables employees to use their EDC to the benefit of the organisation, as they may perceive opportunities to advance their careers, maintain a stable job, and endure the crisis (Blaique et al., 2023).

The reaction of employees to a crisis, manifested through fluctuations in their work engagement, appears to be contingent not only on their work experience but also on their organisation's position (Greenhalgh & Rosenblatt, 1984). Most aspects pertaining to work engagement are notably intertwined with an employee's perceptions of it. For instance, literature corroborates that "in the midst of a crisis, when employees harbour concerns about job security and the potential loss of employment, they may struggle to fully engage in their work, given the accompanying sentiments of anxiety, anger, or frustration" (Bieńkowska et al., 2021; Wiesenfeld et al., 2001; Kiefer, 2005; Mauno et al., 2007; De Spiegelaere, 2014). However, alternative perspectives, as presented by authors such as Berg, Wrzesniowski, and Dutton (2010), posit that certain employees may interpret job reductions associated with the crisis as a challenge

necessitating heightened effort and increased efficiency to secure their retention within the organisation, consequently elevating the role of work engagement in shaping their job performance (Lu et al., 2014).

It is important to recognise that market conditions and the perception of organisational performance also exert a significant influence in this context. Employees may perceive that their heightened engagement, extra exertion, and enhanced productivity can diminish the likelihood of job loss, a source of considerable apprehension during economically challenging circumstances (Blaique, 2023; Moshoeu & Geldenhuys, 2015). Empirical studies validate the notion that employees within organisations grappling with crises intensify their work efforts, extending their working hours to underscore their value to the organisation (Moshoeu & Geldenhuys, 2015; Luthans & Youssef, 2007).

Consequently, it appears that the initial decline in work engagement and its role in shaping job performance during a crisis may transpire during the initial phase of the crisis (though this is not unequivocal). Subsequently, this job-related attitude assumes an especially pivotal role in moulding job performance during various stages of the crisis, with the potential to positively impact other job-related attitudes beyond job performance itself. It may function as a catalyst that enables EDCs to fully manifest into elevated job performance as employees begin to perceive an opportunity to surmount the crisis and recognise the indispensability of their work in ensuring organisational survival. Consequently, they intensify their engagement and endeavour to leverage their full range of competencies, of which EDCs are particularly vital, thereby potentially facilitating the organisation's recovery from the crisis.

1.5. Indirect influence of EDC on job performance during a crisis

Based on the above-mentioned literature review, it should be concluded that the role of EDC as a positive influence on job performance during various crisis stages is undeniable (Tworek et al., 2023; Bieńkowska et al., 2022; Mercedes & Burell, 2022). P-J fit should also be considered as a valid bridge between EDC and various job-related attitudes. However, the role of each job-related attitude will differ during various stages of crisis. Hence, the following hypotheses can be formulated:

H1: EDC influences job performance only through P-J fit and work motivation during the prodromal crisis stage.

H2: EDC influences job performance through P-J fit, work motivation, and work engagement during acute, chronic and resolution crisis stages.

H3: EDC influences job performance only through P-J fit and work motivation to the highest extent during the resolution crisis stage.

2. Research methodology

Empirical research was undertaken employing a questionnaire-based data collection method to validate the proposed hypotheses. The research commenced with a pilot study aimed at assessing the instrument's quality. This preliminary investigation involved 25 managers who acted as competent evaluators. Their feedback was instrumental in refining the research instrument employed in the primary phase, which entailed revising questions that were not adequately comprehended and mitigating the potential for common method bias. The primary survey was conducted during the first quarter of 2021 and encompassed 1160 organisations operating in Poland, Italy, and the USA. This survey took place amid the active wave of the COVID-19 pandemic, characterised by a surge in active cases and the implementation of various restrictions such as social distancing, travel limitations, and the adoption of remote work policies in most countries. This pandemic wave is often regarded as an illustrative instance of the Black Swan phenomenon, leading to crises in organisations operating across diverse countries globally. The questionnaire responses were obtained utilising the Computer-Assisted Web Interview (CAWI) method through the SurveyMonkey platform. Respondents were sourced from a purchased panel comprising high-level managers within organisations employing more than ten individuals. It is important to note that the questionnaire focused exclusively on organisational aspects and did not involve individual employees as respondents.

2.1. Sample selection

The sample of organisations for the study was purposefully selected and limited by the geographical scope of their activity (Poland, Italy, and the USA — countries that were severely hit by the COVID-19 pandemic and implemented restrictions that resulted in crises within organisations). It should be noted that not all organisations provided answers to all questions: 1160 respondents answered questions related to the occurrence of the crisis in the organisation induced by the COVID-19 pandemic, and only those organisations were chosen for the study sample. Despite the fact that the selection of organisations for the sample was not representative, it seems possible to formulate conclusions due to the diversity of the organisations included in the study and the fact that it included organisations which were not in crisis, which have not survived the crisis and those operating in various crisis staged.

The study assumed four stages of a crisis: the prodromal stage (when the crisis-causing event has already happened but the full-blown crisis has not started yet), the acute crisis stage (when there is a sudden onset of changes, most turbulent and unpredictable), chronic crisis stage (when the organisation is trying to respond to the crisis, which is still happening), and the resolution stage (when the organisation is returning to pre-crisis functioning). Based on that, the multigroup path analysis was performed. Therefore, the obtained sample of 1160 organisations was divided into six groups: organisations which were not in the crisis (not considered here), organisations which did not survive the crisis (not considered here), and organisations in 1st, 2nd, 3rd, and 4th stage of crisis according to the above-mentioned differentiation. Table 1 includes the sample characteristic, showing the number of organisations operating in each country in various stages of crisis. The questionnaire was filled in by higher-level managers (as respondents), but no metrics concerning the respondent were gathered, as all questions concerned the organisation as a whole.

Tab. 1. Research sample characteristic

Country	Not in crisis	1st stage	2nd stage	3rd stage	4th stage
Poland	81	75	124	121	25
USA	70	120	212	85	14
Italy	72	94	44	17	6
Total	223	338	377	127	38

Therefore, only metrics concerning organisations as a whole were gathered.

2.2. Variables — scales reliability and validity

The following variables were used to verify the hypotheses: EDC, P-J fit, work motivation, job satisfaction, work engagement, and job performance.

Employees' Dynamic Capabilities (EDC) were evaluated through a set of six items that encompassed sensitivity to environmental changes, adaptability to environmental shifts, problem-solving abilities in the workplace (including workplace innovation), and the capacity for continuous personal development.

The Person–Job Fit (P-J Fit) was gauged using a 5-point Likert scale with three items that focused on the alignment between employee knowledge, skills, abilities (including talent), and job requirements.

Work Motivation was quantified on a 5-point Likert scale with three items, which revolved around the willingness and readiness of employees to fulfil assigned tasks, including their willingness to exert extra effort.

Job Satisfaction was assessed on a 5-point Likert scale with three items, which measured employee attitudes towards their job, encompassing aspects such as happiness and the intention to remain in their current employment.

Work Engagement was evaluated using a 5-point Likert scale with three items, which examined employee attitudes towards their job, including their enthusiasm and the depth of their immersion in their work.

Job Performance was quantified based on a 5-point Likert scale, employing a set of seven items that measured task proficiency, task meticulousness, and work discipline.

To address the issue of the crisis stage, to variable was included, in which organisations were asked whether the COVID-19 pandemic caused a crisis within the organisation, which needed to be addressed by changing the way of their operations (and introducing virtual mode of operations) and if so, in which crisis stage the organisation is currently operating (the prodromal, acute, chronic or resolutions stage).

To be able to assess whether the discussed scales can be used in the study, Cronbach's α (CA value) and the Confirmatory Factor Analysis (AVE and CR values) were performed (Table 3). This approach seems to be sufficient because the scales used have been previously validated by the creators. The obtained results were sufficient to use the given variables in the study, as most CA values were above 0.7 and in the cases in which it was lower, the AVE value remained above 0.5, and the CR value remained above 0.7. Similarly, in the case of EDC, the AVE value remains close to 0.5, which is enough, together with a high CA value and satisfactory CR value (above 0.7). The systematic method variance was controlled to ensure no common method bias was observed. The Harman's Single-Factor Test was performed in IBM SPSS, using the Dimension Reduction Procedure. Incorporating all variables into the Confirmatory Factor Analysis with a predetermined number of factors (i.e., one), it was observed that these variables collectively accounted for 32 % of the variance. The outcomes derived from this analysis provide substantial support for the adequacy, reliability, and internal consistency of the measurement scales. Furthermore, to establish discriminant validity and ascertain that latent variables representing distinct theoretical constructs are statistically distinct, all Heterotrait–Monotrait (HTMT) values were below 0.68. This finding affirms the suitability of the selected variables for the subsequent path analysis.

Tab. 2. Variables overview

Variable	Items	CA	AVE
Satisfaction (Satisf)	3	0.630	0.576
Motivation (Motiv)	3	0.714	0.637
Work engagement (WrkEng)	3	0.714	0.636
Job performance (JobPerf)	4	0.753	0.577
Person — job fit (PJfit)	3	0.585	0.547
EDC (EDC)	8	0.843	0.478

2.3. Multigroup Path analysis

The variables' scales analysis was used to show that they meet all the criteria for the path analysis. To make sure that the results may be a basis for forming conclusions, the model was at first controlled for variables connected with the organisation as a whole (based on the Leavitt Diamond organisation model), showing that the model is valid for all types of conditions within the organisation (using linear regression performed using IBM SPSS).

Next, the path analysis was done, and the well-fitted and statistically significant model was created using IBM SPSS AMOS. The fit of the model was measured first and assessed with CFI (sufficient values above 0.8) and RMSEA (sufficient values below

Tab. 3. Total and indirect effects in the model for the prodromal stage of crisis

1ST STAGE	EDC		PJFIT		SATISF		MOTIV		WRKENG	
	t.e.	id.e	t.e.	id.e	t.e.	id.e	t.e.	id.e	t.e.	id.e
PJfit	.653	.000	.000	.000	.000	.000	.000	.000	.000	.000
Satisf	.368	.368	.563	.000	.000	.000	.000	.000	.000	.000
Motiv	.309	.309	.473	.000	.000	.000	.000	.000	.000	.000
WrkEng	.316	.316	.483	.000	.000	.000	.000	.000	.000	.000
JobPerf	.184	.184	.281	.281	.049	.000	.341	.000	.192	.000

Tab. 4. Total and indirect effects in the model for the acute stage of crisis

2ND STAGE	EDC		PJFIT		SATISF		MOTIV		WRKENG	
	t.e.	id.e	t.e.	id.e	t.e.	id.e	t.e.	id.e	t.e.	id.e
PJfit	.598	.000	.000	.000	.000	.000	.000	.000	.000	.000
Satisf	.306	.306	.512	.000	.000	.000	.000	.000	.000	.000
Motiv	.283	.283	.474	.000	.000	.000	.000	.000	.000	.000
WrkEng	.325	.325	.544	.000	.000	.000	.000	.000	.000	.000
JobPerf	.187	.187	.313	.313	.218	.000	.240	.000	.162	.000

Tab. 5. Total and indirect effects in the model for the chronic stage of crisis

3RD STAGE	EDC		PJFIT		SATISF		MOTIV		WRKENG	
	t.e.	id.e	t.e.	id.e	t.e.	id.e	t.e.	id.e	t.e.	id.e
PJfit	.628	.000	.000	.000	.000	.000	.000	.000	.000	.000
Satisf	.328	.328	.523	.000	.000	.000	.000	.000	.000	.000
Motiv	.353	.353	.562	.000	.000	.000	.000	.000	.000	.000
WrkEng	.321	.321	.512	.000	.000	.000	.000	.000	.000	.000
JobPerf	.219	.219	.349	.349	.147	.000	.301	.000	.201	.000

Tab. 6. Total and indirect effects in the model for the resolution stage of crisis

4TH STAGE	EDC		PJFIT		SATISF		MOTIV		WRKENG	
	t.e.	id.e	t.e.	id.e	t.e.	id.e	t.e.	id.e	t.e.	id.e
PJfit	.707	.000	.000	.000	.000	.000	.000	.000	.000	.000
Satisf	.466	.466	.659	.000	.000	.000	.000	.000	.000	.000
Motiv	.515	.515	.729	.000	.000	.000	.000	.000	.000	.000
WrkEng	.392	.392	.555	.000	.000	.000	.000	.000	.000	.000
JobPerf	.356	.356	.504	.504	.026	.000	.516	.000	.262	.000

Tab. 7. Regression weights for the prodromal stage of crisis

	1ST STAGE		ESTIMATE	S.E.	C.R.	P
PJfit	<---	EDC	.758	.066	11.531	<.001
WrkEng	<---	PJfit	.480	.064	7.453	<.001
Motiv	<---	PJfit	.537	.074	7.214	<.001
Satisf	<---	PJfit	.598	.065	9.183	<.001
JobPerf	<---	WrkEng	.194	.071	2.717	.777
JobPerf	<---	Motiv	.300	.062	4.823	<.001
JobPerf	<---	Satisf	.046	.067	.686	.493

Tab. 8. Regression weights for the acute stage of crisis

	2ND STAGE		Estimate	S.E.	C.R.	P
PJfit	<---	EDC	.628	.046	13.632	<.001
WrkEng	<---	PJfit	.598	.051	11.805	<.001
Motiv	<---	PJfit	.518	.053	9.841	<.001
Satisf	<---	PJfit	.553	.051	10.886	<.001
JobPerf	<---	WrkEng	.136	.044	3.090	.322
JobPerf	<---	Motiv	.203	.044	4.633	<.001
JobPerf	<---	Satisf	.186	.045	4.166	.532

Tab. 9. Regression weights for the chronic stage of crisis

	3RD STAGE		Estimate	S.E.	C.R.	P
PJfit	<---	EDC	.644	.041	15.642	<.001
WrkEng	<---	PJfit	.629	.054	11.560	<.001
Motiv	<---	PJfit	.684	.052	13.234	<.001
Satisf	<---	PJfit	.575	.048	11.922	<.001
JobPerf	<---	WrkEng	.152	.037	4.153	<.001
JobPerf	<---	Motiv	.230	.037	6.179	<.001
JobPerf	<---	Satisf	.124	.041	3.023	.003

Tab. 10. Regression weights for the resolution stage of crisis

	4TH STAGE		Estimate	S.E.	C.R.	P
PJfit	<---	EDC	.753	.068	11.153	<.001
WrkEng	<---	PJfit	.677	.090	7.493	<.001
Motiv	<---	PJfit	.852	.072	11.906	<.001
Satisf	<---	PJfit	.779	.079	9.833	<.001
JobPerf	<---	WrkEng	.206	.059	3.467	<.001
JobPerf	<---	Motiv	.424	.066	6.427	<.001
JobPerf	<---	Satisf	-.021	.064	-.324	.746

0.2). The obtained model was statistically significant and well-fitted: Chi2 (91) = 953.663; p = 0.001; CFI = 0.836 (AGFI = 0.898); RMSEA = 0.088. Hence, it can be established that the comparative fit index (including the adjusted goodness of fit index) is sufficient to form conclusions based on the obtained model, and the RMSEA shows a very good fit in the model (showing a more than satisfactory level of badness of the model).

Total and indirect effects occurring in the model for each stage of crisis are presented in Tables 3–6. The overview of the obtained model for each of the crisis stages (regression coefficients) is presented in Tables 7–10.

The obtained results allow the forming of conclusions, which may be a base not only for the verification of developed hypotheses but also for formulating the overall conclusions. At the very beginning, in general terms, it should be noted that — as predicted

— in each phase of the crisis, the shape of the EDC-JP model is different than in the initial model (Bieńkowska & Tworek, 2020), which was used as a base. To elaborate, not only does the strength of the effects change within the model for each stage of crisis, but also the shape of the model (set of mediators included in the model) changes for each of them.

In the context of the assumed hypotheses, it should be stated that first, the obtained model shows that work motivation is a statistically significant mediator among organisations from all stages of the crisis. Second, its mediating effect is the highest in the resolution stage. Third, the results show that work engagement is a statistically significant moderator in the case of acute, chronic and resolution stages. Those most important results may also be amended as the P-J fit is a statistically significant mediator, which allows EDC to translate into job performance through those job-related attitudes in all stages of a crisis,

which shows that the shape of the JP-EDC model is not entirely different from the model obtained for normal conditions. Hence, based on the results, the H1-H3 should be accepted, stating that:

• The EDC influences job performance only through P-J fit and work motivation during the prodromal crisis stage.
• The EDC influences job performance through P-J fit, work motivation, and work engagement during acute, chronic and resolution crisis stages.
• The EDC influences job performance only through P-J fit and work motivation to the highest extent during the resolution crisis stage.

3. DISCUSSION

The results show definite differences between models for each stage of the crisis. The prodromal crisis stage (Fig. 2) is a moment in which the first signals arrive, and employees start to realise that a Black Swan event occurred and it has the potential to severely influence the organisation; it is characterised by the lack of work engagement and job satisfaction in the model. It shows that EDC can influence job performance (hence, be actually used by employees) through work motivation, which (besides P-J fit) is the only job-related attitude which is a significant mediator in this stage. It is consistent with the assumptions showing that it allows employees to stay alert and act appropriately during the initial signals of a crisis. They are capable of that in given conditions (EDC is enabling it through P-J fit) and also full of energy (the influence of work motivation, which is boosted by maintaining the ability to work even though the circumstances are tough). Such influence of work motivation on job performance during a crisis is underlined, e.g., by Wiradendi Wolor et al. (2020), and the results seem to confirm their findings. Moreover, the results show that work motivation allows employees to boost their job performance using EDC, which enables them to track crisis signals and start acting based on them. It also confirms that job satisfaction and work engagement are losing their relevance, as employees tend to be occupied with the actual Black Swan event and its negative influence on their lives (outside of work). It is hard to expect that job satisfaction and work engagement will be sustained in the face of a deep crisis as both of these categories require action over a longer period of time than motivation. Another issue is the effect of motivation on work engagement and satisfaction, described, among others, by Kuligowski et al.

(2021), stating that work motivation has by far the most intrinsic nature among all job-related attitudes.

In the acute stage (Fig. 3), which is a moment in which sudden changes start within the organisation and are mostly unpredictable and turbulent, the role of work engagement becomes relevant again as it mediates the influence of EDC on job performance. Work motivation is the mediator, having the highest mediating effect in the model; however, it is no longer the only job-related attitude in the model. It is important to underline that motivated and engaged employees have more potential to properly use EDC to boost job performance at this stage. It further develops the conclusions of Moshoeu and Geldenhuys (2015) and Arifin et al. (2019), who stated that work engagement has the potential to positively influence not only the job performance itself during the crisis but also act as a booster allowing, e.g., EDC to fully translate into higher job performance. The study by Berg, Wrzesniowski, and Dutton (2010) accurately posited that employees often perceive a crisis as a unique challenge, compelling them to exert greater effort. Furthermore, this heightened effort corresponds to an augmented emphasis on work engagement. This observation underscores the profound influence of crisis situations on employee motivation and their active involvement in their work, aligning with the insights provided by the aforementioned authors.

The chronic crisis stage (Fig. 4), which is the moment when an organisation is trying to respond to the crisis, is characterised by the fact that all three job-related attitudes are becoming important in the model. Hence, the results go even a step further than assumed hypotheses (which covered only work engagement active role), showing that even job satisfaction becomes an important mediator, allowing EDC to translate into job performance (even though its effect in the model is the lowest). It may confirm the views of Markovits (2014), underlining that the role of job satisfaction during a crisis in an organisation is heavily distorted. The results show the need to analyse this stage of crisis further, determining the role of job satisfaction in the process of translating EDC into job performance.

In the resolutions stage (Fig. 5), which is happening when the organisation is starting to return to its normal functioning, the role of work motivation as a key to recovery is clearly visible. The mediation effect is not only the highest in the case of this stage (compared to other stages, as assumed in the developed hypothesis), but it is also the strongest mediator in that particular model (stronger than work engagement). This seems to be consistent with the fact that, in this
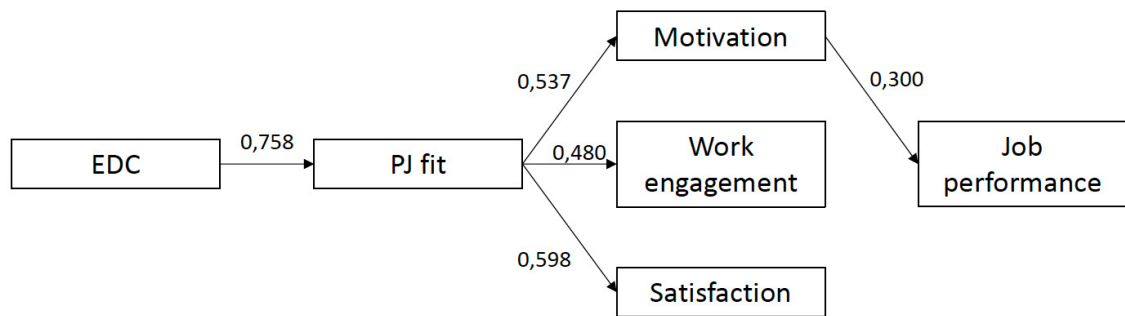
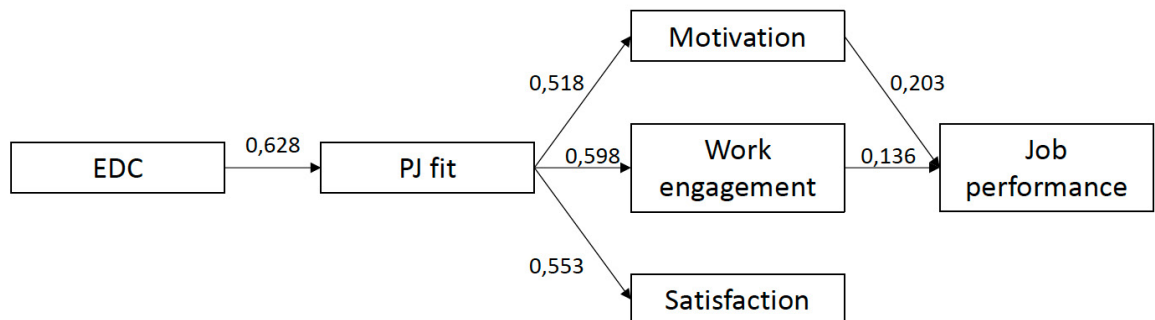Fig. 2. JP-EDC model in the prodromal crisis stage
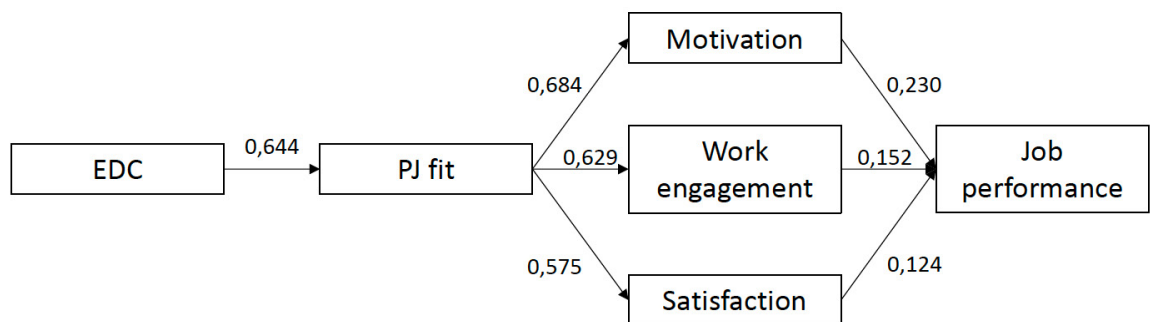

Fig. 3. JP-EDC model in the acute crisis stage

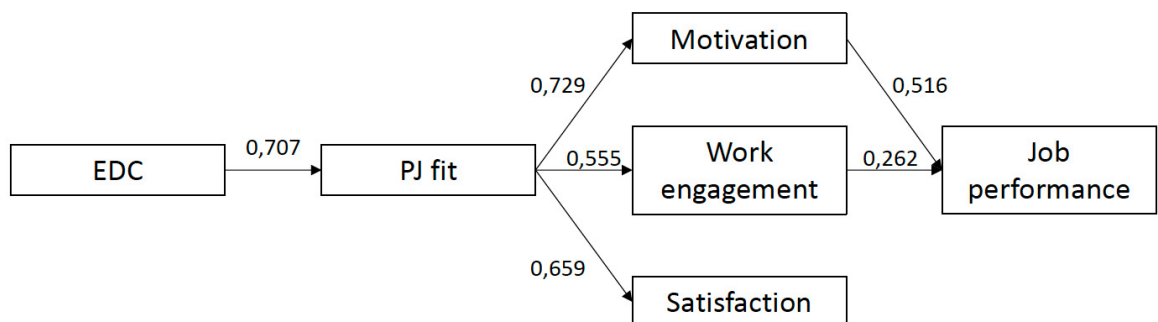Fig. 4. JP-EDC model in the chronic crisis stage

Fig. 5. JP-EDC model in the resolution crisis stage

stage, employees need to make an extra effort to finalise all the tasks aimed at continuity assurance. The model also confirms that work engagement is still relevant at this stage. This observation expands upon the perspectives outlined by Moshoeu and Geldenhuys (2015), lending support to their assertion that employees may perceive heightened engagement in their work, increased effort, and enhanced productivity as potential strategies for mitigating the risk of job loss. This, in turn, can foster a sense of alignment with the organisation's efforts to navigate and overcome the crisis. In essence, the findings corroborate the idea that employees view their proactive contributions as a means to collectively weather the crisis alongside the organisation as it begins to surmount the challenges posed by the crisis.

Conclusions

The research results allowed for confirming the indicated hypotheses and verifying the JP-EDC model in four stages of a crisis, i.e., the prodromal, acute, chronic, and resolution stages, identifying the role of P-J fit, work motivation, job satisfaction, and work engagement in boosting the job performance through EDC during a crisis, which fulfilled the aim of the article. It is worth underlining that the COVID-19 pandemic was used in the empirical research as an example of a Black Swan event, and the discussion formed based on a much broader literature review (intentionally not limited to studies concerning the COVID-19 pandemic) and those empirical research results allow for obtaining relevant conclusions for organisations operating in any crisis caused by a Black Swan event.

The research showed that the role of work motivation, job satisfaction and work engagement is distorted among organisations operating in a crisis, and the role of each of those job-related attitudes changes from stage to stage of a crisis. P-J fit and work motivation were verified as significant mediators allowing employees to boost their job performance through their EDC. It shows that organisations should make an extra effort to maintain their employee work motivation during the crisis. Moreover, work engagement was verified to be an important mediator boosting job performance because of the use of EDC, showing that the engagement among employees allows them to use their skills while responding more efficiently to the existing crisis (its role was not significant with the prodromal stage). It shows that during those stages, organisations should

also put an emphasis on maintaining work engagement among employees. Most importantly, the overall results confirm the importance of EDC in shaping the job performance of employees during all stages of a crisis.

The results of this study wield significant and conspicuous implications for the existing body of knowledge within the fields of management and quality sciences. In the realm of fundamental research, this paper contributes by offering a novel multivariate model of Job Performance based on EDC, specifically tailored for organisations grappling with crises precipitated by the Black Swan phenomena. This expansion augments the understanding of the crisis theory. From a practical standpoint, the findings hold particular importance as they facilitate the development of strategies aimed at preserving job performance across various phases of exogenic crises. Additionally, these results provide valuable insights that can aid organisations in effectively navigating and surviving such crises. This is especially crucial during crises induced by Black Swan events, during which organisations are often caught unprepared, and any guidance that steers them toward survival assumes paramount significance. In the contemporary landscape, organisations are confronted with the imperative to endure exceptionally adverse conditions resulting from a diverse range of Black Swan events, such as the COVID-19 pandemic and conflicts. These events exert a profound impact on organisational functionality, underscoring the critical need for guidance that can influence their survival prospects.

The study has some limitations, as it was performed based on a sample of organisations operating in three countries, and it is not a representative sample for them; however, it is diverse enough to allow for overall conclusions. Moreover, shortened versions of measurement scales were used for some job-related attitudes due to the need to use a 100-item questionnaire. However, the testing revealed that the chosen scales were good enough for the statistical analysis.

The results also show the future direction of research, which should be connected with a more detailed analysis of the role of EDC in shaping not only job but also organisational performance in various stages of a crisis.

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BEHAVIOURAL MIMICRY OR HERD BEHAVIOUR OF GENERATION Z? SOCIAL MEDIA INTERACTIONS IN THE CONTEXT OF INFORMATION OVERLOAD

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A B S T R A C T

The article aimed to examine the relationship between Generation Z's interactions on social networking sites in the context of herd behaviour and behavioural mimicry through central and peripheral content processing pathways. The study was conducted using the CAWI method on a group of 142 representatives of Generation Z from selected universities in Poland. Nonparametric tests were used for statistical analyses. In the case of information overload, approximately 20 % of respondents' interactions on different social media platforms may result from behavioural mimicry and herd behaviours. This type of activity is influenced primarily by the observed number of interactions and the emotional nature of other users' reactions. The observed differences are determined by gender, the type of social media platform, and related content specificity. Research limitations result from the specificity of the research sample in the context of its homogeneity and size. The theoretical contribution is related to the development of the cognitive-emotional-behavioural theory of memes about the imitation of interactions of social media users' conditioned herd behaviour and behavioural mimicry. The novelty of the research lies in the application of the theoretical Elaboration Likelihood Model approach to the analysis of herd behaviour and behavioural mimicry in the context of research on the cognitive, emotional, and behavioural activities of various social media platform users.

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INTRODUCTION

Social media interaction is any connection between different user types on a social networking site (SNS), expressed as a numerical indicator of user attitudes towards the shared content (Stavrositu & Kim, 2014). Interactions, including likes, comments, shares, tags, and profile following, are perceived as specific "social media virality metrics (SMVM)", informing viewers of how other people have reacted to the media content (Park & Jung, 2023). Such interactions can be determinants of a brand's success in social media communication

activities (Lauron, 2023). In peer-to-peer relations, the reactions could also be perceived as specific "digital social evaluation" (Fatt & Fardouly, 2023). In the realm of SNS presence, the primary motivation behind content creation is the desire to reach a broad audience (Müller & Christandl, 2019) and elicit a substantial number of interactions. The absence of reactions can potentially heighten the stress levels of individual content creators (Haug et al., 2024). For brands, it may signify a lack of interest in the content (Kohli et al., 2015), indicating the ineffectiveness of brand marketing communication activities in social media channels.

Popular content generates a high level of interaction, which may result, among other things, from the phenomenon of herd behaviours (Sun, 2013) or behavioural mimicry (Chartrand & Bargh, 1999) as a specific "social glue" in the context of creating relationships. Cialdini et al. (1991) suggested that if a particular action (behaviour) is common, there are real and substantive reasons to behave in a particular way. This approach may result from the social learning theory (Bandura & McClelland, 1977), which maintains that human activity is conditioned by observation and imitation of the behaviours of others. Observation, in turn, is conditioned by the perception of other user interactions in a digital media environment (Bandura, 2001).

Based on Chung et al. (2020), in the universally understood virtual space, which includes the space of social media, individual users learn specific behaviours from each other. As mentioned by Cracco et al. (2018), imitation can be understood as a way to achieve positive consequences, including social ones, by the imitator. The specific "positivity" of the consequences arises from the suggestion put forward by Conte (2000), according to which people are not vectors of cultural transmission but actors who drive this process.

In this context, it can be assumed that high content popularity represented by a single post and its specific reactions most likely result from the observed high number of interactions. Thus, their increase may be determined not so much by the substance of the post but by its popularity (Chang et al., 2020). In this case, the interactions associated with the post can refer to imitating the behaviour of others without delving into the content of the post itself. This type of dependency can be highly probable, especially from the perspective of fan pages with many followers and the presence of multiple and varied digital relations with peers or brands and digital communities. In such circumstances, content recipients are functioning under conditions of information overload (Jacoby et al., 1974) and attention economy (Menczer & Hills, 2020).

This is particularly interesting from the viewpoint of multiple interactions between Generation Z groups operating on SNS, where disseminated content can influence several behaviour types of information recipients, and the behaviour of individual users. Both behavioural mimicry and herd behaviours can be perceived as one, although the latter involves a declaration of rejection of one's own preferences in favour of the choices of other users.

Bearing in mind the fact that recipients sometimes disregard their own beliefs and imitate the behaviour of others (Whelan et al., 2013), an interesting research problem would be to relate imitation behaviour to the theory of behavioural mimicry and herd behaviour to the central and peripheral routes (Petty & Cacioppo, 1986), ways of processing shared content in the context of the observed number of interactions.

The article aimed to identify the phenomenon of behavioural mimicry and herd behaviours related to the imitation of specific SNS user interactions under conditions of information overload and the economy of user attention. Due to the specific nature of Generation Z (Levickaitė, 2010; Herman et al., 2021; Krippes et al., 2024; Graczyk-Kucharska & Erickson, 2020), who, unlike previous generations, are perceived as "digital natives" (Smith, 2017), the study included this group.

The paper consists of separate sections. The literature review offers an extensive overview of theories related to social media content and user interactions in the context of behavioural mimicry and herd behaviours. This section culminates in presenting research questions and outlining specific objectives. Then, the methodological part provides detailed insights into the research methods. The results section presents the research findings. The subsequent section discusses the results and their practical and theoretical implications of SNS behavioural mimicry and herd behaviours, particularly in the context of memetic imitation theory. The need and areas for further research were also highlighted. The conclusion section discusses and summarises the most important findings from the study and describes the examination limitations, along with concluding explanations and remarks.

1. Literature overview

1.1. Social media content and user interactions

The functionalities of social media platforms provide users with a broad spectrum of options for content creation and dissemination. Social media content may take the form of User Generated Content (UGC), created by individual users and representing their unique experiences (Fu et al., 2015). It could also be Marketer Generated Content (MGC), directly or indirectly associated with a specific brand or product (Qian et al., 2022) created and shared by businesses or other commercial and non-commercial entities. The primary motivation behind content creation is the desire to reach a broad audience (Müller & Christandl, 2019) and elicit a substantial number of reactions. Thus, the obtained reactions could be perceived as a specific "digital social evaluation" (Fatt & Fardouly, 2023). The absence or low level of interactions, defined as "paralinguistic digital affordances" (Hayes et al., 2016), particularly in UGC, can potentially heighten the stress levels of content creators (Haug et al., 2024). It could also be perceived as a lack of social support (Wohn et al., 2016).

The reactions are directly connected with content popularity, measured by the volume of specific metrics such as likes, comments, and shares (Vandenbosch et al., 2022). The metrics are related to cognitive (i.e., connected with content consumption and assimilation of specific knowledge resulting from content processing), affective (referring to the usually emotional effect triggered by the assimilation of knowledge/ideas arising from content and externalised through likes or dislikes in various graphical forms depended on a platform), and behavioural user activities externalised through comments and shares. Such a typology of activities is based on the AIDA model of consumer behaviour (Strong, 1925). The model was the core for other models related to web content consumption, i.e., AIDAT (Attention, Interest, Desire, Action, Tell; Charlesworth, 2012) and COBRA (Muntinga, 2013), which is based on the level of consumption of the shared content without distinction of the affective stage, indicating the lowest level of content consumption (viewing and reading), a moderate level of content consumption (commenting), and the highest level of contribution, which refers to creating and sharing user-generated content (UGC).

1.2. Information overload and attention economy

Information overload is a recipient's condition caused by too much information (Jacoby et al., 1974). Information overload, next to communication overload (i.e., too frequent occurrence of communication episodes), is one of the elements of universally understood technological overload (Karr-Wisniewski & Lu, 2010), which significantly reduces the individual's productivity and reduces the ability to properly process the message. Information overload combined with system function overload (a factor related to the presence of too many complex software functions in the context of user needs) are key elements contributing to emotional exhaustion and social media fatigue (Sheng et al., 2023) and causing user dissatisfaction (Zhang et al., 2016).

Similarly, Cao et al. (2021) indicate that information overload from a cognitive–emotional–behavioural perspective may generate recipients' lack of independent thinking and the resulting unfavourable socio-economic consequences and contributes to the excessive and uncontrolled spread of fake news (Zhang & Ghorban, 2020). Therefore, user attention is a factor for which different information sources compete in the context of the attention economy (Menczer & Hill, 2020).

A way to reduce the inability to consume excess content may be the phenomenon of behavioural mimicry, i.e. imitating the behaviour of known and trusted people, i.e., influencers (Geyser, 2022), or peers. This happens when content feels valuable because of shared experiences or represented views (Modgil et al., 2021; Sasahara et al., 2021).

1.3. Behavioural mimicry, herd behaviours, and SNS

Mimicry is an individual's interaction with others through observing and imitating attitudes, expressions, and behaviours (Stel & Vonk, 2010). Mimicry occurs in a variety of contexts and situations, e.g., in face-to-face interactions (Chartrand & Bargh, 1999). From the perspective of social media, mimicry may involve, among others, user willingness to imitate the lifestyle and behaviours of online idols (Ruvio et al., 2013). From the perspective of mimicry itself, the emotions of message recipients result from imitating the sender's statements (Hatfield et al., 2011). As suggested by Harringan et al. (2012), SNS users build and strengthen mutual relationships by

interacting with others and sharing knowledge. Users imitate not only themselves but also the behaviour of virtual avatars (Fasya et al. (2024). In the context of the spread of offensive speech, Song et al. (2022) proposed four mechanisms related to imitating interactions: general reciprocity, direct reciprocity, leader mimicry, and peer mimicry related to mutual imitation of the behaviour of others.

Flores and Hilbert (2023) analysed microblogs and showed that from the perspective of shares, negative emotions are imitated in information cascades. Luo et al. (2023) showed that the greater the popularity of the shared content in the Q&A community, the greater the likelihood of imitating the author's linguistic style. Similarly, Fleck and Quester (2007) and Xu et al. (2022) showed the influence of the cognitive-emotional factor, which may contribute to imitating both the language of the message and its emotional nature.

Of course, imitation of behaviour can also take the form of herd behaviour, where users, despite having different views or opinions, may react similarly to the majority (Sun, 2013). From this perspective, Mattke et al. (2020) showed that only "likes" from well-known users or those who are perceived as knowledgeable users (i.e., perceived as experts) can generate similar intentions to click. Tan and Cousin (2016) pointed out this type of dependency in Weibo comments. Ahmad (2023) also confirmed this mechanism in the case of sharing content.

1.4. Theoretical framework

Therefore, in the context of the cognitive–emotional–behavioural models indicated above, user actions may take the following form (individual or in combination with others):

- Cognitive, relating to the acquisition of knowledge (Kowalczyk-Purol, 2015), e.g., associated with shaping public opinion on various aspects of social life (Firth et al., 2019).
- Affective, referring to the usually subconscious emotional effect produced by acquiring knowledge and influencing behaviour (Zhang et al., 2024).
- Behavioural, linked to behaviour patterns based on the assimilated message (Sun et al., 2024).

The above considerations fit directly into the elaboration likelihood model (ELM, Petty & Cacioppo, 1986; Bhattacherjee & Stanford, 2006), which constitutes the theoretical framework of the study. In this model, peripheral (affective) and central (cognitive) signals (cues) may be responsible for the development of a specific activity. Affective signals accompanying the message are processed superficially and peripherally (i.e., without direct consumption of the content). From a central perspective, emerging behaviours are related to direct consumption and holistic processing of content. It was assumed that behavioural mimicry and herd behaviours are related to the peripheral route and involve the development of imitative behaviours related to generating interactions in response to shared content without delving into the substance of the content (Chang et al., 2020).

With the above in mind, the following research questions were stated:

RQ1: From the perspective of content shared on SNS, can the phenomenon of imitation of behaviours be observed through behavioural mimicry or herd
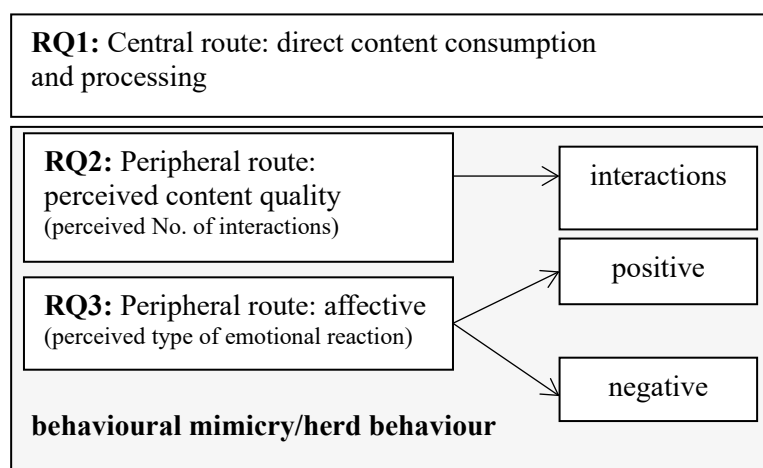

Fig. 1. Theoretical framework of the study

behaviours and related to generating interactions without consuming the content?

RQ 2: How does the number of reactions prompt users to behavioural mimicry or herd behaviours without delving into the content of the shared content?

RQ3: Which of the interactions of varied emotional nature — likes, comments, or shares — most often influence the occurrence of behavioural mimicry and herd behaviours?

A graphical representation of the research questions is shown in Fig. 1.

2. Methods

2.1. Participants

The target group consisted of bachelor's and master's students (n=143) from Bialystok (Bialystok University of Technology — PB; n=69), Rzeszów (Rzeszów University of Technology — RUT; n=46) and Krakow (Krakow University of Economics — KUE; n= 25). Single surveys were received from Poznan (Poznan University of Economics — UEP; n=2) and Warsaw (Warsaw University of Life Sciences — WULS; n=1). Respondents were identified through purposive sampling (Davies et al., 2024). One respondent from PB refused to indicate their gender; therefore, this questionnaire was omitted from the statistical analyses. The number of responses was significantly lower than the number of people who were given both forms to access. From the point of view of respondents from PB and RUT, the number of responses represented approximately 40 % of the total number of invited respondents. For KUE, it was about 20 %. In turn, for PUE and SGGW, this value was below 5 %. The survey ensured complete anonymity, as it included no questions allowing respondents to be identified by name, nationality, specific age, or contact information. Consequently, it was determined that the act of completing and returning the survey would, in itself, imply consent to participate in the study (Trinity College Dublin, 2024). Data was collected in March and April 2024.

2.2. Research procedure

The CAWI (Computer Assisted Web Interview) technique was used to collect data. The research tool was a survey generated in Google Forms and made available to respondents thanks to the kindness of lecturers from the universities indicated above. The form was made available as a QR code or a direct link to the survey. The questionnaire consisted of four parts (Table 1).

2.3. Data processing and analysis

Basic descriptive statistics were calculated for each of the analysed variables, i.e., mean and standard derivation (SD). Normality tests for each variable were performed using the Shapiro–Wilk (W) test. The reliability of individual questionnaire items was calculated using the Cronbach's Alpha coefficient. It is assumed that α values ≥ 0.7 are satisfactory (George & Mallery, 2016) and determine the appropriate coherence of the research tool.

During the initial processing of the collected data, four main social media platforms used by respondents were identified, i.e., Instagram (INST), TikTok (TT), Facebook (FB), and X (former Twitter). Those that were indicated sporadically (including Discord, Reddit, and YouTube) are grouped into a common category (Other).

From the perspective of the research questions presented above, it was assumed that although most respondents declare behaviours related to the central route (CR), some of them will declare behaviours related to the peripheral route (PR). Therefore, a linear relationship was assumed between PR and the number of interactions (RQ2), and PR and the emotional nature of these interactions (RQ3).

To establish a statistically significant relationship between reporting of herd behaviour (PR3a)/behavioural mimicry (PR3b) in the context of the number of observed interactions (PR3c) and from the perspective of the most frequently used platform, Spearman's correlation analyses were performed. A similar relationship was analysed in the context of RQ3 for the variables PR3a/PR3b versus PR4a-PR4h. Spearman's nonparametric correlation coefficient is widely used in social networking exploratory data analysis (Xiao et al., 2016). The following scale was used for interpreting Spearman coefficients: $0.0 \leq |\rho| \leq 0.2$ — a lack of correlation; $0.2 < |\rho| \leq 0.4$ — weak correlation; $0.4 < |\rho| \leq 0.7$ — average correlation; $0.7 < |\rho| \leq 0.9$ — strong correlation; $0.9 < |\rho| \leq 1.0$ — a very strong correlation.

Statistical analyses were conducted separately for each platform using the Statistica 13.3 software. The collected data and analyses were deposited in the Mendeley Data repository. ChatGPT 3.5 was used for final language corrections.

Tab. 1. Structure of the research tool (questionnaire)

GROUP OF VARIABLES	VARIABLES	SOURCE
demographics	• age (A1a); • sex (S1b); • mostly preferred SM platform (choose one: Instagram, Facebook, TikTok, YouTube, other; P1c); • city of studying (C1d)	Mattke et al. (2020), modified;
statements referred to the central route (CR2) of content consumption and processing	• I leave the emotional reaction (I like/dislike) only after reading the content of the post (CR2a); • I comment only after reading the content of the shared post (CR2b); • I share the post only after reading its content (CR2c)	Petty and Cacioppo (1986); Bhattacherjee and Stanford (2006); Charlesworth (2012); Muntinga (2013)
statements referred to the peripheral route (PR3) of content consumption and processing from the perspective of the perceived number of interactions	• being active in the virtual space, sometimes I react to shared content like most reacting users, even though I have a different opinion on a given topic (PR3a); • sometimes, I react to shared content without reading it, in the same way that most of the reacting users did (PR3b); • if a shared post causes many reactions (likes, comments, shares), sometimes I also react this way without going into the content of the post (PR3c)	Petty and Cacioppo (1986); Bhattacherjee and Stanford (2006) Sun (2013); Chang et al. (2020); Bandura (2001); Charlesworth (2012); Muntinga (2013)
statements referred to the peripheral route (PR4) of content consumption and processing from the perspective of the perceived type of emotional reaction	• if positive likes dominate, I react similarly, without going into the content of the post (PR4a); • if negative likes dominate, I react similarly without going into the content of the post (PR4b); • when people I know and respect leave their emotional reactions (I like/dislike), I react similarly without going into the content of the entry (PR4c); • when positive comments dominate, I comment in the same way as users I know and/or respect, without reading the content of the posts (PR4d); • I share posts with a large number of positive likes, but I do not read their content (PR 4e); • I share posts with a large number of negative likes without reading their content (PR4f); • I share posts with a large number of positive comments without reading their content (PR4g); • I share posts with a large number of negative comments without reading their content (PR4h)	Petty and Cacioppo (1986); Bhattacherjee and Stanford (2006) Sun (2013); Chang et al. (2020); Bandura (2001); Charlesworth (2012); Mattke et al. (2020); Muntinga (2013)

Informants were to respond to the indicated statements using a 5-point Likert scale, where "1" — strongly disagree; "2" — disagree; "3" — I do not know; "4" — agree", and "5" — strongly agree.

3. FINDINGS

The analyses used the results obtained from 142 respondents. Fifty-four per cent (77) of respondents were women, and 46 % (65) were men. Informants use Instagram (61; 43 %), TikTok (36; 25 %), Facebook (21; 15 %), X (16; 11 %), and "Other" (8; 6 %) platforms. The age structure (variable A1a) of the study sample by gender (variable S1b), the most frequently used social media platform (variable P1c), and home university are presented in Table 2.

The results of the Shapiro–Wilk test suggest that none of the analysed variables has a normal distribution. The values of the W statistic for individual variables ranged from 0.68 to 0.86 (p = .00).

The value of Cronbach's alpha internal consistency coefficient for the questionnaire components used was α = .92 in the case of the central path (CR2) related to direct consumption and processing of content (subscale composed of three items: CR2a-CR2c). For the peripheral route (PR3; PR3a-PR3c) related to the perceived quality of content (perceived number of interactions), the subscale consisting of three items, the mentioned coefficient was .77. From the point of view of the last subscale, consisting of eight items (Peripheral route: affective, related to the perceived type of emotional reaction; PR4a–PR4h) α = .90. Details are shown in Table 3.

Considering RQ1, regarding the central path of consuming and processing information (CR), the obtained descriptive statistics indicate the dominant

Table 2. Characteristics of participants

	No. of participants (F/M)	Age of participants	FB (F/M)	Platform				
				INST (F/M)	T-T (F/M)	X (F/M)	OTHER (F/M)	
BUT	68 (32/36)	18–21	52 (76 %)	1/8	16/16	12/2	1/8	2/2
		22–25	14 (21 %)					
		26–29	2 (3 %)					
RUT	46 (29/17)	18–21	45 (98 %)	3/5	9/5	14/4	3/2	0/1
		22–25	1 (2 %)					
		26–29	-					
KUE	25 (14/11)	18–21	2 (8 %)	2/1	8/5	4/0	0/2	0/3
		22–25	23 (92 %)					
		26–29	-					
PUE & WULS	3 (2/1)	18–21	-	1/0	1/1	-	-	-
		22–25	3 (100 %)					
		26–29	-					
Total	142 (77/65)			21 (15 %)	61 (43 %)	36 (25 %)	16 (11 %)	8 (5 %)

Tab. 3. Descriptive statistics

	Variables	Cronbach's A		M		SD	W
CR2	CR2a	.92	3.71	4		1.42	.79
	CR2b		3.92	5		1.45	.72
	CR2c		3.99	5		1.48	.68
PR3	PR3a	.77	2.31	2		1.12	.85
	PR3b		2.37	2		1.15	.86
	PR3c		2.36	2		1.22	.85
PR4	PR4a	.90	2.06	2		1.05	.8
	PR4b		1.88	2		.9	.78
	PR4c		2.31	2		1.12	.84
	PR4d		1.92	2		.95	.8
	PR 4e		1.68	2		.86	.74
	PR4f		1.62	1		.83	.69
	PR4g		1.66	2		.82	.74
	PR4h		1.57	1		.77	.69

tendency of users to consume content shared on their preferred social media platforms through the central route, followed by a reaction in the form of likes, comments or shares. However, some respondents (Fig. 2a) exhibit characteristics of herd behaviour or behavioural mimicry ("strongly disagree" and "disagree") concerning emotional reactions (CR2a), commenting (CR2b), and content sharing (CR2c). This is also reflected in the context of a direct declaration of herd behaviour (PR3a — "strongly agree" and "agree") and behavioural mimicry (PR3b, PR3c — "strongly agree" and "agree") related to the peripheral route of processing shared content (Fig. 2b).

In both cases, approximately 20 % of respondents declared this type of behaviour.

Therefore, from the perspective of RQ2, it was analysed whether the number of interactions occurring under a post could have an impact on this type of behaviour. The findings indicate probable differences related to the type of platform, the structure of the content available on it, and gender-related differences. Facebook and Instagram (medium and strong correlations) are platforms where both genders are willing to engage in behavioural mimicry and herd behaviours in terms of the number of reactions observed. TikTok is a platform where this type of
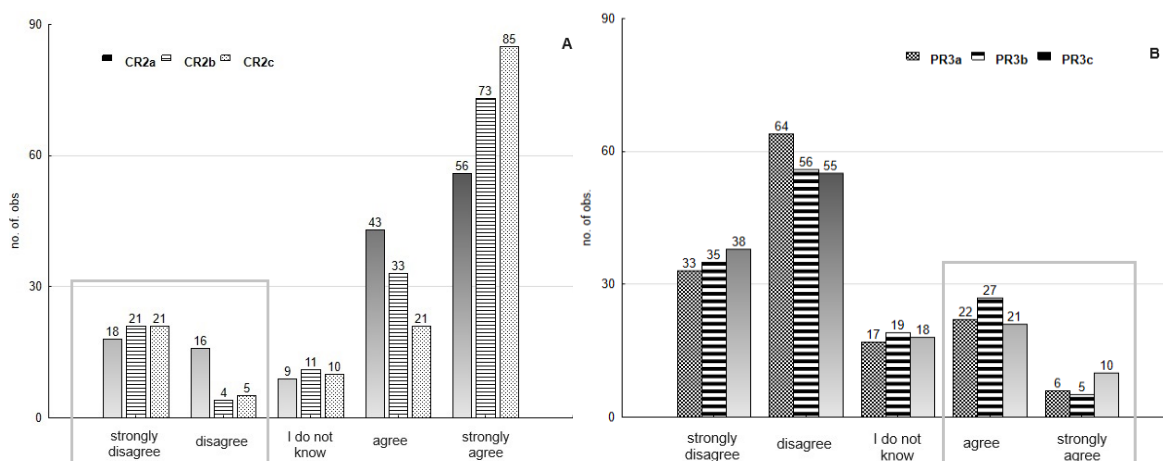
Fig. 2. Distribution of respondent answers from the perspective of central (A) and peripheral (B) routes of content consumption and processing; n=142

Tab. 4. Influence of the number of interactions on the occurrence of behavioural mimicry and herd behaviours based on the value of Spearman's ρ coefficient; n = 142

		FACEBOOK	INSTAGRAM	TIKTOK	X	OTHER
♀	PR3a	0.88*	0.44*	0.59*	0.57	-
	PR3b	0.76*	0.56*	0.5*	0.54	-
♂	PR3a	0.61*	0.73*	0.6	0.34	0.87*
	PR3b	0.52	0.41*	0.45	0.51	0.84*

* — statistically significant; p < .05

Tab. 5. Respondent tendency to herd behaviour in the context of selected emotional and behavioural reactions; n = 142

			PR4A	PR4B	PR4C	PR4D	PR4E	PR4F	PR4G	PR4H
Facebook		♀	0.86*	0.90*	0.81*	0.40	0.16	0.16	0.16	0.16
		♂	0.08	0.25	-0.11	0.21	0.22	0.22	0.22	0.22
Instagram	PR3a	♀	0.41*	0.33	0.48*	0.44*	0.26	0.02	0.09	0.06
		♂	0.69*	0.52*	0.43*	0.63*	0.63*	0.46*	0.61*	0.45*
TikTok	(herd	♀	0.44*	0.55*	0.39*	0.44*	0.30	0.19	0.37*	0.16
	behaviours)	♂	0.54	0.54	0.79	0.49	0.11	-0.11	-0.11	-0.11
X		♀	1.00	1.00	0.71	1.00	1.00	0.58	0.94	0.58
		♂	0.21	0.26	-0.03	-0.17	-0.31	-0.25	-0.25	-0.25
Other		♀	-	-	-	-	-	-	-	-
		♂	0.51	0.51	0.08	0.02	0.06	0.06	0.06	0.06

* — statistically significant; p < .05

behaviour is typical for women (average value of correlation coefficient). Users of the "X" platform do not show behavioural mimicry, which may result from the specificity of the content. Due to the small number of respondents declaring the use of platforms grouped in the "Other" category, the results obtained there are most likely to be highly questionable. Details are presented in Table 4.

The analysis also encompassed the possibility of a potential relationship between the tendency of various platform users to imitate the behaviour of others in the context of diverse emotional and behavioural reactions. Imitation in the context of herd behaviour (PR3a) was defined as "being active in the virtual space, I sometimes react to the shared content like most reacting users, even though I have a different

Tab. 6. Respondent tendency to engage in behavioural mimicry in the context of selected emotional and behavioural reactions; n = 142

			PR4A	PR4B	PR4C	PR4D	PR4E	PR4F	PR4G	PR4H
Facebook		♀	0.73	0.78*	0.64	0.25	0.00	0.00	0.00	0.00
		♂	0.37	0.79*	0.55*	0.53	0.55*	0.55*	0.55*	0.55*
Instagram	**PR3b**	♀	0.54*	0.51*	0.66*	0.45*	0.21	0.24	0.32	0.15
		♂	0.34	0.29	0.47*	0.23	0.15	-0.06	0.07	0.04
TikTok	(behavioural	♀	0.48*	0.29	0.49*	0.31	0.43*	0.41*	0.48*	0.39*
		♂	0.77	0.77	0.70	0.82*	0.82*	0.61	0.61	0.61
X	mimicry)	♀	0.94	0.94	0.50	0.94	0.94	0.82	0.78	0.82
		♂	0.69*	0.71*	0.36	0.41	0.28	0.32	0.32	0.32
Other		♀	-	-	-	-	-	-	-	-
		♂	0.65	0.65	0.49	0.00	-0.32	-0.32	-0.32	-0.32

* — statistically significant; p < .05

opinion on a given issue". About behavioural mimicry in the strict sense (PR3b), respondent tendency to directly imitate behaviour was examined about the statement, "I sometimes react to shared content without reading it, in the same way as most of the reacting users did".

From the perspective of herd behaviour (PR3a), in the case of women (♀) using Facebook, a strong correlation was found in the context of potential imitation of like/dislike reactions, including those conditioned by the influence of friends (PR4a–PR4c). An average relationship was also observed in TikTok. In this case, an additional weak positive relationship was observed in relation to the imitation of comments with an emotionally positive tone (PR4g). From the perspective of men (♂), a similar average relationship was observed only for Instagram in relation to a large number of comments and likes, regardless of their emotional nature (PR4a–PR4h). Details are presented in Table 5.

In the context of women's behavioural mimicry (♀) concerning Instagram, an average relationship was observed in terms of likes, regardless of the emotional tone and preferences conditioned by the influence of friends (PR4a–PR4c). This also applies to comments (PR4d). A similar relationship was also observed in the case of TikTok (PR4a, PR4c, PR4e–PR4h) in terms of the intensity of positive comments, comments from the perspective of the influence of friends and shares of posts conditioned by a large number of reactions, regardless of their emotional nature. A strong relationship was observed in the case of negative comments on Facebook (PR4b).

From the perspective of men (♂), a tendency towards behavioural mimicry was observed on Facebook in connection with negative comments (PR4b) and sharing posts characterised by a large number of

emotionally diverse comments and likes (PR4e–PR4h). In the context of Instagram, an average tendency to respond similarly to friends was also observed (PR4c). A medium association with men's imitation of an emotional response was observed for X (PR4a–PR4b). There was also a strong relationship related to imitating the behaviour of friends in commenting and sharing posts on TikTok (PR4d, PR4e). Details are presented in Table 6.

DISCUSSION AND CONCLUSIONS

Liking, commenting, and sharing content are behaviours related to both the central and peripheral content processing routes. These activities can be described as consequences of direct content consumption and, in some parts, as a synthesis of herd behaviour (HB) and behavioural mimicry (BM) related to respondents' SNS activity. This statement is a direct reference to RQ1. Hence, interesting theoretical and practical implications regarding the possibility of using the ELM model in research on SNS content processing from the perspective of HD and BM in the aspect of various social media platforms. So far, Zha et al. (2018) have used the ELM model to analyse, among others, the quality of information in social media and the credibility of the source, demonstrating the important role of the central route in terms of the impact of information quality and the peripheral route in the context of the role played by the source of the message and the level of trust in it. The obtained results also confirm the significant role of the peripheral route in the context of the influence of the peers interacting with content and the influence of reactions left by other known and trusted users.

Similarly, Moradi and Zihagh (2022) pointed out the dominant role of the peripheral route from the point of view of content disseminated on social media platforms. In turn, Xu and Warkentin (2020) analysed the role of herd behaviour in the context of the ELM model, building messages related to information security and engaging employees in related behaviours. The current approach combines both the ELM model and the theory of herd behaviour and behavioural mimicry in the context of various social media platforms. It was shown (RQ2) that the number of reactions left by other users and the influence of friends' reactions, especially from the women's perspective, on the appearance of HB (Facebook, Instagram, and TikTok) play a significant role. In the context of RQ3, related to the influence of the emotional context of various reactions of other users, a relationship was found between HB and the imitation of likes/dislikes by women (Facebook, Instagram, and TikTok), which was most likely determined by the influence of friends (Facebook, Instagram, and TikTok). The same goes for positive comments (Instagram and TikTok). The full spectrum of herd behaviour for the analysed variables in terms of the peripheral route is also observed in men who are Instagram users.

Behavioural mimicry in the context of the observed number of likes and positive comments is declared by women who use Facebook, Instagram, and TikTok. Imitation activities related to sharing posts with a large number of reactions are particular to TikTok. In turn, men active on Facebook show BM in the context of posts with a large number of reactions, while those active on the X platform imitate the behaviour of other recipients in the context of the number of likes.

As previously mentioned, it is important to emphasise that HB and BM can occur individually and jointly in the context of different social media platforms. The judgment also raises interesting implications regarding the directions of further research. Research should examine the extent to which HB and BM occur and the influence that opinion leaders have on them (Katz & Lazarsfeld, 1955). Their typology, presented by Bamakan et al. (2019), deserves special attention in this context, considering the scope of the impact, the positive or negative emotional nature of the impact, or the time (long-term vs. short-term). It would also be interesting to develop a theory about when and under what conditions HB and BM activities mainly occur. How do influencers (Geyser, 2023) contribute to the emergence of HB and BM, and what is their role in disseminating information (Casaló et al. 2018) based on both types of imitative behaviour?

Of course, the scope of the study should show managerial implications for content management that will encourage recipients to react in the way intended by the source of the message. From the viewpoint of the sample characteristics, it would be interesting to indicate personality traits that predispose users to represent HB and/or BM. This would be particularly important from the point of view of building guidelines for creating or preventing herd behaviour. In the first case, creating herd behaviour or behavioural mimicry could help disseminate messages related to universally understood social marketing to increase their reach. In the second case, both types of activities could be related to limiting the pace of dissemination of fake news or universally understood disinformation campaigns.

From the viewpoint of the central route, the effect of content processing and assimilation should be the emergence of a specific pattern of cognitive, emotional (like/dislike) and/or behavioural activity that increases the level of adaptation of the individual to the group or community in their virtual environment. But such an effect could also be achieved using BM or HB, which is from the perspective of about 20 % of users who react to content without reading it or react in the same way as people they consider important to them (peers in this study). Both approaches can be justified in the context of specific social rewards (Matyjek et al., 2020; Smeijers et al.,2022). In this case, the occurrence of HB and BM can be viewed as one of the mechanisms for creating social bonds (Laninga-Wijnen & Veenstra, 2023) in a virtual environment.

In the above approach, imitation in terms of HB and BM is related to the transmission of cultural information, including methods of behaviour, which is related to the theory of memes. In the classic approach (Dawkins, 1976), memes are carriers of cultural information and are the subject of cultural evolution. Schlaile et al. (2018), based on Distin (2014), suggest that memes can be defined as a mental representation of cultural content that can influence and control behaviour. The more a meme increases the level of adaptability, the more often it is assimilated and replicated from the perspective of social learning and imitation (Bandura, 2001). This means that the basic characteristics of a meme (Dawkins, 1976), such as copy fidelity, longevity, and fecundity, are high, and the meme itself tends to spread and express itself quickly.

Therefore, BM and HB can be seen as expressions of specific memes. However, explaining this phenomenon also requires detailed research on refining the meme concept and developing the related theoretical and practical implications. The current considerations can be related to the concept of the meme as a cognitive–emotional–behavioural continuum mentioned by Cao et al. (2021), with the difference that it is consolidated and replicated only when it brings tangible benefits. Hence, the manifestations of BM and HB in the SNS, which in conditions of information overload (Jacoby et al., 1974) determine a specific non-verbal social reward, can be perceived as memes — cultural units of information transmission that may have a cognitive nature, affective and behavioural impact on recipients.

The study has some limitations. It applies to Generation Z only. The behaviour of respondents from other generations (Levickaitė, 2010) would be different. Another problem is the small sample size, resulting from respondents' reluctance to participate in even short CAWI surveys.

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Green Human Resource Management in the manufacturing sector: a bibliometric literature review

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ABSTRACT

This study aims to examine the structure of Green Human Resource Management (GHRM) within the manufacturing industry research field and identify future research directions in this area as GHRM increasingly gains scholarly attention. This study utilised a comprehensive three-step approach. Initially, Scopus was selected as the primary database for its extensive coverage, followed by applying a targeted search strategy to gather literature on GHRM in the manufacturing sector, yielding 117 relevant articles. The analysis was twofold: a performance analysis to assess the impact and role of research elements within the field and a co-words analysis for mapping scientific relationships and trends in GHRM, using tools like VosViewer and MS Excel for visualisation. This methodology enabled a detailed exploration of the GHRM landscape, focusing on established research and emerging trends. The findings indicate a growing interest in GHRM in manufacturing since 2020, yet the total volume of publications remains relatively modest. The research identified four main clusters of focus: the integration of sustainability in business practices, the effects of environmental management behaviours on organisational performance, the role of sustainability in enhancing competitive advantage and sustainable development, and the formation of conceptual and strategic frameworks for sustainable practices. Notably, emerging research areas from 2021 to 2023 encompass digital challenges related to Big Data and digital transformation, the interplay of organisational learning and knowledge management in green management, and the influence of employee engagement on GHRM. This paper contributes to the field by mapping out the current state and evolution of GHRM within the manufacturing sector, highlighting both established and emerging areas of interest. It provides a comprehensive overview of how sustainability is integrated into business operations and impacts organisational performance and competitive advantage. The study offers some implications for practitioners in the manufacturing industry by identifying key areas of focus for implementing and enhancing GHRM practices. It underscores the importance of digital transformation, organisational learning, and employee engagement in the successful adoption of green management practices.

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Introduction

The increasing awareness of climate change and its severe impacts on the planet, such as rising temperatures, extreme weather events, and melting ice caps, has heightened concerns about the need for environmental sustainability, which balances economic and environmental priorities. Environmental degradation can have direct and indirect impacts on human health. As the global population continues to grow, there is a heightened awareness of the finite nature of many natural resources, including water, fossil fuels, and certain minerals. Furthermore, air

and water pollution, exposure to harmful chemicals, and the loss of green spaces can contribute to various health issues. In this context, focusing on "green" aspects aims to ensure that natural resources are used efficiently and conserved for future generations (Morelli, 2011).

At the same time, governments and international organisations are implementing stricter environmental regulations to address pressing issues, such as climate change and pollution. This regulatory environment pushes industries to adopt more sustainable practices (Čiarnienė et al., 2020). Consumers increasingly expect businesses to adopt sustainable practices in their supply chains, manufacturing processes, and overall operations. The attitudes of top managers also play a significant role (Piwowar-Sulej, Malik et al., 2023).

The concept of managing human resources in a sustainability-oriented way has emerged as modern businesses increasingly recognise the importance of sustainability in their operations, and the effective implementation of any management concept requires employee engagement. Green human resource management (GHRM) aims to develop employees' environmental knowledge and awareness and to create a sustainability-oriented corporate culture (Piwowar-Sulej, Austen et al., 2023; Ren et al., 2018; Abu-Mahfouz et al., 2023; Suharti & Sugiarto, 2020). GHRM practices are usually discussed in terms of green recruitment and selection, green performance appraisal, rewarding, training, and HR flow (Piwowar-Sulej, 2021). Many research projects revealed that GHRM practices stimulate employees' environmental behaviour (in-role, extra-role, innovative behaviour) (e.g., Dumont et al., 2017; Piwowar-Sulej, Austen et al., 2023). At this point, it is worth emphasising that the literature also provided evidence about the positive impact of these practices on employee job satisfaction and retention (Wagner, 2011).

The challenge of going green is particularly visible in the manufacturing sector, historically viewed as a significant environmental threat (Panagiotopoulou et al., 2022). Although many companies consider the safeguarding of the natural environment as a primary responsibility (Piwowar-Sulej, 2022) and are also more active in developing employee competencies than other businesses (Bidwell & Briscoe, 2010). there is a need to examine green issues, also in the context of HRM.

It has been noted that GHRM as a research topic has attracted more scholars in recent years (Pham et al., 2020). As researchers play a role in advancing sci-ence by analysing and synthesising existing studies (Templier & Paré, 2015). several recent literature reviews have attempted to understand the antecedents and outcomes of GHRM practices (e.g., Ren et al., 2018; Yong et al., 2019). There is also a review integrating GHRM with green supply management (Jabbour & De Sousa Jabbour, 2016) and ISO standards (Akdeniz, 2023). In turn, Tanova and Bayighomog (2022) synthesised research on GHRM in service industries. Finally, Pham et al. (2020) analysed GHRM literature in terms of business sectors and Industry 4.0. They found that most articles focus on implementing GHRM in the manufacturing industry; however, they identified only 22 such articles in their research sample. Consequently, this research addresses the following research questions:

RQ1. What is the structure of the manufacturing sector's GHRM research field?

RQ2. What research areas constitute promising gaps to be filled in the future?

The systematic literature review process is designed to highlight the theoretical viewpoints and key attributes found in published papers. Additionally, it seeks to outline emerging issues, identify gaps and limitations in the current body of literature (Snyder, 2019). Therefore, to answer the above RQs, this article employs a systematic review. Bibliometric reviews enable the exploration of bibliographical material from both objective and qualitative perspective to identify, organise, and analyse information in a specific research domain (Zhang et al., 2017).

To the best of the authors' knowledge, this work is the first literature review on GHRM in the manufacturing sector. It contributes to the existing literature on GHRM through the objective and replicative synthesis of the analysed research field based on publications indexed in Scopus, which is the most widely used database of academic works covering more journals and records than Web of Science (Falagas et al., 2008). Furthermore, in this study the authors applied different types of analyses, which allows for deeper understanding of the research topic.

This study is organised as follows. The second section presents the methodology used. The third section presents the results of the bibliometric analyses related to the publications on GHRM in the manufacturing. In the fourth section, the authors provide the discussion of the results. The last section presents conclusions, limitations of this study as well as future research directions.

1. Methodology

In the first step, the authors selected the most suitable database. As presented above, Scopus offers about 20 % more coverage than Web of Science, whereas Google Scholar results are inconsistently accurate (Falagas et al., 2008). Furthermore, it allows for the extraction of data in the files, which are accepted by the VosViewer tool. In this study, VosViewer was used to analyse the scientific networks according to guidelines presented by van Eck and Waltman (Van Eck & Waltman, 2013).

In the second step, the authors applied the following search strategy for documents published before 2023: (TITLE-ABS-KEY("green HRM" OR "green human resource management") AND TITLE-ABS-KEY("manufacturing" OR "production")). It resulted in 155 documents (on 1 February 2024). Then the authors included further limitations such as: (LIMIT-TO (SUBJAREA , "BUSI") OR LIMIT-TO (SUBJAREA , "ENVI") OR LIMIT-TO (SUBJAREA , "SOCI") OR LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "ENER") OR LIMIT-TO (SUBJAREA , "DECI")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j")) and abstracts of the articles were scanned to decide about the relevancy of a given paper. The result was a base of 124 articles, yet seven of them were excluded after a manual screening of the database.

In the third step, the authors selected the proper analysis techniques. First, knowledge structure was described using performance analysis metrics. The assessment of performance analysis focuses on understanding the role and impact of research elements in their respective fields (Donthu et al., 2021). The analysis, which is descriptive in nature, is the hallmark of bibliometric studies. It presents the performance of different research constituents (e.g., authors, institutions, countries, and journals) and the number of citations (Chen & Xiao, 2016). Then, one of the analyses used for science mapping was conducted. Science mapping examines the relationships between research constituents (Donthu et al., 2021). The co-words analysis, which utilises words present in documents to establish connections and construct the conceptual framework of a particular domain, was used for the synthesis and structuring of existing knowledge within GHRM, helping to delineate potential future research directions. To illustrate the results in tabular and/or graphical form, the authors used MS Excel and VOSViewer. In VOSViewer, the analyses were performed based on full counting.

2. Results

2.1. Publication pattern

Interest in the Green Human Resource Management (GHRM) concerning the manufacturing sector has been evident since 2012. However, the volume of publications remained sparse until 2020. Later, a discernible shift occurred towards a more systematic dissemination of articles, albeit the overall quantity is still relatively low, as depicted in Fig. 1.

2.2. Most influential journals

Most papers were published in five journals with SSCI. The highest numbers of papers were published in Sustainability (14) and Journal of Cleaner Production (12). yet the latter had been publishing papers in GHRM since 2016 and has the higher number of citations (1815). while the former started just in 2020 (number of citations is 202) (Fig. 2, Tab. 1). Articles
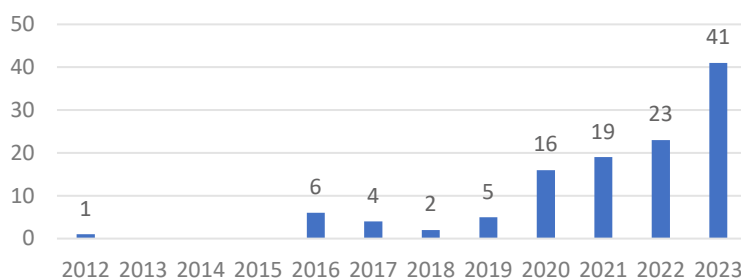
Fig. 1. Temporal distribution of articles
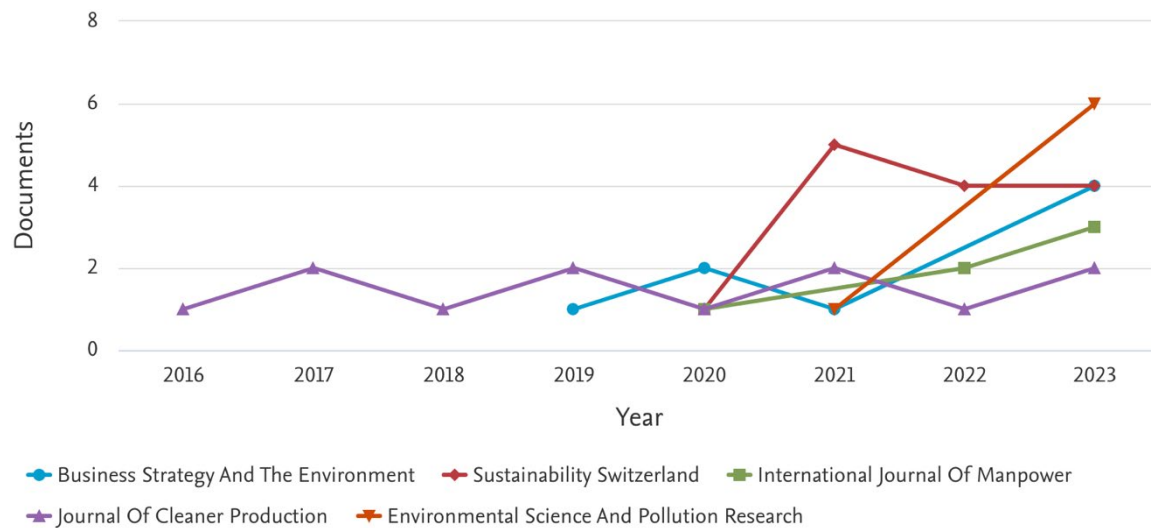
Fig. 2. Number of papers per journal

Tab. 1. Most influential journal

JOURNAL NAME	NO. OF ARTICLES	NO. OF CITATIONS	NO. OF CITATIONS PER ARTICLE
Journal Of Cleaner Production	12	1815	151.3
Business Strategy And The Environment	8	754	94.3
Benchmarking	5	236	47.2
Sustainability (Switzerland)	14	202	14.4
International Journal Of Manpower	6	126	21.0
Environmental Science And Pollution Research	7	99	14.1

Tab. 2. Most contributing countries

COUNTRIES	NO. OF DOCUMENTS	NO. OF CITATIONS	NO. OF CITATIONS PER ARTICLE
China	41	1200	29.3
Pakistan	34	873	25.7
Malaysia	32	1657	51.8
India	15	379	25.3
United Kingdom	13	754	58
France	11	1950	177.3
United States	10	584	58.4
Italy	7	1332	190.3
Brazil	7	766	109.4
Saudi Arabia	6	337	56.2
Indonesia	6	242	40.3
Australia	5	448	89.6

published in Business Strategy and Environment were cited 754 times.

The table below presents the most influential journals with numbers of articles, citations and citations per article. The pattern of citations per article almost completely overlaps with the number of citations.

2.3. MOST CONTRIBUTING COUNTRIES

Analysing country statistics, most citations relate to documents affiliated to French, Malaysian, Italian, and Chinese Institutions (Tab. 2). Also, Pakistan, Brazil, and United Kingdom made huge contributions. Regarding the number of documents, most were produced by Chinese, Pakistani, and Malaysian scientists.

2.4. MOST IMPACTFUL AUTHORS

In total, 383 authors contributed to the scientific development of GHRM in the context of production and manufacturing. The number of global citations was used to determine the most influential authors (Hashemi et al., 2022). Nine authors were cited more than 500 times. Based on the number of articles, the most productive author is C.J.C. Jabbour, who wrote eight papers and was cited 1389 times (Tab. 3). M.Y. Yusliza presented nine papers which were cited 778 times. S.S. Kumar with 768 citations and two papers.

Additionally, numbers of citations per authors were calculated. The table below shows the results of this analysis, presenting authors with the analysed index higher than 300.

2.5. MOST INFLUENTIAL ARTICLES

The number of citations indicates the impact or influence of a document (Svensson, 2010). The top-cited article by Singh et al. (2020) presented research on the interplay of green human resource management on the relationships among green transformational leadership, green innovation, and environmental performance (Tab. 5). The objective of the research conducted by Zaid et al. (2018) was to explore the connections between bundles of green human resource management practices and green supply chain management, encompassing both external and internal practices, and their collective influence on the Triple Bottom Lines of sustainability performance. The next article investigated the link between GHRM practices, factors that contribute to

a green organisational culture, and a company's environmental effectiveness (Roscoe et al., 2019a).

2.6. CO-WORD ANALYSIS

The co-word analysis was applied to document keywords; thus, the unit of analysis was a concept (Zupic & Čater, 2015). Fig. 3 shows the keywords' network designed with the use of VosViewer. The threshold value for total link strength was set at ten, which indicates a stronger relationship between the concepts.

1.   Red cluster (four items). This cluster emphasises the integration of sustainability into key business practices, particularly in human resources and supply chain management. It includes terms like "Green HRM", "Green supply chain management" (GSCM). "Sustainability", and "Sustainable operations". This suggests a focus on how businesses can embed environmental considerations into their core operations, developing sustainable human resource policies and environmentally conscious supply chain processes. It highlights the importance of aligning organisational practices with broader sustainability goals, ensuring that internal and external operations contribute to environmental stewardship. Yong, Yusliza, Jabbour et al. (2020) explored how different organisational factors support Green HRM adoption. The study highlights the internal mechanisms that enhance sustainable practices within firms, reinforcing the need to integrate HRM with environmental management strategies for long-term sustainability. Masri and Jaaron (2017). Yong, Yusliza, Ramayah et al. (2020). and Roscoe et al. (2019) explored how GHRM practices contribute to broader sustainability goals. Other authors examined how GHRM enhance GSCM strategies (Chiappetta Jabbour et al., 2017; Nejati et al., 2017). Several papers focus on research linking GHRM, GSCM and sustainability performance. Saeed et al. (2022) explored the connection between Green GHRM and environmental performance, with GSCM serving as a mediating factor. Another paper explored the synergistic influence of GHRM and GSCM on various aspects of business performance, including operational, market, financial, social, and environmental outcomes (Acquah et al., 2021). By confirming the positive correlation between green training and the successful adoption of green supply chain practices, Teixeira et al. (2016) highlighted how aligning HR efforts with supply chain operations contributes to broader sustainability goals. Findings from Jermsittiparsert et al. (2019) align with the

Tab. 3. Most impactful authors based on the number of citations

Author	No. of articles	citations
Chiappetta Jabbour, Charbel José	8	1389
Yusliza, M.-Y.	9	778
Singh, Sanjay Kumar	2	768
Giudice, Manlio Del	1	764
Chierici, Roberto	1	764
Graziano, Domenico	1	764
Jaaron, Ayham A.M.	3	686
Yong, Jing Yi	6	633
Ramayah, Thurasamy	6	586

Tab. 4. Most impactful authors based on the number of citations per article

Author	No of articles	No of citations	No. of citations per article
Giudice, Manlio Del	1	764	764.0
Chierici, Roberto	1	764	764.0
Graziano, Domenico	1	764	764.0
Singh, Sanjay Kumar	2	768	384.0
Talib Bon, Abdul	1	384	384.0
Roscoe, Samuel	1	357	357.0
Subramanian, Nachiappan	1	357	357.0
Chong, Tao	1	357	357.0

Tab. 5. Most impactful papers

Authors	Article title	Journal	No. of citations
(Singh et al., 2020)	Green innovation and environmental performance: The role of green transformational leadership and green human resource management	Technological Forecasting and Social Change	764
(Zaid, Jaaron & Talib Bon, 2018)	The impact of green human resource management and green supply chain management practices on sustainable performance: An empirical study	Journal of Cleaner Production	384
(Roscoe et al., 2019b)	Green human resource management and the enablers of green organisational culture: Enhancing a firm's environmental performance for sustainable development	Business Strategy and the Environment	357
(Masri & Jaaron, 2017)	Assessing green human resources management practices in Palestinian manufacturing context: An empirical study	Journal of Cleaner Production	300
(Rehman et al., 2021).	Analyzing the relationship between green innovation and environmental performance in large manufacturing firms	Technological Forecasting and Social Change	265
(Yong, et al., 2020)	Pathways towards sustainability in manufacturing organizations: Empirical evidence on the role of green human resource management	Business Strategy and the Environment	260
(Yong et al., 2019)	Nexus between green intellectual capital and green human resource management	Journal of Cleaner Production	236
(Teixeira et al., 2016)	Green training and green supply chain management: Evidence from Brazilian firms	Journal of Cleaner Production	232
(Nejati et al., 2017)	Envisioning the invisible: Understanding the synergy between green human resource management and green supply chain management in manufacturing firms in Iran in light of the moderating effect of employees' resistance to change	Journal of Cleaner Production	221

cluster's focus on integrating sustainability into key business practices by demonstrating that Green HRM influence the link between green logistics and environmental outcomes. Several recent studies examine the intersection of digital transformation (DT) with GHRM and GSCM. Trujillo-Gallego et al. (2022) highlight how digital technologies (DTs) and GHRM contribute to improving economic and environmental performance by building environmental capabilities, such as GSCM operational practices. Ma et al. (2023) focused on the synergistic effects between GHRM, GSCM, and digital technologies, highlighting how businesses can align internal operations to meet broader sustainability objectives.

2. Green cluster (three items). This cluster centres on the behavioural and performance aspects of environmental management within organisations. It comprises terms like "Employee green behaviours", "Environmental management", and "Sustainable performance". This indicates an interest in how individual behaviours within an organisation contribute to overall environmental objectives, the strategies employed in managing an organisation's environmental footprint, and the measurement of organisational performance in sustainability terms. It underscores the role of human behaviour in achieving environmental goals and the need for effective management practices that foster sustainable performance. In many studies, these topics were raised. Khan et al. (2021) underscored the importance of individual behaviours and structured environmental management practices in achieving sustainability goals. Malik et al. (2021) further supported the connection between GHRM and sustainable performance through the mediating role of organisational citizenship behaviour towards the environment (OCBE). Also, Aftab et al. (2023) demonstrated the role of pro-environmental behaviour in the impact of GHRM on environmental performance. Some papers focus on ways of enhancing green behaviours. Islam et al. (2020) highlighted the role of ethical leadership and GHRM in promoting green in-role and extra-role behaviours among employees. The research of Zhu et al. (2021) and Waqas, Yahya et al. (2021) support the green cluster by providing evidence of how GHRM practices foster different types of employee green behaviours, reinforcing the role of individual behaviours in achieving organisational environmental goals. The other area of research refers to the meaning of green management for sustainable performance. Huo et al. (2020) claimed that environmental regulation positively regulates the relationship

between commitment to GHRM and offers practical enlightenment for enterprises to carry out environmental management and achieve sustainable development. Khan et al. (2021) discussed the environmental management system (EMS) as a mediator between GHRM and sustainable performance. By embedding environmental management within the organisation's operational framework, the EMS facilitates the translation of GHRMP initiatives into measurable improvements in environmental performance, reinforcing the critical role of structured environmental strategies in achieving sustainable outcomes. On the other hand, environmental management indirectly influences Green HRM adoption by being embedded in the organisational knowledge and innovation systems that drive sustainable practices (Yong et al., 2020). Also, Liu et al. (2021) found support for the influence of green management on the implementation of GHRM.

3. Blue cluster (three items). This cluster explores the strategic and innovative dimensions of sustainability, particularly their role in competitive advantage and sustainable development. It includes "Competitive advantage", "Green innovation", and "Sustainable development". This suggests a strategic approach to sustainability, where environmental initiatives are not just seen as compliance requirements but as opportunities for innovation and market differentiation. It highlights the importance of developing sustainable products, services, and processes that contribute to long-term sustainability goals and provide a competitive edge in the market. In many studies, authors focus on linking green innovation to competitive advantage. Ogiemwonyi et al. (2023) examined how GHRM, green innovation, environmental policy, and green workplace behaviour influence environmental performance. Muisyo et al. (2022) focused on how GHRM and Green Innovation Culture (GIC) contribute to CA. By exploring how green HRM mediates the relationship between leadership and innovation, Singh et al. (2020) underscored how sustainable practices can be leveraged to achieve green performance. Obeng et al. (2023) found the mediating role of green innovation in the relationship between GHRM and organisational competitiveness. Additionally, Shahzad et al. (2023) emphasise green innovation and organisational culture as strategic drivers of sustainable performance. In some research, Big Data Analytics (BDA) has also been considered in this context. Waqas, Honggang et al. (2021) explored the strategic role of Big Data Analytics (BDA) in enhancing green innovation,
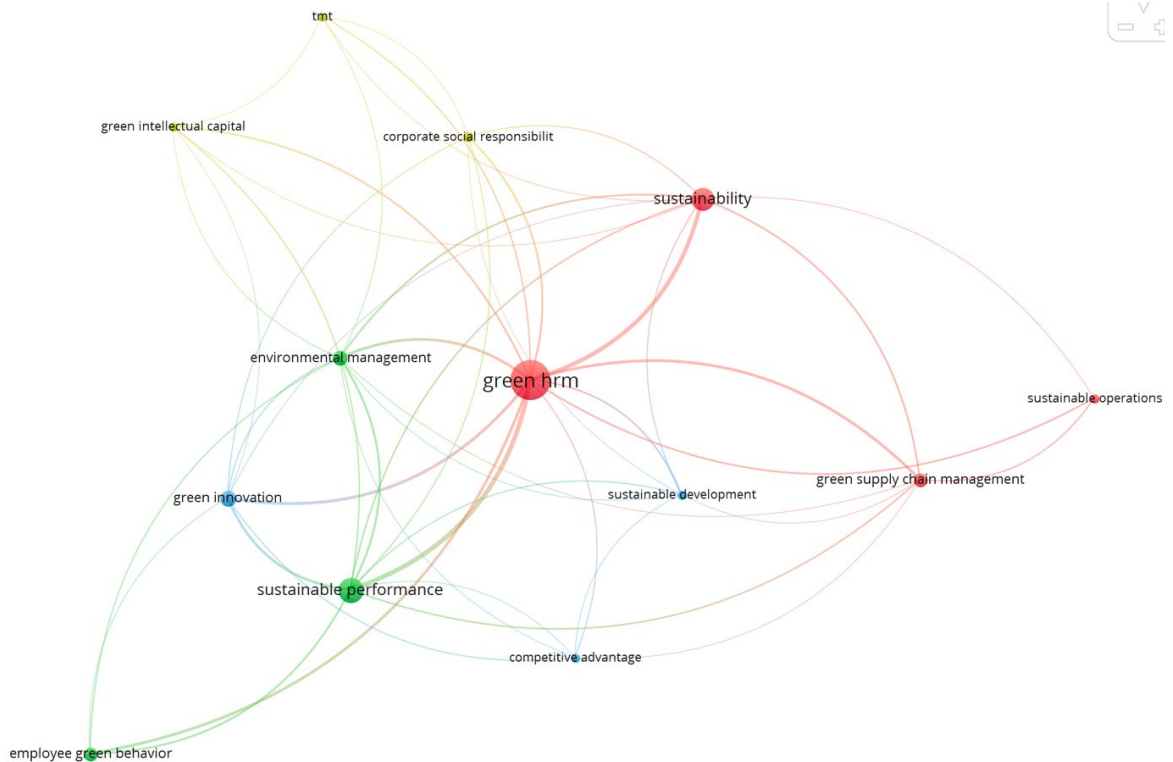
Fig. 3. Keywords' map

competitive advantage, and environmental performance. Green innovation and big data analytics further strengthen the relationship between GHRM and performance by acting as key mediators and moderators (Chau et al., 2024).

4. Yellow cluster (three items). This cluster focuses on the conceptual and strategic frameworks that guide sustainable practices, especially in relation to corporate social responsibility and intellectual capital. It encompasses "CSR", "Green intellectual capital", and "TMT". This cluster implies a focus on the role of corporate governance and leadership in driving sustainability, the importance of incorporating environmental thinking into the organisation's knowledge base, and the strategic role of top management in embedding sustainability into the corporate ethos. It reflects an understanding that sustainable practices are deeply intertwined with corporate strategy, knowledge management, and leadership commitment. Many studies focus on the role of green intellectual capital (GIC). For example, Yong et al. (2023) highlighted the importance of investing in green IC to achieve sustainability through green HRM practices. Ullah et al. (2023) found that GIC enhances a firm's ability to innovate in environmentally friendly ways, which in turn improves the firm's

environmental performance. On the other hand, Yong et al. (2019) emphasised the role of GIC in GHRM. Other papers focus on the activities of the Top Management Team (TMT). A strong positive link between top management commitment and both CSR and GHRM was found (Yusliza et al., 2019). Moreover, TMT's influence is critical in ensuring that external pressures translate into actionable environmental practices within the firm. Thus, TMT is key to embedding sustainability into corporate strategies and decision-making processes (Gedam et al., 2021; Ma et al., 2021) and for ensuring that GHRM policies are effectively implemented (Huo et al., 2020). A third stream of research refers to CSR. First, CSR positively impacts sustainable performance (Zhao et al., 2021) both directly and through the mediation of GHRM and green innovation (Zhou et al., 2023). It also plays a mediating role between green HRM practices and environmental sustainability (ES) (Wen et al., 2022).

2.7. FUTURE AVENUES FOR GHRM RESEARCH

Following Subramanian et al. (2023). to designate avenues for future research, the authors focused on publications from the last three years (2021–2023) and analysed 87 articles. Such an approach allowed

for the identification of current areas of interest and contemporary trends in GRHM research. The analysis revealed three emerging areas of interest.

The first area refers to the digital issues. Big Data Analysis, data-driven culture and digital transformation may support firms suffering from sustainability issues if they are interconnected with GHRM. As Waqas et al. (2021) noted, Big Data Analysis is an underexamined topic. The cited authors examined the role of BDA in boosting green innovation, competitive advantage, and environmental performance. Chau et al. (2023) proposed to focus on big data analytics and data-driven culture as moderators in the relationship between GHRM and performance. Also, Awan et al. (2023) emphasised the need to examine data-driven culture in existing routines and use them to improve sustainable environmental development. Ma et al. (2023) and Trujillo-Gallego et al. (2022) proved that digital transformation and GHRM may enhance green performance.

The second research area includes organisational learning and knowledge management that support green management and performance. First, Subramanian and Suresh (2022) emphasised that the role of organisational learning in the transition to a more circular economy remains unknown. Cited authors investigated the model that explains factors of organisational learning and green human resource management practices, which create a circular economy. Awan et al. (2023) link data-driven culture with organisational learning capability and GHRM in the context of environmental performance. Also, green knowledge processes are discussed (Rashid et al., 2023; Wang et al., 2023).

The last research area covers employee issues labelled as employee engagement. Rashid et al. (2023) and Islam et al. (2020) examined the moderating role of individual green values between GHRM and different results. Apart from focusing on in-role and extra-role behaviours, Liu et al. (2021) and Malik et al. (2021) examined organisational green citizenship behaviours. Tariq et al. (2016). Khatoon et al. (2021). and Yusliza et al. (2017) emphasised the role of green employee empowerment in the implementation of GHRM and performing their tasks.

3. Discussion of the results

The first research question was about the structure of the manufacturing sector's GHRM research field. Based on the analyses, future research should focus on several key areas. While there's a growing interest post-2020, which is a natural consequence of the trend noticed by Shah et al. (2024). the overall volume of GHRM publications remains relatively low. Future research should aim to expand the body of work in this field, contributing to a more comprehensive understanding of GHRM. Key journals in this field include the Journal of Cleaner Production and Sustainability and Business Strategy and the Environment, with the former having the highest number of citations. These journals are significant contributors to the GHRM literature. However, considering the journals in which the most influential articles were published, Technological Forecasting and Social Change needs also to be mentioned. With significant contributions from countries like France, Malaysia, Italy, China, Pakistan, Brazil, and the UK, there's a clear global interest in GHRM. Yong, Yusliza and Fawehinmi (2019b) noticed that the importance of GHRM research has increased noticeably among scholars since 2016. The most frequent sources of articles were the Journal of Cleaner Production and The International Journal of Human Resource Management. Most of the research was carried out in developing countries, with Brazil being the most productive region. They found only 12 GHRM studies that were conducted in developed countries. According to Pham et al. (2020). the most popular journals are the Journal of Cleaner Production and The International Journal of Human Resource Management. Papers from Brazil and China prevailed in their sample. Future research should continue to foster this international perspective, possibly exploring region-specific challenges and solutions in GHRM implementation.

Co-word analysis of all analysed articles revealed four clusters. For integrating sustainability into business practices, future research should delve deeper into how sustainability can be effectively embedded in various business contexts and the role of HR in this process. Studies may also focus on how environmental management behaviours within organisations affect performance, exploring the dynamics between employee behaviour, GHRM practices, and organisational outcomes. Third, exploring how sustainability contributes to competitive advantage and sustainable development is crucial. Finally, there's a need to develop and refine conceptual and strategic frameworks guiding sustainable practices, especially in relation to corporate social responsibility and intellectual capital. This research partially supports research conducted by Fachada et al. (2022). who

identified (1) the GHRM implementation as a facet of environmental management, (2) consequences for employees (such as "organisational citizenship behaviour", "employee green behaviour", "empowerment"). (3) consequences for organisations (e.g. "sustainability", "environmental performance"). Also, Shah et al. (2024) referred to such clusters as environmental performance and green behaviour.

The second research question was aimed at discovering research areas that constitute promising gaps to be filled in the future. Three emerging areas were identified while analysing articles from 2021 to 2023: (1) digital issues, highlighting the role of Big Data and digital transformation in enhancing firms' sustainability when integrated with GHRM, (2) organisational learning and knowledge management, focusing on their contribution to green management and performance, particularly in transitioning to a circular economy, and (3) employee engagement, emphasising the impact of individual green attitudes and behaviours and employee green empowerment on GHRM effectiveness and various organisational outcomes. These trends are visible also in the general HRM literature. Relating to GHRM in all industries, Shah et al. (2024) indicated digital issues and the examination of relationships between the organisational level and the employee level of analysis. Moreover, they proposed to focus on sustainability, environmental management, green training, and sustainable performance. In the presented research, only the role of the top management team (TMT) was emphasised, yet as Bahuguna et al. (2023) noticed in their bibliographic review, future research should focus on line managers and HR managers. Jabbour and De Sousa Jabbour (2016) proposed to focus on employee-related outcomes such as job satisfaction and well-being. Many more potential avenues may be examined, e.g., the integration of GHRM practices and Industry 4.0 for a company's sustainability or exploring the effects of GHRM practices on employees' green activities outside of the organisation Pham et al. (2019) and the perspective of society (e.g., greenwashing) (Paulet et al., 2021).

Conclusions

Although researchers have recently been reviewing literature in the field of GHRM, according to the authors' knowledge, none of the articles focused exclusively on the manufacturing sector. The study enabled the authors to understand current state-of-

art and to highlight future research directions. The bibliometric analysis of GHRM in the manufacturing sector reveals several significant findings. There has been a noticeable increase in scholarly interest in GHRM within the manufacturing sector since 2020. However, the overall volume of publications remains modest, indicating a relatively nascent field that requires further exploration and academic attention. The analysis identified four primary research clusters: integration of sustainability into business practices, the impact of environmental management behaviours on organisational performance, the role of sustainability in competitive advantage and sustainable development and the development of conceptual and strategic frameworks for sustainable practices. Recent studies (2021–2023) highlight emerging areas such as the role of Big Data and digital transformation in sustainability, the interplay between organisational learning, knowledge management, and green performance, and the influence of employee engagement on GHRM practices.

Literature reviews can also serve as overviews of a topic for practitioners and thus have real-world implications (Piwowar-Sulej & Iqbal, 2023). First, environmental considerations should be embedded into core operations through sustainable HR policies and eco-conscious supply chains, ensuring alignment with broader sustainability goals. Second, managers should foster individual green behaviours within the organisation. Moreover, sustainability should be perceived as a strategic opportunity. Finally, incorporating environmental thinking into the organisation's knowledge base and embedding sustainability into corporate strategy through effective leadership and intellectual capital management are crucial for the successful adoption of sustainable practices.

To point out limitations, a literature search by using keywords does not guarantee an exhaustive outcome, and other techniques like bibliographic coupling or meta-analysis could provide different results. Second, the study analysed only articles available in Scopus. Nevertheless, such a review allows for several benefits. The manufacturing industry has unique environmental impacts and sustainability challenges. A targeted bibliometric analysis of 117 articles revealed specific trends, practices, and research gaps pertinent to GHRM in this sector. Focusing on a specific industry allowed for a more in-depth analysis of the relevant literature, which provides richer and more detailed insights than a general overview might. We hope that providing context-specific evidence and insights can fill impor-

tant gaps in the literature, offering future directions relevant to the field.

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EVALUATION AND SPATIOTEMPORAL EVOLUTION OF GREEN INNOVATION EFFICIENCY IN CHINA: A TWO-STAGE VALUE CHAIN PERSPECTIVE

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A B S T R A C T

As the global problems of environmental pollution and ecological degradation are becoming important obstacles to the realisation of sustainable development, green technological innovation (GTI) has received wide attention in the academic and practical communities worldwide. Commonly, the GTI process can be divided into two stages: green technology R&D and green achievement transformation. The contribution of GTI to economic development and environmental protection depends to a large extent on green innovation efficiency (GIE). Based on the panel data on inputs and outputs of 30 provinces in China from 2007 to 2021, this study applied the super efficiency SBM model considering undesirable outputs to evaluate green technology R&D efficiency (GTRDE) and green achievement transformation efficiency (GATE). Additionally, this study adopted the global and local Moran's I index for spatial autocorrelation analysis. First, GTRDE showed a trend of "eastern > western > central > northeastern", while GATE showed a trend of "eastern > central > western > northeastern". Second, although GATE was higher than GTRDE in most provinces, the differences between provinces were significantly larger for the former than for the latter. Third, global spatial autocorrelation in GIE across provinces was significant only in a few years, while local spatial autocorrelation existed only in a few provinces. Based on the two-stage value chain perspective, the green innovation process is divided into green technology R&D and green achievement transformation. This paper also introduces a super-efficiency SBM model that considers undesirable outputs when calculating GIE. This is in line with the basic laws of GTI and development in reality. Thus, to enhance the efficiency of green innovation, governments and enterprises should raise awareness of GTI, enhance inter-regional exchanges and collaboration, and take a variety of measures to narrow the gap between regions.

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K E Y W O R D S

green innovation efficiency, spatiotemporal evolution, two-stage value chain, green technology R&D, green achievement transformation, super-efficiency SBM model

INTRODUCTION

As an integral part of the world's economic system, China's economy has grown by leaps and bounds over the past few decades. According to the World Bank (2023), China's GDP grew at an average annual rate of 6.056 % from 2013–2022 and is now firmly established as the world's second-largest economy, just after the United States. China eliminated absolute poverty and hunger by the end of 2020, a world-renowned achievement that makes it an important representative of developing countries and emerging economies. However, such rapid development is often

characterised by high inputs, high consumption and high emissions and comes at the expense of the environment and ecology, further leading to environmental pollution and ecosystem degradation (Cao et al., 2021; Fan et al., 2021). For instance, according to the World Resources Institute (2023), China is the world's largest emitter of greenhouse gases. Greenhouse gas emissions have become an important environmental issue in China and worldwide. To change this critical situation and achieve the goal of sustainable development, China proposed the goals of carbon peaking before 2030 and carbon neutrality before 2060 (dual carbon goals) in September 2020, pledging to make every effort to repair the environment and solve ecological problems. Then, the concept of green development has continued to receive extensive attention from the academic and practical communities. In short, green development advocates resource conservation, ecological protection and environmental governance. It seeks to realise the harmonious coexistence between humans and nature and is an important means of achieving the sustainable development goal. At present, the governments at all levels in China have incorporated the concept of low-carbon and green development into policymaking and planning (Zhang et al., 2022).

The realisation of green development cannot be separated from the support of technological innovation. Technology is an important force for human development and social progress, bringing many conveniences to human production and daily life. Specifically, technology helps to free humans from various boring, tedious, and dangerous tasks and move them to other, more important tasks. This way, it accomplishes the social division of labour and collaboration between humans and machines. However, the creation and existence of technology does not always have only positive aspects but also negative impacts, especially for the environment and ecology in the case of non-green parts in technologies. For instance, although the invention of plastics has facilitated people's daily lives, their characteristics of being difficult to degrade and recycle lead to environmental degradation. Some of the discarded plastics have seriously threatened the survival of marine life, such as fish. Additionally, the convenience of technology tends to divert human beings towards extravagant enjoyment, resulting in greater environmental pollution and waste of resources. Therefore, green technologies, as compared with traditional technologies, need to be the focus of attention to realise green development. The active development of green tech-

nologies is the key to realising a green and low-carbon transformation of society and resolving the conflict between economic growth, resources, and the environment (Du & Li, 2019; Shan et al., 2021). It has become a consensus to promote economic growth and environmental improvement by raising the level of green technological innovation (GTI) (Faulkner, 2004). GTI can drive rapid economic growth while avoiding negative externalities that innovation activities may bring to the ecology and the environment (Cao et al., 2021; Fang et al., 2022a; Shan et al., 2021; Moskalenko et al., 2022; Fu et al., 2023; Fu & Chang, 2024). Thus, combining green development and technological innovation has become an effective means to achieve sustainable development (Fan et al., 2021; Zeng et al., 2021).

Obviously, the effectiveness of GTI in realising the goal of sustainable development depends largely on the efficiency of green innovation. Normally, efficiency reflects the ratio between the quantities of various inputs and outputs at a specific time (Xu et al., 2020). Under the conditions of a given range of resource inputs and technologies, regions with higher green innovation efficiency (GIE) can produce more desirable outputs (i.e., environmentally friendly outputs) and fewer undesirable outputs (i.e., non-environmentally friendly outputs). According to the National Bureau of Statistics of China (2023), the intramural expenditure on R&D in China grew at an average annual rate of 11.228 % from 2013–2022 and reached 3.087 trillion yuan in 2022. Similarly, the full-time equivalent of R&D personnel in China reached 6.041 million man-years in 2022. However, even with all these inputs, the desirable outputs produced are still relatively insufficient. The low efficiency of green innovation in China may be due to the loss or waste of technology in serving production and life, or it may be due to the management system. In addition, there are differences in GIE between regions due to the differences in geographic location, resource endowment and policy planning. So, measuring the GIE in China's provinces and improving GTI are important issues that China needs to address at present, and they are also the starting point of this study.

The contributions and innovations of this study compared to existing studies are in the following three main aspects. First, the contribution to the research perspective. On the basis of the two-stage value chain perspective, the green innovation process is divided into green technology R&D and green achievement transformation. Besides, considering the time lag effect, this study calculates the green

technology R&D efficiency (GTRDE) and the green achievement transformation efficiency (GATE) separately. This is aligned with the reality of the basic laws of GTI and development. Second, the contribution to research methodology. This study introduces a super-efficiency SBM model that considers undesirable outputs when calculating GIE. The efficiency values calculated by this method can be greater than 1.000, avoiding the inability to compare decision-making units (DMUs) when they are simultaneously effective. Meanwhile, this method considers undesirable outputs, such as carbon emissions and energy consumption, and the global frontier-based measure allows for horizontal and vertical comparisons of GIE. Third, the contribution to research content. This study calculates the GIE based on the two-stage value chain perspective. Additionally, this study analyses and visualises the spatial and temporal evolution of GIE in different provinces, as well as the spatial autocorrelation. So it can ensure that the results align with social development's reality.

1. Literature review

1.1. GIE

As an effective means of improving the utilisation efficiency of energy and nature's resources, easing environmental pollution and ecological degradation, and realising sustainable development, the GTI has received extensive attention from academic and practical circles (Cao et al., 2021; Miao et al., 2017; Sun et al., 2017). Among them, much of the existing research provides an in-depth portrayal of the GTI process as a whole (Shan et al., 2021). However, the approach of considering the GTI as a whole is flawed and does not allow for effective differentiation between the subcategories. So, Song and Han (2022) considered categorising GTI into green product innovation and green process innovation. However, such a categorisation still fails to differentiate GTIs from the sequence of processes. In terms of the sequence of processes, based on the innovation value chain perspective, GTI can be categorised into two stages: green innovation of R&D activities and transformation activities of green innovation achievement (Sun et al., 2022; Zhu et al., 2021). Obviously, these two stages are chronologically sequential and can provide a good GTI explanation.

Several research efforts have focused on GTI, measured by using indicators related to green patents

(i.e., green invention patents and green utility model patents) applications and grants (Feng et al., 2022; Gao et al., 2022; Zhang & Liu, 2022). For instance, Suki et al. (2022) used green technological patents as the proxy of GTI and evaluated the GTI in the ASEAN region. Wang et al. (2019) also used the patent data to measure the GTI in China. Besides, Xue et al. (2022) used green patents granted to measure the GTI. However, the GTI using green patents as the proxy considers more quantitative performance and neglects the quality and efficiency. Therefore, many research efforts focus on the GIE, e.g., Fang et al. (2022b), Liao and Li (2023), and Miao et al. (2021). In addition, Fan et al. (2021) and Wang et al. (2023) evaluated the GIE of 235 cities and 285 prefecture-level or above cities in China, respectively. Sun et al. (2022) calculated the GIE in tourism in 30 Chinese provinces. So, the existing literature suggests that evaluating the GIE of the study area yields more useful conclusions than evaluating GTIs.

Currently, the research topic of GIE is related to different hierarchies and industries. Specifically, the hierarchies of existing studies include the national level (Dong et al., 2022; Jian & Afshan, 2023; Obobisa et al., 2022; Razzaq et al., 2021; Sharif et al., 2022), the provincial level (Cao et al., 2021; Chen et al., 2023), and the municipal level (Lin & Ma, 2022; Wei et al., 2023). For instance, Song and Han (2022) and Zhao et al. (2023) evaluated the GIE of 30 Chinese provinces. Fan et al. (2021), Huang and Wang (2020), Zeng et al. (2021), and Zhang et al. (2020) also calculated the GIE of 235 cities, 108 cities in the Yangtze River Economic Belt, 26 cities in Yangtze River Delta region, and Xi'an, China, respectively. A careful summary of studies on GIE in China found that most of them were regionally focused, and most of them were at the municipal level. In the industrial sectors, studies were mainly focused on intensive pollution industries (Li & Zeng, 2020; Li et al., 2022b), manufacturing industry (Wang, 2023), industrial enterprises (Miao et al., 2021; Xu et al., 2022b), family enterprises (Zheng et al., in press), and so on. For instance, He et al. (2021) calculated the GIE of listed Chinese paper-making enterprises and showed that the overall GIE of the 12 selected listed paper enterprises was low, as well as significant differences in efficiency between enterprises. In addition, Yin and Wang (2021) measured the GIE of new equipment manufacturing and showed apparent differences in the GIE of different new equipment manufacturing and uneven development. Also, Sun et al. (2022) evaluated the innovation efficiency of China's tourism industry and indicated

that all provinces showed some differences in green R&D efficiency and green achievement conversion efficiency.

Studies use various methodologies to evaluate GIE. Specifically, the main methods for evaluating GIE are the slacks-based measure of super-efficiency (Super-SBM) model (Xu et al., 2020; Li & Du, 2021; Li & Zeng, 2020; Zhang et al., 2022; Xu et al., 2022a), the super-SBM model considering the undesirable outputs (Li et al., 2022b), and SBM model considering undesirable outputs (Fan et al., 2021). Also, some scholars have adopted the super network SBM model (Liao & Li, 2023), global super epsilon-based measure (EBM) model (Wang et al., 2023), the two-stage SBM model considering undesirable output (Miao et al., 2021), the super EBM-undesirable model (Wang et al., 2022), and the slacks-based measure of directional distance functions (SBM-DDF) model (Zhang et al., 2020). In addition, some scholars focus on the changes in productivity rather than efficiency itself when evaluating the GIE. Therefore, they apply the global Malmquist-Luenberger index to measure GIE (Lv et al., 2021; Long et al., 2020; Zeng et al., 2021). To summarise, the studies show that the super-efficiency SBM model, including undesirable outputs, has become an effective method for evaluating the GIE.

1.2. Application of the super-efficiency SBM model

In 1978, Charnes et al. first introduced the data envelopment analysis (DEA) model to evaluate the effectiveness of decision-making units (DMUs). The DEA model plays an important role in evaluating the effectiveness of multiple inputs and outputs of multiple DMUs. Then, considering the shortcomings of the traditional DEA model, Tone (2001) greatly improved it and named it the slacks-based measure (SBM) model. In addition, when multiple DMUs are effective (i.e., the efficiency value is equal to 1), the traditional DEA model cannot be further compared,

which poses a challenge for effectiveness evaluation. So, Tone (2002) introduced the concept of super-efficiency and proposed the super-efficiency SBM model. Then, due to the widespread academic interest in undesirable outputs, Tone (2003) developed the SBM model, which considers undesirable outputs. Thereafter, the super-efficiency SBM model, which considers undesirable outputs, has become one of the most commonly used methods for evaluating the effectiveness of multiple DMUs.

Up to now, the super-efficiency SBM model has been widely used in the evaluation of effectiveness in many fields, such as social, economic and environmental aspects. In the social and economic aspects, this method was used to measure the efficiency of the hotel industry (Ashrafi et al., 2013), urban land use (Zhu et al., 2019), green growth (Razzaq & Yang, 2023), sustainable development (Khan et al., 2021), commercial banks (Shah et al., 2022), green total factor productivity (Wu et al., 2020), and green economic growth (Zhao et al., 2022). Additionally, in the environmental aspect, this method was applied to measure the energy efficiency (Gökgöz & Erkul, 2019; Tran et al., 2019), the environmental efficiency (Dirik et al., 2019; Li et al., 2022a; Taleb et al., 2023), and carbon emission efficiency (Fang et al., 2022a).

2. Materials and methods

2.1. Research process

The following steps were taken to carry out the study described in this paper: the definition of the research topic; the development of a literature review on GIE and application of the super-efficiency SBM model; selection of the study area; the definition and measurement of input and output indicators in the green technology R&D stage and green achievement transformation stage; the data collection; evaluation, spatiotemporal evolution and spatial autocorrelation
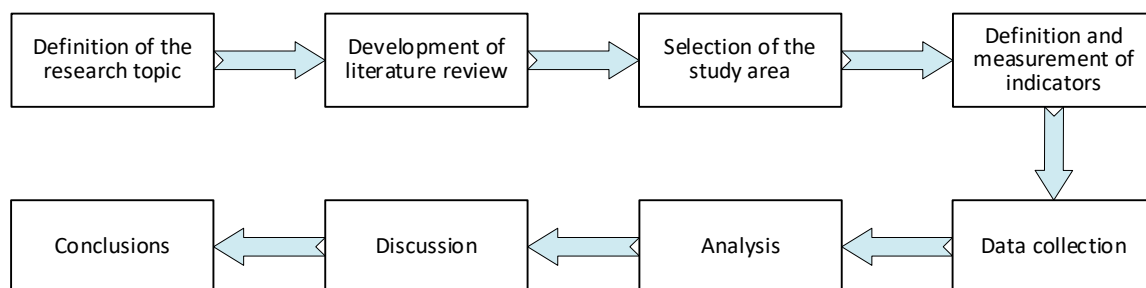
Fig. 1. Research process flow chart

analysis of China's GIE; discussion; and conclusions. The research process flow chart is presented in Fig. 1.

2.2. Study area

The study area in this research, i.e., the administrative division of China, is shown in Fig. 2. According to the definition of the National Bureau of Statistics of China, the country's 34 provincial administrative units can be divided into five regions: Eastern, Central, Western, Northeastern, and Hong Kong, Macao and Taiwan. Also, according to the Codes for the Administrative Divisions of the People's Republic of China (GB/T 2260-2007), a two-letter code for each provincial administrative unit is also labelled in Fig. 2. The eastern region includes ten provinces, the central region includes six provinces, the western region includes twelve provinces, while the northeastern region includes three provinces.

2.3. Definition and measurement of indicators

The study aims to evaluate the efficiency of green innovation; hence, the selected variables are mainly related to input and output indicators. The undesirable outputs, such as carbon dioxide emissions and energy consumption, are fully considered in the output indicators selected. Additionally, as mentioned previously, the green innovation process can be divided into two stages, i.e., green technology R&D and green achievement transformation. Typically, technological innovation has a significant time lag effect, i.e., outputs in a specific year are supposed to result from inputs in previous years. That is, for technological innovation, it is difficult to have a relatively large number of associated outputs within a short period of time for the current year's inputs. Hence, considering that green technologies need to go
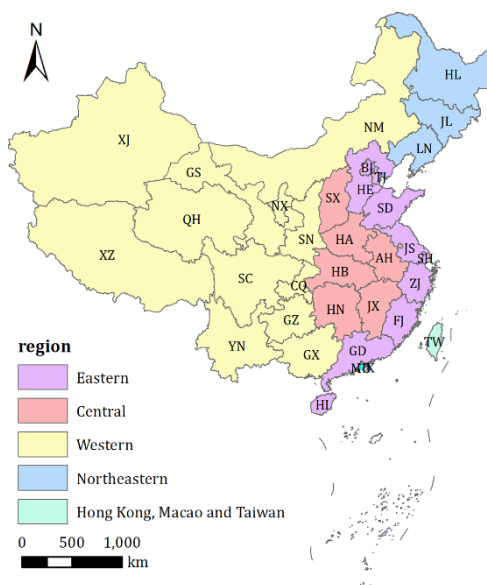
Fig. 2. Division of administrative regions in China

Tab. 1. Definition and measurement of the input and output indicators in the green technology R&D stage

Indicator	Definition and measurement	Unit
Input (4)		
IERD	Intramural expenditure on R&D	billion yuan
GPEST	General public expenditure on S&T	billion yuan
ENPD	Expenditure on new products development	billion yuan
FERDP	Full-time equivalent of R&D personnel	10000 man-years
Output (3)		
NGPA	Number of green patent applications	1000 unit
NGPG	Number of green patent grants	1000 unit
PNPD	Projects for new products development	1000 unit

through a relatively long period of time from R&D to transformation, the input and output indicators for these two stages should be different. When constructing an indicator system to evaluate the efficiency of green innovation, a distinction should be made between the selection of indicators for these two different stages.

The definition and measurement of the input and output indicators in the green technology R&D stage are shown in Table 1. In this stage, the input indicators consist mainly of capital (IERD, GPEST and ENPD) and labour (FERDP).

The output indicators of the green technology R&D stage, which is the antecedent of the green achievement transformation stage, should be considered as part of the input indicators of the green achievement transformation stage. Energy consumption and non-R&D inputs are also input indicators to be considered at this stage. Among them, non-R&D inputs are mainly obtained by adding the expenditure for the acquisition of foreign technology, assimilation, purchase of domestic technology, and technology renovation. The undesirable outputs are mainly considered in the green achievement transformation stage. As one of the undesirable outputs, the comprehensive index of environmental pollution is derived from four indicators (industrial COD discharged, industrial SO_2 emission, common industrial solid wastes generated, and CO_2 emissions) and is calculated by the entropy weighting method. The evaluation indicators selected for the green achievement transformation stage are shown in Table 2.

2.4. Data sources

In this study, raw data on inputs and outputs of Chinese provinces from 2007 to 2021 were selected to calculate GIE. Four provinces, Hong Kong, Macao, Taiwan and Xizang, were not included in the study area due to the missing data. Hence, only 30 provinces in China were included in the study area, yielding a sample of 450. This study mainly obtained raw data from the National Bureau of Statistics of China, Chinese Research Data Services (CNRDS) Platform, China Statistical Yearbook, China Energy Statistical Yearbook, China Statistical Yearbook on Environment, and China Statistical Yearbook on Science and Technology. Simultaneously, this study filled in the missing data through other official sources (e.g., statistical yearbooks released by the provinces) to ensure the accuracy of the data and the rigour of the study. None of the raw data has been transformed in any way other than that. The data sources of all indicators are shown in Table 3.

Additionally, the descriptive statistics for all indicators are shown in Table 4. In the green technology R&D stage, the time range for the data of IERD, GPEST, ENPD and FERDP is 2007–2019. Correspondingly, the time range of NGPA, NGPG and PNPD is 2008–2020. Similarly, in the green achievement transformation stage, the raw data of TEC and NRDI, besides NGPA, NGPG and PNPD, also range from 2008 to 2020. As output indicators, the raw data of SRNP, TVTM, VAI, CIEP and ECGDP range from 2009 to 2021. That is, considering the time lag effect

Tab. 2. Definition and measurement of the indicators in the green achievement transformation stage

INDICATOR	DEFINITION AND MEASUREMENT	UNIT
Input (5)		
NGPA	Number of green patent applications	1000 unit
NGPG	Number of green patent grants	1000 unit
PNPD	Projects for new products development	1000 unit
TEC	Total energy consumption	million tce
NRDI	Non-R&D inputs	billion yuan
Desirable output (3)		
SRNP	Sales revenue of new products	billion yuan
TVTM	Transaction value in technical markets	billion yuan
VAI	Value-added of industry	billion yuan
Undesirable output (2)		
CIEP	Comprehensive index of environmental pollution	index
ECGDP	Energy consumption per unit of GDP	tce/10000 yuan

Tab. 3. Sources of raw data for all indicators

INDICATOR	SOURCE
ENPD, PNPD, SRNP, TVTM	The National Bureau of Statistics of China
NGPA, NGPG	Chinese Research Data Services (CNRDS) Platform
GPEST, VAI, ECGDP	China Statistical Yearbook
TEC, CIEP, ECGDP	China Energy Statistical Yearbook
CIEP	China Statistical Yearbook on Environment
IERD, FERDP, NRDI	China Statistical Yearbook on Science and Technology

Tab. 4. Descriptive statistics for all indicators

INDICATOR	MEAN	MIN	MEDIAN	MAX	ST. D	SKEWNESS	KURTOSIS
IERD	39.560	0.260	17.614	309.849	50.860	2.325	9.068
GPEST	9.573	0.252	4.604	116.879	13.439	3.711	22.585
ENPD	29.936	0.225	12.706	386.498	48.187	3.649	19.768
FERDP	10.963	0.126	6.510	80.321	12.664	2.384	9.599
NGPA	6.296	0.031	2.750	63.361	9.579	3.105	14.364
NGPG	3.420	0.016	1.578	35.825	5.060	3.166	15.660
PNPD	13.128	0.083	6.237	166.140	21.410	3.715	19.832
TEC	144.218	11.350	117.735	421.329	87.645	0.928	3.273
NRDI	15.231	0.152	10.695	111.691	15.071	2.469	11.851
SRNP	538.918	0.857	262.760	4968.490	787.099	2.806	11.940
TVTM	42.908	0.056	10.374	700.565	87.154	4.080	23.503
VAI	850.608	27.370	590.480	4573.070	807.624	1.955	7.318
CIEP	0.284	0.001	0.249	0.866	0.202	0.725	2.830
ECGDP	0.869	0.173	0.670	2.611	0.523	1.186	3.714

of GIE, this study sets the time lag for both inputs and outputs of the green technology R&D stage and the green achievement transformation stage to one year.

2.5. METHODS

The Super-efficiency SBM Model. In this study, the super efficiency SBM model considering undesirable outputs is applied to calculate the GTRDE and the GATE in 30 provinces in China. Specifically, this model combines the advantages of both the SBM model and the super-efficiency model, i.e., it considers undesirable outputs and allows for further differentiation of relatively efficient DMUs. This model assumes n DMUs, and each DMU involves input, desirable output, and undesirable output indicators. Then, referring to Xu et al. (2020), this model can be constructed as in Eq. (1).

$$\min \rho = \frac{1 + \frac{1}{m}\sum_{m=1}^{M}\frac{s_m^x}{x_{jm}^t}}{1 - \frac{1}{l+h}\left(\sum_{l=1}^{L}\frac{s_l^y}{y_{jl}^t} + \sum_{h=1}^{H}\frac{s_h^b}{b_{jh}^t}\right)}$$

$$s.t.\begin{cases} x_{jm}^t \geq \sum_{j=1,j\neq 0}^{n} \lambda_j^t x_{jm}^t + s_m^x \\ y_{jl}^t \geq \sum_{j=1,j\neq k}^{n} \lambda_j^t y_{jl}^t - s_l^y \\ b_{jh}^t \geq \sum_{j=1,j\neq k}^{n} \lambda_j^t b_{jh}^t + s_h^b \\ \lambda_j^t \geq 0, s_m^x \geq 0, s_l^y \geq 0, j = 1,\cdots,n \end{cases} \quad (1)$$

where ρ denotes the GIE of provinces, and the larger the value, the higher the GIE of the specific province. λ represents the constant vector of the j-th DMU. Moreover, x_j^t, y_j^t and b_j^t denote the input, desirable output, and undesirable output indicator of the j-th DMU in the t-th year, respectively. m, l and h denote the number of the input, desirable output, and undesirable output indicator, while s_m^x, s_l^y and s_h^b are the slack vector of the input, desirable output, and undesirable output indicator, respectively.

Global and Local Moran's I Index. In this study, the global Moran's I index is adopted to investigate the global spatial autocorrelation, i.e., the overall distribution of the GIE, and to judge whether there is a spatial clustering characteristic and the degree of clustering of all provinces. The value range of the global Moran's I index is [-1,1]. Also, a global Moran's I index greater than 0 means that provinces with higher (or lower) values of GIE are spatially clustered, i.e., the contiguous provinces have very similar GIE. Conversely, a global Moran's I index of less than 0 implies the existence of negative spatial autocorrelation, i.e., strong variability in GIE among contiguous provinces. When the global Moran's I index is equal to 0, it indicates that there is no spatial autocorrelation, i.e., the GIE of each province is spatially randomly distributed. Referring to Li et al. (2023) and Mei et al. (2023), the global Moran's I index can be calculated as in Eq. (2).

$$Global \ Moran's \ I = \frac{n \times \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} (x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{n} (x_i - \bar{x})^2 \times \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}} \quad (2)$$

where n represents the number of provinces. Also, x_i denotes the GIE of the i-th province. $\bar{x}$ is the average of the green innovation efficiencies of all provinces. Moreover, w_{ij} is the spatial weight matrix that indicates the adjacency relationship between the i-th province and j-th province. When the i-th province and j-th province are adjacent, $w_{ij} = 1$; otherwise, $w_{ij} = 0$. In addition, a specific province is not adjacent to itself, i.e., it is specified that $w_{ii} = 0$.

The local Moran's I index is used to measure the local spatial autocorrelation and spatial distribution of the GIE of each province in relation to adjacent provinces. Thus, referring to Li et al. (2023) and Mei et al. (2023), the local Moran's I index can be calculated as in Eq. (3).

$$Local \ Moran's \ I = \frac{n \times (x_i - \bar{x}) \times \sum_{j=1}^{n} w_{ij} (x_j - \bar{x})}{\sum_{i=1}^{n} (x_i - \bar{x})^2} \quad (3)$$

3. RESULTS AND DISCUSSION

3.1. EVALUATION OF GIE

The evaluation of GTRDE in each province is shown in Table 5. Due to layout constraints, Table 5

only shows the evaluated efficiencies for even-numbered years. Among all the GTRDEs, the highest value appeared in Hainan in 2008, with an efficiency of 1.406, while the lowest value appeared in Inner Mongolia in 2012, with an efficiency of 0.185. That is, the highest value was 7.6 times the lowest value. Inner Mongolia ranked in the top ten lowest GTRDEs in seven years; hence, it became the province with the lowest average GTRDE, with a value of only 0.314. Other provinces with low GTRDE included Jilin, Shanxi, Shanghai, and Liaoning, with average values below 0.5. On the contrary, the province with the highest GTRDE was Zhejiang, followed by Hainan, Beijing, Sichuan, Chongqing, and Ningxia, with average values above 0.7. Additionally, with the exception of Guangdong and Inner Mongolia, persistent fluctuation was a distinctive characteristic of the GTRDE exhibited by the vast majority of provinces. The GTRDE of Guangdong and Inner Mongolia generally showed a steady upward trend during the examined time period.

The evaluation of GATE in each province is shown in Table 6. Due to layout constraints, Table 6 only shows the efficiencies for odd-numbered years. GATE in Hainan in 2014 was 1.835, which was the highest of all efficiencies. In comparison, Guangxi had the lowest efficiency in 2015, at 0.054. The top 26 lowest-ranked of all efficiencies were from some selected years in Guangxi, Guizhou, Xinjiang, and Ningxia. In consequence, Ningxia, Guizhou, and Guangxi became the three provinces with the lowest average GATE, with an average efficiency of 0.142, 0.247, and 0.259, respectively. On the contrary, Xinjiang was ranked 14th with an efficiency of 0.650. This is mainly due to the very large fluctuations in the GATE in Xinjiang in different years, spanning from 0.079 (in 2016) to 1.101 (in 2011), a difference of nearly 14 times. Furthermore, Hainan, Guangdong, and Henan had GATE higher than 1, followed closely by Qinghai, Jiangxi and Beijing, which had efficiencies higher than 0.9. Overall, compared with the GTRDE, the disparity in the GATE in different provinces was more apparent.

3.2. TEMPORAL EVOLUTION OF GIE

The temporal evolution of GTRDE in each divided region in China is shown in Fig. 3. As shown in Fig. 3, the temporal evolution of GTRDE is highly consistent across regions. Nationwide, while the GTRDE has remained on the rise amidst fluctuations, it has only increased from 0.651 in 2008 to 0.757 in

Tab. 5. Evaluation of GTRDE

| Province	Code	2008	2010	2012	2014	2016	2018	2020	Average
Zhejiang	ZJ	1.066	0.469	0.660	0.620	0.825	1.181	1.072	0.863
Hainan	HI	1.406	1.054	0.598	0.571	0.686	1.073	1.132	0.845
Beijing	BJ	1.160	0.439	0.573	0.781	1.010	1.099	0.611	0.798
Sichuan	SC	0.769	0.524	0.678	0.620	0.828	1.063	0.657	0.748
Chongqing	CQ	1.039	0.593	0.685	0.665	0.767	0.717	0.607	0.743
Ningxia	NX	1.047	0.384	0.607	0.550	0.731	1.035	0.778	0.724
Guizhou	GZ	1.051	0.438	0.516	0.589	0.659	1.065	0.650	0.690
Tianjin	TJ	1.022	0.405	0.483	0.491	0.583	1.033	1.005	0.681
Anhui	AH	0.625	0.411	0.585	0.591	0.829	1.072	0.636	0.677
Jiangsu	JS	0.559	0.434	0.557	0.537	0.649	1.064	1.073	0.677
Guangxi	GX	1.006	0.304	0.366	0.499	1.011	0.774	0.627	0.632
Shaanxi	SN	1.069	0.484	0.602	0.553	0.443	0.559	0.650	0.620
Guangdong	GD	0.392	0.419	0.435	0.410	0.553	1.154	1.092	0.609
Shandong	SD	0.508	0.460	0.460	0.452	0.589	0.638	1.011	0.597
Yunnan	YN	0.518	0.390	0.454	0.528	0.728	1.007	0.641	0.594
Fujian	FJ	0.361	0.411	0.470	0.441	0.743	1.046	0.659	0.575
Hebei	HE	0.414	0.399	0.481	0.436	0.637	0.773	1.005	0.552
Heilongjiang	HL	0.561	0.419	0.436	0.506	0.563	0.711	0.754	0.550
Qinghai	QH	1.079	0.286	0.411	0.205	0.344	0.675	1.084	0.545
Jiangxi	JX	0.435	0.344	0.381	0.407	0.672	1.039	0.535	0.526
Hubei	HB	0.775	0.453	0.435	0.422	0.443	0.565	0.470	0.519
Hunan	HN	0.683	0.412	0.482	0.485	0.492	0.603	0.528	0.516
Henan	HA	0.525	0.437	0.413	0.442	0.535	0.723	0.582	0.515
Gansu	GS	0.533	0.386	0.478	0.435	0.443	1.031	0.703	0.512
Xinjiang	XJ	0.450	0.365	0.328	0.375	0.545	1.007	1.037	0.510
Liaoning	LN	0.391	0.347	0.357	0.311	0.486	0.742	0.649	0.453
Shanghai	SH	0.418	0.341	0.402	0.394	0.430	0.484	0.496	0.426
Shanxi	SX	0.277	0.313	0.318	0.295	0.446	0.615	0.663	0.405
Jilin	JL	0.359	0.276	0.319	0.292	0.320	0.457	0.488	0.402
Inner Mongolia	NM	0.217	0.186	0.185	0.228	0.296	0.460	0.818	0.314
Average	/	0.691	0.419	0.472	0.471	0.610	0.849	0.757	0.594
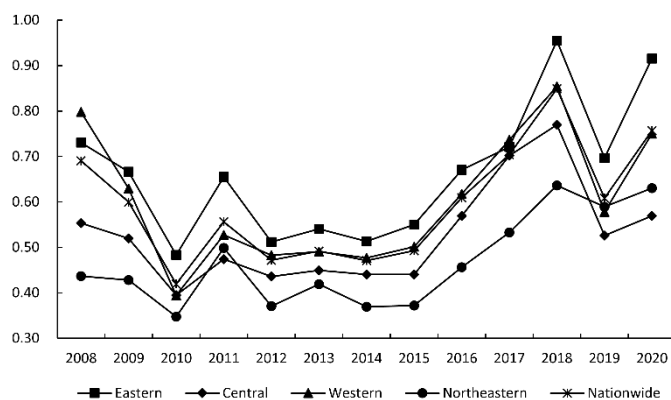
Fig. 3. Temporal evolution of GTRDE by region

Tab. 6. Evaluation of GATE

PROVINCE	CODE	2009	2011	2013	2015	2017	2019	2021	AVERAGE
Hainan	HI	1.529	1.119	1.016	1.033	1.035	1.136	1.041	1.173
Guangdong	GD	1.013	1.045	1.016	1.040	1.020	1.113	1.111	1.050
Henan	HA	1.016	1.030	1.014	0.867	1.023	1.011	1.028	1.006
Qinghai	QH	1.236	1.073	1.066	1.101	1.140	1.049	0.410	0.971
Jiangxi	JX	1.014	1.050	1.044	1.001	0.762	0.469	1.072	0.952
Beijing	BJ	1.027	1.035	1.020	0.590	0.651	1.191	1.217	0.946
Fujian	FJ	0.620	1.024	0.606	1.012	1.002	1.021	1.048	0.886
Hubei	HB	0.262	0.640	0.890	1.023	1.047	1.059	1.069	0.868
Jiangsu	JS	1.033	1.015	0.627	0.576	0.641	1.001	1.080	0.866
Chongqing	CQ	0.524	1.004	0.562	0.645	1.005	1.015	1.047	0.815
Shanghai	SH	0.584	0.703	0.611	0.635	1.015	1.011	0.737	0.811
Inner Mongolia	NM	1.038	1.017	1.002	0.338	0.477	0.434	1.047	0.774
Shaanxi	SN	0.222	0.341	0.604	0.498	1.012	1.044	1.067	0.734
Hunan	HN	1.210	0.380	0.403	0.470	1.007	0.622	1.032	0.720
Shandong	SD	1.014	1.003	0.489	0.474	0.462	0.519	1.033	0.673
Tianjin	TJ	0.468	0.524	0.513	0.641	0.701	0.577	0.826	0.661
Xinjiang	XJ	0.172	1.101	1.007	0.093	0.089	1.018	1.029	0.650
Shanxi	SX	0.371	1.019	0.431	0.224	0.658	0.413	0.597	0.541
Jilin	JL	0.419	0.831	0.264	0.302	0.652	0.870	0.458	0.516
Zhejiang	ZJ	0.321	0.348	0.179	0.308	0.320	0.491	1.039	0.492
Hebei	HE	0.486	1.016	0.337	0.276	0.261	0.428	0.648	0.472
Anhui	AH	0.474	0.486	0.367	0.344	0.301	0.346	0.889	0.449
Gansu	GS	0.445	0.499	0.350	0.242	0.249	0.438	0.539	0.445
Sichuan	SC	0.326	0.348	0.366	0.405	0.466	0.577	0.666	0.445
Liaoning	LN	0.317	0.386	0.411	0.344	0.410	0.400	0.482	0.394
Yunnan	YN	0.225	1.012	0.443	0.344	0.320	0.251	0.298	0.360
Heilongjiang	HL	0.178	0.221	0.256	0.233	0.365	0.297	0.477	0.294
Guangxi	GX	0.121	0.296	0.128	0.054	0.172	0.300	1.016	0.259
Guizhou	GZ	0.078	0.219	0.122	0.149	0.227	0.405	0.490	0.247
Ningxia	NX	0.122	0.299	0.080	0.106	0.115	0.124	0.185	0.142
Average	/	0.596	0.736	0.574	0.512	0.620	0.688	0.823	0.654

2020 over the examined period, with an average annual growth rate of only 1.265 %. Moreover, only in 2017, 2018, and 2020 was the national average GTRDE higher than in 2008. Only in 2018 and 2020, with an efficiency of 0.954 and 0.916, respectively, was the GTRDE in the eastern region higher than in 2008 (with an efficiency of 0.731). The GTRDE in the central region was higher in 2016, 2017, 2018, and 2020 than in 2008. In contrast, in the western region, only 2018 (with an efficiency of 0.854) has a higher GTRDE than 2008. Also, the temporal evolution of GTRDE in the northeastern region is more unique than in other regions, with higher efficiency in 2011 and the years after 2016 than in 2008. It should be noted that regardless of region, the highest value of GTRDE occurred in 2018, while the lowest value occurred in 2010. Besides, Fig. 3 also shows that the temporal evolution of GTRDE showed the basic characteristic of "eastern>western>central>northeastern".

Overall, the temporal evolution of GTRDE in each region can be divided into four stages: 2008–2010, 2010–2015, 2015–2018, and 2018–2020. In the first stage (2008–2010), GTRDE was characterised by a continuous decline, even reaching its lowest value in 2010 for the entire examined period. In 2008, several global events (e.g., the Beijing 2008 Summer Olympics) were held in China, promoting GTI in

industries such as information technology, construction, transportation, tourism and services. This has resulted in increased investment in green technology research and development in the relevant industries, leading to many green technology patents and new products. Due to the Asian Financial Crisis that erupted in 2008, many firms had to cut back on unnecessary expenditures, including R&D, in the following year or two, which seriously affected the output of products and services produced via green technology. As China gradually recovered from the recession in the second stage (2010–2015), green technology R&D inputs and outputs began stabilising, and the efficiency remained on a relatively flat trend. In the third stage (2015–2018), the GTRDE increased rapidly and reached its highest value in 2018 for the examined period. This may be attributed to the fact that the government had introduced a number of policies to promote GTI, such as supporting financial subsidies and tax incentives to the firms that actively research and develop green technologies and opening up green channels to support the introduction of advanced talents. In addition, the GTRDE fluctuated and was characterised by a clear V-shaped pattern in the fourth stage (2018–2020). In summary, the GTRDE of each region shows an upward trend in the long term.

The temporal evolution of GATE in China is shown in Fig. 4. In similarity to the temporal evolution of GTRDE, while GATE maintains a long-term growth pattern over the period examined, the growth amplitude is relatively small and varies considerably across regions. The difference is that the temporal evolution of GATE generally shows the characteristic of "eastern>central>western>northeastern". Also, all regions, except the northeastern, reached their highest values for the period examined in 2014 in terms of GATE. Specifically, in the northeastern region, the highest value occurred in 2019 at 0.522. Due to a good economic foundation and a well-developed infrastructure and business environment, the GATE is significantly higher in the eastern and central regions compared to others. The GTRDE and GATE in the northeastern region are the lowest among all regions, and the efficiency gap with other regions tends to widen. One possible explanation is that it is difficult to adjust the long-standing national economic system of the northeastern region based on heavy industry to environmental and ecological constraints. Also, owing to its geographical location and natural environment, the region is less likely to attract advanced technical talents.

Generally, the temporal evolution of GATE can be divided into three stages: 2009–2013, 2013–2015, and 2015–2021. In the first stage (2009–2013), the GATE experienced the first significant fluctuation in the period examined, with the turning point occurring in 2011. This year, China's science and technology authorities issued a number of documents related to the "Twelfth Five-Year Plan", as well as the National Medium- and Long-Term Plan for the Development of S&T Talents (2010–2020). The second significant fluctuation occurred in the second stage (2013–2015), with the turning point occurring in 2014, and was characterised by an obvious reverse V-shape. In the third stage (2015–2021), beginning in 2015, the GATE entered a period of steady growth. In 2015, China amended the Law of the PRC on Promoting the Transformation of S&T Achievements to further provide policy support for promoting the transformation of green achievements. The trend in efficiency during this stage remained upward, although there were occasional slight fluctuations. In addition, the similarity in the temporal evolution of GTRDE and
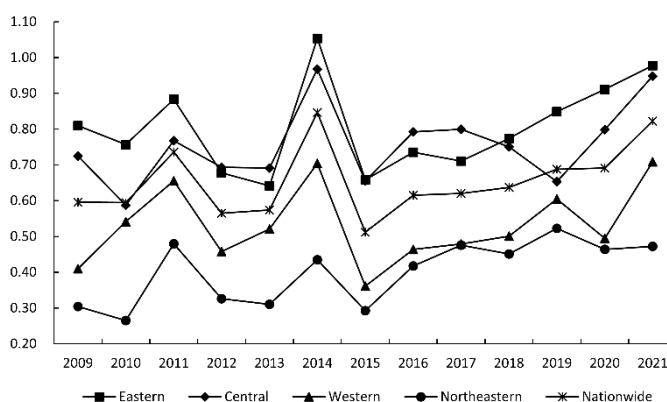

Fig. 4. Temporal evolution of GATE by region

GATE suggests, to some extent, a correlation between the two. This further justifies this study's consideration of the time lag effect of technology in calculating the GIE. However, there are also differences in the temporal evolution of the two, indicating that green technologies need to go through many complex processes, from R&D to the translation of achievements. Management systems, technology preferences, and corporate mission and vision may all influence the effectiveness of green technology transformation. In fact, the low efficiency of technology transformation has always been an urgent and critical issue in China's technology sector. Many green technologies are often shelved after being invented, and difficult to commercialise.

3.3. SPATIAL EVOLUTION OF GIE

Fig. 5 shows the spatial evolution of GTRDE in each province in 2008, 2012, 2016, and 2020. As shown in Fig. 5(a), the highest GTRDE in 2008 was in Hainan (1.406), and the lowest was in Inner Mongolia (0.216), with the former being 6.5 times higher than the latter. Besides, the GTRDE was higher in the western region than in the east, followed by the cen-

tral and northeastern regions, and there was a very large gap between the former two and the latter. The efficiency in the western region encompassed all five levels, with no clear pattern in the spatial distribution of the different levels. But, except Qinghai, the provinces in the western region with high GTRDE showed a clear spatial concentration characteristic, i.e., the vertical type. These provinces were better geographically and resource-wise than other provinces in the western region. Also, they were in a better economic condition to provide financial support for R&D in green basic technologies. In contrast, the spatial distribution of GTRDE in the central region was complex, contained in four different levels, and the distribution of each level was generally concentrated. GTRDE was included in three levels in the eastern region while in two levels in the northeast region. Provinces in the eastern region with higher GTRDE appeared in Beijing, Tianjin and Zhejiang, all of which were more economically developed regions. However, GTRDE in Shanghai, Guangdong and Fujian, which also had good economic development, was relatively low in 2008. A possible explanation is that although Guangdong and Fujian had high levels of economic development in 2008, there was a wide
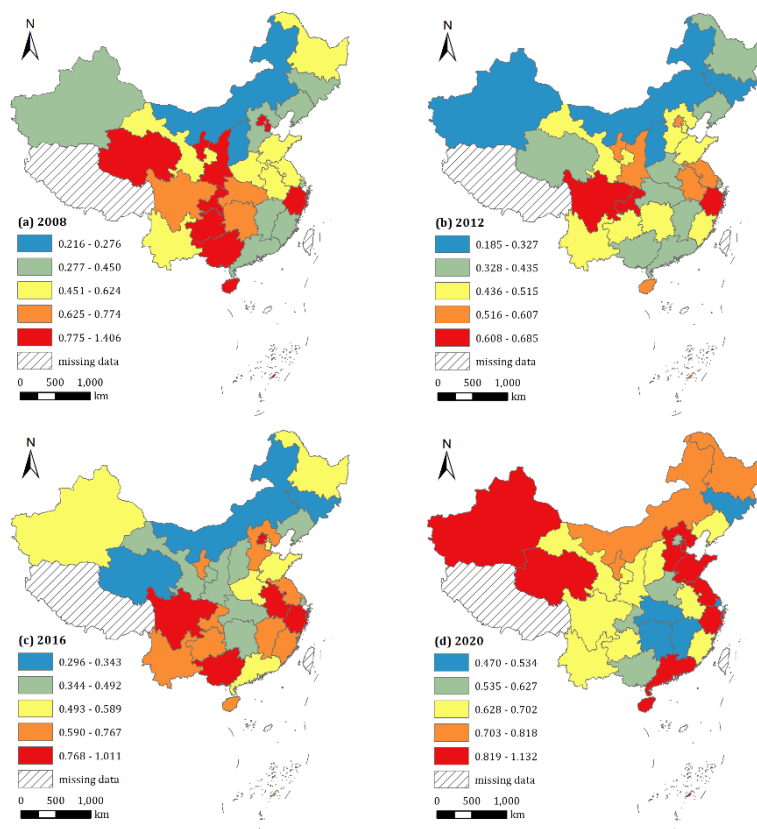

Fig. 5. GTRDE in 2008, 2012, 2016 and 2020 by province

gap in economic development among cities within the provinces. Some cities were still at the stage of having a relatively weak economic base and did not have sufficient funds to invest in technology R&D.

In 2012, the GTRDE was lower in almost every province than in 2008. As seen in Fig. 5(b), the spatial distribution of GTRDE became more dispersed and irregular. Overall, provinces with high GTRDE showed relatively isolated points. In 2012, the province with the highest GTRDE was Chongqing (0.685), while the lowest remained Inner Mongolia (0.185), and the majority of the efficiencies ranged from 0.3 to 0.6. Moreover, the efficiency in the western region included all five levels, and only two provinces (i.e., Chongqing and Sichuan) were at the highest level, falling from six in 2008. Both the eastern region and the central region contained four levels, of which the former had no provinces at the lowest level, and the latter had no provinces at the highest level. Specifically, in the eastern region, only Zhejiang was at the highest level, while Shanxi in the central region was at the lowest. Compared with the previous period, the GTRDE of the three provinces in the northeast region had continued to decline, with Jilin's GTRDE being only 0.319.

As shown in Fig. 5(c), the spatial concentration distribution characteristics of GTRDE in 2016 in each province were relatively evident. In 2016, the highest GTRDE in Guangxi (1.011) was 3.4 times higher than the lowest in Inner Mongolia (0.296). In the eastern region, Zhejiang and Beijing were at the highest level of GTRDE. All other eastern provinces except Guangdong and Shandong were in the second-highest level. Hence, areas with high GTRDE in the eastern region were mainly concentrated in the Beijing-Tianjin-Hebei region and the Yangtze River Delta region, which were almost the most important economic zones and urban clusters in China. Actually, green technology R&D in these two areas benefited from good location advantages, policy favouritism, and the introduction of technological talents. In the western region, the spatial concentration of GTRDE was characterised by a very significant and clear demarcation line. Among them, the provinces with higher efficiency were mainly concentrated in the southwestern area, especially in Sichuan and Guangxi. The central region had a spatial correlation between the provinces with high GTRDE. Also, the provinces in the central region, which were spatially neighbouring to the eastern region, were relatively more efficient in green technology R&D than other provinces in the central region. This evidence con-

firmed that the eastern region had a strong but limited radiation effect on green technology R&D in the central region. Generally, nationwide, the provinces with high GTRDE were mainly concentrated in the southwestern area and the eastern region, and the concentration characteristic was very significant.

In 2020, in 21 provinces, the GTRDE was higher than the efficiency in 2016. Of the nine remaining provinces, two (Beijing and Fujian) were from the eastern region, two were from the central region (Jiangxi and Anhui), and the others were from the western region. As seen in Fig. 5(d), the spatial concentration characteristic of the GTRDE was most significant in 2020 compared with the previous years. Nationwide, in 2020, the areas with high GTRDE were mainly concentrated in the eastern region, Qinghai and Xinjiang in the northwestern area, and Heilongjiang and Inner Mongolia in the northern area. Similarly, the spatial correlation of regions with low GTRDE was also very clear, mainly concentrated in certain provinces in the central and western regions. Normally, the eastern region attracted more technical talents by virtue of its good economic foundation and continuously increased its investment in technological research and development to improve efficiency. The sudden outbreak of the new crown epidemic that swept the world in 2020 posed a serious challenge to some of the less economically developed provinces. Regardless, the GTRDE in most provinces may be increasing in the long run.

Fig. 6 shows the spatial evolution of GATE by province in 2009, 2013, 2017, and 2021. In 2009, the province with the highest GATE was Hainan, with an efficiency of 1.529, and the province with the lowest was Guizhou, with only 0.078. The former was 19.6 times more efficient than the latter, which was a huge gap. As seen in Fig. 6(a), GATE in the eastern provinces included four levels, among which Zhejiang was alone in the second-lowest level. The spatial distribution of GATE of the provinces in the other three regions was relatively decentralised, and there was generally no obvious spatial correlation. Moreover, with the exception of Heilongjiang, Liaoning, Zhejiang, Shanxi, and Hubei, most of the provinces within the lowest and second-lowest levels belonged to the western region. This indicates that in 2009, the spatial distribution of GATE was still relatively loose. There was no unified system for green achievement transformation, resulting in huge differences between regions. Meanwhile, the spatial radiation effect of the provinces with high GATE on the neighbouring areas was not well-reflected. In terms of geographical dis-
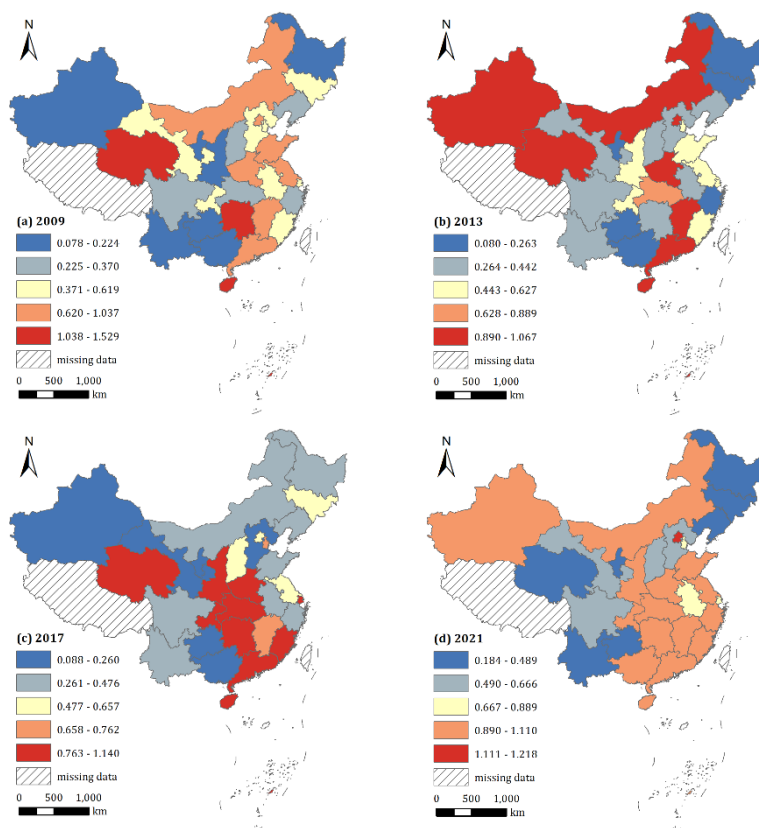
Fig. 6. GATE in 2009, 2013, 2017, and 2021 by province

tribution, GATE was characterised by "high in the east and low in the west". This result was at variance with that presented in Fig. 5(a) (in 2008); thus, most of the provinces with high GTRDE, especially in the southwest area, had low GATE. This is a further indication that the gap between green technology R&D and transformation needs to be narrowed.

The province which had the highest GATE in 2013 was Qinghai (1.067), while the lowest was Ningxia (0.080), with the former 13.3 times higher than the latter. As shown in Fig. 6(b), the spatial distribution of the GATE in 2013 was relatively concentrated compared to that of 2009. Both provinces with high and low GATE showed pronounced concentration characteristics. Hence, it means that some provinces with high GATE were gradually having a radiation effect on neighbouring areas. In addition, the GATE of the eastern and western regions contained four levels. Similarly, the central region contained three levels, and the northeastern region contained two levels. The GATE across several levels was a powerful indication that the differences between provinces were significant. Besides, in the eastern region, only Beijing, Guangdong, and Hainan were at

the highest level of GATE, and in the central region, they were Henan and Jiangxi. In the western region, there were three provinces ranked at the highest level, namely Xinjiang, Qinghai, and Inner Mongolia. Similar to 2009, the GATE in the northeastern region was low, which may be related to the economic system based on heavy industry.

Fig. 6(c) depicts the spatial distribution of GATE in each province in 2017. In 2017, the province with the highest GATE was Qinghai (1.140), and it was higher than the efficiency in 2013 (1.067). The province with the lowest efficiency was Xinjiang, with an efficiency of 0.088. As can be seen in Fig. 6(c), nationwide, except Qinghai, the provinces with high GATE were concentrated and had a general north-south direction. Additionally, in the eastern region, Shanghai, Fujian, Guangdong, and Hainan were located at the highest level. Namely, the spatial distribution of GATE in the provinces in the eastern region had both concentrated features and isolated points. The provinces in the central region had a higher average value of GATE than other regions, which could be verified by Fig. 6(c). This indicated that the provinces in the central region had a relatively strong radiation effect

on the neighbouring regions. Furthermore, in the western region, only Qinghai, Shaanxi, and Chongqing were located at the highest level, while all other provinces were located at the lowest and second-lowest levels. This might be connected to the less-than-perfect business environment for hi-tech companies. In contrast, the spatial distribution of GATE in the northeast had not changed much from the previous years, and its efficiency had always stabilised at a low level.

As shown in Fig. 6(d), in 2021, Beijing was the province which had the highest GATE, with an efficiency of 1.218. The lowest was Ningxia (0.184). The former was 6.6 times higher than the latter. In the eastern region, except the Beijing-Tianjin-Hebei region and Shanghai, all the other provinces were located in the second-highest level. Similarly, in the central region, all provinces except Shanxi and Anhui were in the second-highest level of efficiency. And, the three provinces in the northeastern region were located at the lowest level. That is, in the eastern, central and northeastern regions, the gaps in efficiency between provinces within the specific region had narrowed. However, the spatial distribution of GATE in the western region was more complicated. In the western region, there were distinct spatial concentration characteristics in the provinces with high and low efficiency, respectively. Compared with 2017, the GATE in Xinjiang and Inner Mongolia was improved to a large extent, while the situation in Qinghai was completely opposite. Specifically, in 2009, 2013 and 2017, Qinghai's GATE was consistently at the highest level, but in 2021, its efficiency fell to the lowest level. In addition, Fig. 6(d) also showed

that there were significant differences in efficiency within major city clusters, especially in the Beijing-Tianjin-Hebei region. This further suggests that further synergies are needed in the transformation of green technology achievements among the provinces.

3.4. Spatial autocorrelation analysis

Table 7 shows the global Moran's I index of GIE (i.e., GTRDE and GATE). As the table shows, the spatial autocorrelation of GTRDE was not significantly manifested overall. Of all the years, the largest global Moran's I index was 0.2032 in 2018 (P-value of 0.037), while the smallest was -0.0205 in 2019 (P-value of 0.441). Furthermore, the global Moran's I index of GTRDE did not show a significant upward or downward trend during the period examined. In individual years, i.e., 2012, 2014–2016, and 2018, GTRDE exhibited a significant positive spatial autocorrelation. The significance level is 10 % for 2012 and 2014–2016 and 5 % for 2018. This means that, excluding 2013 and 2017, GTRDE exhibited a positive spatial autocorrelation only during 2012–2018.

As shown in Table 7, in terms of GATE, the global Moran's I index exhibited more complex irregularities during 2009–2021. The highest global Moran's I index occurred in 2020 (0.3247), while the lowest occurred in 2011 (-0.1171). However, the global Moran's I index exhibited significant positive spatial autocorrelation only in 2015, 2020, and 2021. The significance level is 10 % for 2015 and 2021 and 1 % for 2020. Thus, this suggests a lack of strong evidence for the existence of spatial autocorrelation overall, although

Tab. 7. Global Moran's I index of GIE

| Year	GTRDE			GATE		
	Moran's I	Z-score	P-value	Moran's I	Z-score	P-value
2008	0.1256	1.2308	0.125			
2009	0.0132	0.3496	0.338	-0.0797	-0.4158	0.353
2010	0.0015	0.4204	0.331	0.0612	0.7388	0.226
2011	0.0902	0.9712	0.171	-0.1171	-0.7220	0.242
2012	0.1627	1.5182	0.074	-0.0577	-0.2158	0.426
2013	0.0997	0.9828	0.163	-0.0479	-0.1508	0.463
2014	0.1920	1.7478	0.054	0.0611	0.7736	0.218
2015	0.1519	1.5733	0.067	0.1309	1.3965	0.095
2016	0.1702	1.7111	0.056	0.0934	1.0422	0.157
2017	0.0844	0.9939	0.166	0.0351	0.5669	0.276
2018	0.2032	1.8642	0.037	0.1165	1.2513	0.114
2019	-0.0205	0.1211	0.441	0.0181	0.4184	0.327
2020	0.0639	0.8464	0.191	0.3247	2.9109	0.004
2021				0.1581	1.4469	0.099
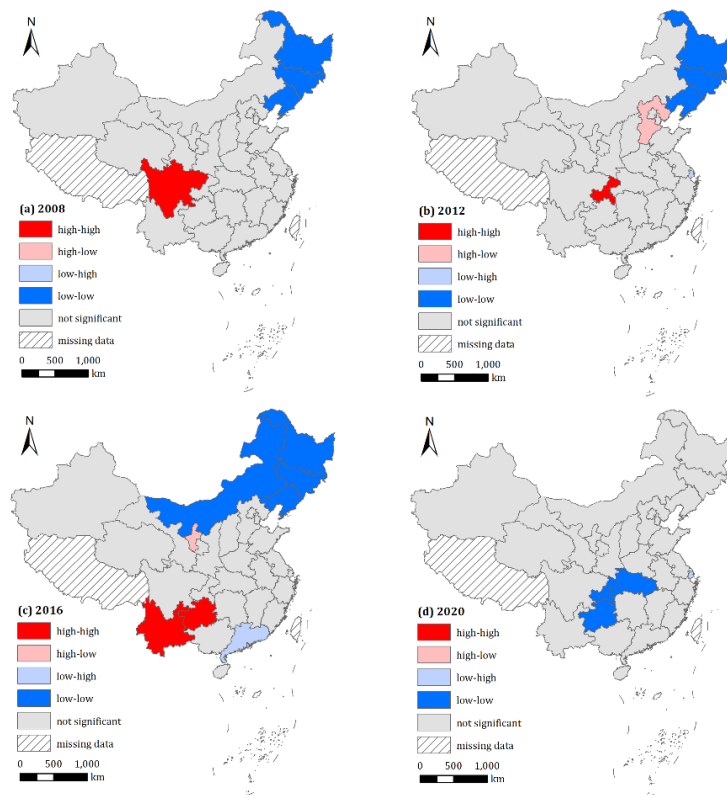
Fig. 7. Local spatial autocorrelation of GTRDE in 2008, 2012, 2016, and 2020 by province
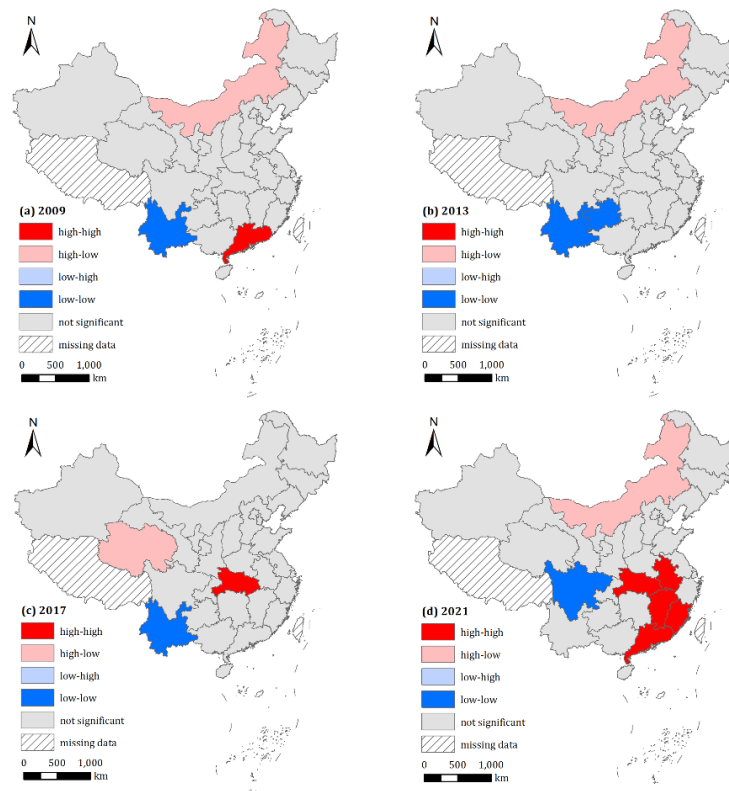

Fig. 8. Local spatial autocorrelation of GATE in 2009, 2013, 2017, and 2021 by province

the global Moran's I index of GATE shifts from negative to positive during 2009–2021. This further validates the results obtained mentioned above when analysing the spatial distribution of GIE.

The results of the local Moran's I index can be shown by the local indicators of spatial association (LISA) clustering map, as seen in Figs. 7 and 8. Specifically, Fig. 7 is the LISA clustering map of GTRDE, and Fig. 8 shows the LISA clustering map of GATE. Besides, in the LISA clustering map, the local spatial aggregation can be grouped into five categories: high-high, high-low, low-high, low-low, and not significant. Hence, in this study, the LISA clustering map can be easily adopted to show the local spatial aggregations of provinces with high and low GIE.

As seen in Fig. 7, the GTRDE exhibited different local spatial aggregation characteristics in the specific years. In 2008, Sichuan was the only province in the high-high region, while the northeastern region was in the low-low region. In 2012, the northeastern region remained in the low-low region. Meanwhile, Chongqing, Hebei and Shanghai belonged to the high-high, high-low, and low-high regions, respectively. In 2016, there had been an increase in the number of provinces belonged to the high-high and low-low regions. Yunnan and Guizhou were in the high-high region, and Inner Mongolia and the northeastern region belonged to the low-low region. Ningxia and Guangdong were in the high-low and low-high regions, respectively. In 2020, there were three provinces belonging to the low-low region, namely, Guizhou, Chongqing, and Hubei. Additionally, Shanghai was the only province in the low-high region.

Fig. 8 shows the local spatial aggregation of GATE. In 2009, Guangdong belonged to the high-high region. Inner Mongolia and Yunnan were in the high-low and low-low regions, respectively. In 2013, provinces in the low-low region were Yunnan and Guizhou. Also, Inner Mongolia still remained in the high-low region. In 2017, Hubei, Qinghai and Yunnan belonged to the high-high, high-low and low-low regions, respectively. In addition, the local spatial aggregation of GATE in 2021 changed significantly when compared to the previous years, especially in the high-high region. Five provinces belonged to the high-high region, namely, Fujian, Guangdong, Jiangxi, Hubei, and Anhui. Inner Mongolia belonged to the low-high region, while Sichuan belonged to the low-low region. Except for the provinces mentioned above, the other provinces shown in Figs. 7 and 8 belonged to the non-significant region.

4. DISCUSSION

As indicated in Figs. 3 and 4, the GTRDE and GATE exhibit significant temporal heterogeneity in China across years and a general trend of increasing volatility. This fully demonstrates the key role played by internal and external factors, such as science and technology policies and the innovation environment, in GIE, as well as the fact that GIE is susceptible to the synergistic interaction of multiple factors. The national and local governments have continued to adopt various policies and measures to enhance the GIE, and although some of these policies and measures have led to large fluctuations in the GIE, the overall trend remains positive and favourable. It should be noted that regardless of GTRDE or GATE, the magnitude of recovery and enhancement of GIE is relatively small compared to the earlier stages, so there is still much room for China's overall GIE to be enhanced. Particularly, in formulating science, technology and innovation policies, the national and local governments should ensure that the policies are relatively forward-thinking and cutting-edge.

With regard to spatial distribution, as indicated in Figs. 5 and 6, the GTRDE and GATE exhibit significant spatial heterogeneity across provinces in China. By and large, this heterogeneity is closely related to the political, economic, social, cultural, environmental, and resource endowments of a region. Among them, the role of economic development is the most powerful because it can provide sufficient financial and human resources and technological support for green innovation. Hence, driven by the nature of chasing profits, enterprises and other science and technology innovation subjects are more willing to promote green innovation. However, in individual provinces, the GIE shows results that mismatch the level of economic development. For instance, Shanghai's average GTRDE is ranked 27th in China, a total mismatch with its level of economic development as reflected in its 2nd-ranked GDP per capita. This may be related to the province's industrial planning, development orientation, urban resilience and development bottlenecks.

With the deepening geospatial correlation of economic development, as well as the deepening communication and cooperation between different spatial units, the green innovation development of individual provinces is not isolated and is susceptible to positive or negative influences from surrounding provinces. Hence, GIE usually exhibits significant

spatial autocorrelation and obvious spatial clustering characteristics. Nevertheless, the findings obtained from Tab. 7, Figs. 7 and 8 are relatively different from such an inference; that is, the spatial autocorrelation of China's interprovincial GIE is significant only in a few years, and its spatial clustering characteristics appear only in a few provinces. This fully demonstrates that there is still no favourable exchange and cooperation mechanism between provinces in China in terms of economic development, technological progress, green innovation, and talent mobility and that the in-depth integration between different geospatial units needs to be strengthened. Hence, the local governments need to take a macro-global perspective when formulating policies to enhance GIE.

CONCLUSIONS

Based on the original panel data of 30 provinces in China from 2007 to 2021, this study adopts the super efficiency SBM model considering undesirable outputs to evaluate the GTRDE and GATE and applies the global and local Moran's I index for spatial autocorrelation analysis. The GTRDE showed the basic characteristic of "eastern>western>central>northeastern", while that of GATE was "eastern>central>western>northeastern". Although the GATE was higher than that of the GTRDE in most provinces, the gap between provinces was significantly larger for the former than for the latter, i.e., the distribution of the former was more discrete while the latter was more concentrated. Also, significant global spatial autocorrelation in GIE across provinces existed only in a few years, and local spatial autocorrelation existed only in a few provinces.

According to the conclusions, a number of practical and targeted policy recommendations were proposed. First, the governments at all levels in China should implement the concepts of green development and technological innovation and closely integrate the two, emphasising that GTI is an important means of achieving environmental protection and ecological sustainability. Second, governments should actively guide the enterprises to strengthen GTI and support green technological research and development and the transformation of achievements through financial policies, tax incentives, and the introduction of talents so as to improve the GIE continuously. Third, the governments should avoid carrying out GTI only in

a small area and should prefer to strengthen the exchanges and collaboration with neighbouring regions to continuously narrow the gap between regions to maximise the radiation and spatial spillover effects of green technology.

This paper evaluated GTRDE and GATE in China's 30 provinces, but some limitations still exist. Due to the constraints of data availability, the selection of input and output indicators for the two stages of GTI was only limited to a few of the most prominent ones. This may affect the results of the efficiency evaluation. Besides, due to missing data, this study had to exclude four provinces and select only 30 provinces in China. Since the evaluation of efficiency based on data envelopment analysis is a relative efficiency, this issue of missing samples may affect the relative effectiveness between regions. Also, although this study divided the GTI process into two stages, it did not provide a more in-depth comparison and analysis of GIEs of these two stages, e.g., regional differences in GIEs.

Future research could focus on the following three main areas. First, based on a comprehensive and complete indicator system and samples, future research can adopt some cutting-edge evaluation methods to scientifically and rationally evaluate GIE in China and the rest of the world. Also, future research can analyse the evaluation results of GIE in depth to enrich the research content. For instance, future research can adopt kernel density estimation to analyse the dynamic evolution of GIE, apply the Dagum Gini coefficient to explore differences between regions and use the convergence model to examine the convergence of GIE. Moreover, future research could analyse in depth the influencing factors of GIE, e.g., with the help of geographically and temporally weighted regression, to explore the impact of different variables on GIE in the temporal and spatial dimensions. Alternatively, in the future, a dynamic qualitative comparative analysis approach can be used to analyse the synergies and configuration effects among the influencing factors and to explore the multivariate configuration paths to enhance the GIE in China's provinces.

ACKNOWLEDGMENTS

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MAPPING THE BARRIER OF HALAL FOOD INDUSTRY PERFORMANCE AND THE POLICY INSIGHT: COMBINATION OF ISM-DEMATEL APPROACH

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A B S T R A C T
The study aims to understand interlinkages and the relative importance of barriers to maximising the performance of the halal industry in Indonesia using Integrated Interpretive Structural Modelling (ISM) and the Decision-Making Trial and Evaluation Laboratory (DEMATEL) methodology. This study uses the content validity method to find the relevant or valid barrier, the ISM methodology to examine the interrelationship between the valid barriers, and the DEMATEL methodology to find the cause–effect relationships and revise the ISM digraph. To the best of the authors' knowledge, this study is the first to investigate the barriers to systematically maximising halal industry performance in Indonesia, elaborating on the relationship between relevant theories and practical issues to identify the barriers. The study's integrated approach helps corporate and political decision-makers identify essential barriers to development and explore the interdependencies between barriers. This can help decision-makers overcome critical obstacles, use resources more efficiently, and find innovative solutions for the industry's viability and dynamic development.

K E Y   W O R D S
 barriers, halal industry, ISM, DEMATEL

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INTRODUCTION

In Islam, halal refers to something that is legal (Aziz & Ahmad, 2018; Tieman, 2011). Halal is considered part of religious conformity and a standard lifestyle choice for Muslims (Golnaz et al., 2010). Halal products have become an important market category worldwide, accounting for 24 % of the world's Muslim population (Sumarliah, 2021). While halal is commonly associated with Muslims, this does not imply that halal product customers are exclusively Muslim. Consumers of halal products from nations

with minority Muslim populations have increased significantly in recent years. For example, Brazil, Australia, and Singapore were among the top ten nations in the halal food industry in terms of the GIEI (Global Islamic Economy Indicator) score in 2017–2018 (Thomson Reuters, 2017). Nevertheless, they are non-Muslim nations (Latif, 2017). The largest market in the halal food sector is meat and poultry, which is surprisingly led by non-Muslim countries. New Zealand and Australia are the global leaders in the export of halal meat. Brazil and Argentina are the world's largest producers of chicken (Nor Ai'han Mujar, 2015). The quality of halal products, also known as Halalan Toyyiban, is why they are not used. The entire production chain is guaranteed to be clean, safe, and high quality (Cruz & Billanes, 2021).

The phrase "halal industry" refers to any economic operation that adheres to Islamic standards (Laldin, 2006). Indonesia's halal industry contributes USD 3.8 billion to its Gross Domestic Product (GDP). Additionally, the halal industry has attracted USD 1 billion in international investment, producing 127,000 employees annually. If re-optimised, the halal industry can raise exports and foreign exchange reserves (Kusumaramdhani & Nusran, 2021). The expected total assets of many halal industrial sectors, including halal food, banking, travel, fashion, medical, entertainment media, and cosmetics, would expand by 31 % by 2023, according to the 2019 State of the Global Islamic Economy Report (DinarStandard, 2019). Consequently, to maximise its economic potential, Indonesia should have started expanding its halal industry.

Despite the positive impact of the halal industry on Indonesia's economy, its potential has yet to be completely realised. This is evident from Indonesia's inability to attain a top spot in all halal industry sectors. According to the State of Global Islamic Economy Report 2022, Indonesia ranks fourth among the top 15 Global Islamic Economic Indicators, behind Malaysia, Saudi Arabia, and the United Arab Emirates. Indonesia ranks second in the classification of halal food producers despite ranking first in the classification of halal food consumers. Indonesia ranks sixth in Islamic Finance, third in modest fashion, and ninth in pharmaceuticals and cosmetics. For Muslim Friendly Travel and Media and Recreation, Indonesia did not rank among the top ten (DinarStandard, 2022).

Therefore, based on the background described above, this research highlights the barrier between the potential to grow a halal industry and the fact that these opportunities are yet to be maximised. Then, to find the relevant barriers to maximising the performance of the halal industry, this study utilised institutional pressure from the institutional theory of DiMaggio and Powel (1983) and the resource-based view (RBV) (Barney, 1991). This study also used some previous studies on halal industry performance (i.e., Hasan & Pasyah, 2022; Batubara & Harahap, 2022; Salahuddin et al., 2021; Adham et al., 2020; Utomo et al., 2021) and notes from the National Sharia Economic and Finance Committee to find relevant barriers, such as the Indonesian Sharia Economic Masterplan 2019–2024 (Ministry of National Development Planning/National Development Planning Agency, 2018). Related to institutional pressure from institutional theory, organisations in a certain industry operate within an institutionalised environment in which different control mechanisms, such as rules, laws, and policies, impact the behaviour and practices of those organisations (Lawrence & Suddaby, 2006). These control mechanisms comprise three dimensions of pressure (coercive, mimetic, and normative), which are also known as drivers or forces that create isomorphism or homogeneity in organisational strategies, structures, and processes, particularly those within the same industry (Glover et al., 2014). As a result, a lack of control systems may be a barrier to maximising industrial performance. Moreover, according to certain academics, institutional pressure from institutional theories is important in driving halal enterprises (Ab Talib et al., 2016a; Zulfakar et al., 2018). Related to RBV theory, this theory is grounded in resources and capabilities as two drivers of competitive advantage and performance. A resource is considered as the core in the RBV theory because of its main role in providing inputs to the firm's processes and activities (Barney, 1991), whereas capabilities arise as a result of the firm's ability to create value of the process by using and combining resources (Amit & Schoemaker, 1993). RBV theory suggests that a firm contains resources, some of which are called strategic because they are rare, valuable, imperfectly imitable, and substitutable (Ali et al., 2022). Related to the Indonesian Sharia Economic Masterplan 2019–2024, in general, there are several challenges in developing the halal industry in the country, namely, inadequate regulations related to the halal industry, inadequate public literacy and awareness of halal products, and the interlinkage of the halal industry and sharia finance, which still need improvement. The other is the increase in consumption and demand for halal products in the country,

which must be balanced with the amount of production. However, governance and risk management in the halal sector remain inadequate. The use of technology is yet to be optimised in the halal industry. Indonesia's halal standards are yet to be accepted globally (Ministry of National Development Planning/National Development Planning Agency, 2018). Thus, referring to the RBV theory, the lack of a firm's ability in the halal industry to provide relevant input to the firm's processes and activities and create value in the process through using and combining resources could be a barrier to maximising the performance of the industry. More details about the barriers originating from the institutional theory and RBV, as well as relevant previous research, can be found in the literature review subsection.

Some previous studies related to the institutional theory and resource-based view in the halal context (such as Islam et al., 2024; Jaswir et al., 2023; Sumarliah et al., 2023; Nee & Mohamad, 2022; Sumarliah et al., 2022; Tan et al., 2022; Hew et al., 2020; Karbhari et al., 2021; Hewege & Perera, 2020; Iswanto & Koeswinarmo, 2020; Rahman et al., 2020; Bashir et al., 2019; Suharko et al., 2018; Ab Talib et al., 2016a; Ab Talib et al., 2016b). Some previous studies related to the halal industry's performance have directly discussed the barriers to maximising the halal industry's performance (such as Hasan & Pasyah, 2022; Batubara & Harahap, 2022; Salahuddin et al., 2021; Adham et al., 2020; Utomo et al., 2021). Table 1 provides a detailed explanation of the results. However, since these previous studies have not differentiated the barriers (group of barriers that affect others and group of barriers that are affected by others) to maximise halal industry performance, policymakers need to know how both groups of barriers are related to each other. This study aims to answer the following research questions.

RQ1. What are the valid barriers to maximising the performance of Indonesia's halal industry?

RQ2. How are the barriers to maximising the performance of the halal industry in Indonesia interlinked with one another?

RQ3. What is the relative importance of each barrier in maximising the halal industry's performance in Indonesia?

RQ4. What recommendations could be generated from the findings of this research?

A content validity analysis, integrated Interpretive Structural Modelling (ISM), and Decision-Making Trial Evaluation and Laboratory (DEMATEL) approach addresses the above research question. The

identified barriers were initially verified using content validity analysis with subject matter experts (Yusoff, 2019). The importance of each barrier is then determined using DEMATEL once an ISM model of the barriers has been built (Manoharan et al., 2022). This study adds to prior research in two ways, based on the research questions. This study is the first to identify and categorise barriers impacting the performance of the halal industry into two groups: "facilitator (affecting others or a cause)" and "dependent (affected by others or an effect)". Consequently, it helps policymakers identify and place barriers according to the direction and strength of their effect on other barriers. It also helps policymakers identify barriers according to their dependence and driving forces. Second, the report proposes a hierarchy of barriers, providing policymakers with advice on systematically removing them to maximise the halal industry in Indonesia. Additionally, the findings of this study contribute to a better understanding of the Indonesian halal industry.

1. LITERATURE REVIEW

The literature review will consist of an explanation of institutional pressure from the institutional theory of DiMaggio and Powel (1983), previous research on halal that used institutional theory, RBV theory, previous research on halal using RBV theory, and previous research related to the performance of the halal industry. Referring to the systematic literature review result by Islam et al. (2024), Institutional Theory and RBV are the leading theories researchers use to underpin the premises of halal studies, pointing to certifiers and producers' perspectives.

1.1. INSTITUTIONAL PRESSURE FROM THE INSTITUTIONAL THEORY

Halal certification is one of the tools that the government must consider for Indonesia to be competitive in the halal industry (Izzudin & Adinugraha, 2021). On the demand side, halal food certification is an essential component of the halal food industry because it influences customer preferences (Mohayidin & Kamarulzaman, 2014), confidence (Mohamed et al., 2013), purchasing behaviour (Shah Alam & Sayuti, 2011), and willingness to pay (Verbeke et al., 2013). On the supply side of the halal food chain, it is essential to ascertain the factors that motivate

firms to implement halal food certification. Then, referring to Izzudin and Adinugraha (2021) and Jaswir et al. (2023), this underlines the Institutional Theory by DiMaggio and Powell (1983) to determine the factors that motivate firms to engage in halal food certification as a prominent condition to maximise the performance of the halal industry.

Referring to Scopus Databases, this study found 14 articles with the keywords "Institutional Theory" and "Halal" in the abstract. Seven out of 14 articles tried to explain how institutional theory is used in the context of halal certification (Jaswir et al., 2023; Hewege & Perera, 2020; Iswanto & Koeswinarmo, 2020; Bashir, 2019; Suharko et al., 2018; Ab Talib et al., 2016a; Ab Talib et al., 2016b), while others discussed institutional theory as one of the underpinning theories in halal or halal logistic research (Islam et al., 2024; Nee & Mohamad 2022; Rahman et al., 2020), institutional theory in Shariah Governance of Islamic Banks (Karbhari et al., 2021), and institutional theory in blockchain technology adoption (Sumarliah et al., 2023; Sumarliah et al., 2022; Tan et al., 2022; Hew et al., 2020). The summaries of the 14 articles can be seen in Table 1.

According to DiMaggio and Powell (1983), Institutional Theory explains that firm strategies and actions are responses to pressure from the external environment. Meyer and Rowan (1977) and Suchman (1995) hypothesised that a firm's endeavours are influenced by its desire to acquire business legitimacy and market recognition. Mariotti et al. (2014) explained that Institutional Theory "depicts firms as passive participants that respond to external pressures and expectations". In the context of the halal food market, this suggests that external factors, such as government regulations, industry standards, and consumer demand, prompt firms' pursuits of halal food certification. Fischer (2015, 2016) showed that the halal food industry is profoundly institutionalised and that firms' operations are compliant with set government regulations.

DiMaggio and Powell (1983) classified Institutional Theory as having three isomorphic mechanisms: coercive, normative, and mimetic isomorphism. These three isomorphic processes further elucidate external environmental pressures (government rules, industry norms, and consumer expectations).

- Coercive Isomorphism. In the case of coercive isomorphism, DiMaggio and Powell (1983) point out that firms are pressured directly or indirectly by government organisations. This view is supported by Arpanutud et al. (2009). In short, according to DiMaggio and Powell (1983) and Arpanutud et al. (2009), governmental factors are significantly related to certification and standards implementation in Coercive Isomorphism. This finding suggests that regulatory commitment and the need to operate a legitimate operation, either directly or indirectly, coerced firms to implement halal food certification. Therefore, in the context of barrier factors, the absence of these factors inhibits firms from implementing halal food certification.

- Normative Isomorphism. According to Mariotti et al. (2014), normative isomorphism is linked to a firm's reputation and image. Mariotti et al. (2014) also emphasised the importance of conforming to industry norms, which may substantially impact a company's image and reputation. Furthermore, because Muslims are known to be sensitive consumers (Rezai et al., 2012) and eating halal food is the norm (Abdur Razzaque & Chaudry, 2013), food firms that serve Muslim markets must ensure that their products are halal, as studies have shown that halal certification portrays a firm's image and reputation. Therefore, in the context of barrier factors, the lack of consumer demand for halal certifications will prevent firms from implementing halal food certification because the absence of a halal certificate does not cause the firm to lose its image and reputation.

- Mimetic Isomorphism. As defined by DiMaggio and Powell (1983), Mimetic Isomorphism is the duplication of a firm's business activities from other businesses. Furthermore, according to DiMaggio and Powell (1983), the mimetic approach is favoured owing to limited knowledge since it creates a sense of comfort in developing firm objectives or strategies. In this circumstance, only the effective or best practices are duplicated. Previous studies (Fikru, 2014a; 2014b; Mariotti et al., 2014; Arpanutud et al., 2009) discovered that enterprises are driven to use certification to achieve the same success as viral firms and thus begin the mimetic approach. Based on this point of view, in the context of barrier factors, the absence of successful enterprises owing to their use of halal certification discourages or even prohibits new firms from using it.

1.2. RBV THEORY

RBV theorists believe that a firm's valuable, uncommon, and unique resources and talent determine its competitive advantage (Barney, 1991). Research recognises that tangible and intangible resources are significant because each may give a business a distinct competitive advantage (Barney, 1991; Karia & Wong, 2013). Physical, information technology, knowledge, managerial competence, and organisational and relational resources (Karia & Wong, 2013).

Referring to Scopus Databases, six articles were found using the keywords "Resource-Based View", "Resource Based View", and "Halal" in the abstract. Among these articles, Islam et al. (2024) and Nee and Mohamad (2022) conducted systematic literature reviews on the use of RBV theory in halal research. Islam et al. (2024) found 32 of 320 articles dealing with halal studies on standards, certification, policymakers and producers, and halal supply chains. Only seven out of 32 articles consulted the RBV (approximately 21 %). Nee and Mohammad (2022) found that the RBV is a theory that has been applied in various aspects of research in halal logistics and supply chains. Then, in conceptual and empirical research, Ali et al. (2022) used RBV to derive supply chain integration, which has significant effects on the dimensions of the Halal Food Supply Chain Integrity; Azhar and Tu (2021) used RBV to find several factors for the successful implementation of sustainable halal food supply chain management; Uthamapurthran et al. (2019) used RBV as a theoretical lens to make a conceptual focus on halal SMEs' resources to support the process of internationalisation; and Ab Talib et al. (2016b) used RBV to find a conceptual model of the relationship between Halal Certification and logistics performance. The summaries of the six articles can be seen in Table 1.

According to Barney (1991) and Dube et al. (2016), certification is a resource that a firm may use to seek profit from the standpoint of RBV theory. In this context, halal food certification, whether in a license, logo, or seal, is a certified identity for a firm whose food items are derived from, produced, and distributed under Islamic standards values (Riaz & Chaudry, 2004). Halal certification has evolved into a new marketing strategy that captures customer attention (Yunos et al., 2014). This strategy allows a firm to operate in a highly competitive business climate and has the potential to generate billions of ruptures. Furthermore, according to RBV theory, the

internal condition of halal food firms, customers, and supplier connections are strategic resources that impact halal food supply chain integrity as a valuable and rare skill that affects food quality performance (Ali et al., 2022). Therefore, in the context of barrier factors, the absence of a competitive business environment, as well as the support from internal firms, customers, and supplier relationships, will inhibit firms from getting or implementing halal certification as their resource, which, in turn, does not maximise the performance of the halal industry in Indonesia.

1.3. RESEARCH RELATED TO THE HALAL INDUSTRY

This research, which identified articles published in Scopus databases (Scopus, n.d.) using the "advanced search" tool with the keyword "halal industry" in the title, found 38 articles. However, upon reading these articles, a significant gap in the literature became apparent. While not entirely on point, five articles were found to be potentially supportive of the research's objectives and could aid in identifying the barriers to maximising the performance of the halal industry: Hasan and Pasyah (2022), Batubara and Harahap (2022), Salahuddin et al. (2021), Adham et al. (2020), and Utomo et al. (2021). The object of their research, methods, variables, and findings are shown in Table 1.

1.4. RESEARCH GAP

Table 1 reveals a significant research gap in the existing literature related to the halal industry. None of the previous studies on institutional and resource-based theories directly addressed the industry performance or its barriers. Understanding these factors is crucial for the growth and optimisation of the halal industry. This gap not only highlights the need for further research but also underscores the potential impact of addressing these issues. Furthermore, none of the previous studies related to the halal industry, which are listed in Table 1, identified barriers to maximising the performance of the halal industry. The review of the existing literature reveals several vital limitations that suggest a critical research gap:

1. Limited focus on comprehensive industry performance. Most studies (Hasan & Pasyah, 2022; Batubara & Harahap, 2022; Salahuddin et al., 2021; Adham et al., 2020; Utomo et al., 2021) do not address the overall performance of the halal industry. This

Tab. 1. Summary of previous studies related to institutional theory and resource-based view in the context of halal research and halal industry performance

Author	Purpose of research	Object of research	Method	Variables	Finding
Institutional Theory					
Jaswir et al., 2023	Identify the factor that could motivate the food industry to take part in the standardisation process and analyse which motive is the most influential. This study also examines the relationship between the motive and the implementation itself	Food and beverage small and medium-sized enterprises, Malaysia	Exploratory Factor Analysis and Covariance-based Structural Equation Modelling	• From the institutional theory: three motives — coercive isomorphism, mimetic isomorphism, and normative isomorphism • Implementation of MS 1500: the perception through implementation; core activities in implementation, and limitation of implementation	The most influential motive is coercive or pressure from the outside of the organisation, either from governmental mandates or political influence. Then, there is a significant relationship between the motive behind the implementation of MS1500 and the implementation itself
Hewege & Perera, 2020	Identify the role of certification bodies and the influence of religious-cultural institutions over a country's supply chains in the context of halal certification	N/A	Qualitative content analysis method involving subjective interpretation of the content of text data through a systematic classification process of coding and identifying themes	• From the institutional theory and Gramsci's theory of Hegemony: religious beliefs, cultural rituals, and diverse social institutions • Halal supply chain	Four research propositions followed by a theoretical framework describing the influence of religious beliefs, cultural rituals, and diverse social institutions on halal supply chains
Iswanto & Koeswinarmo, 2020	Identify the relationship between organisations based on the interpretation of each party related to the Halal Product Guarantee policy and its consequences	Halal industry, Indonesia	Interview with several informants, purposively selected based on their competence in organisations related to halal product policies Document studies and literature studies	• From the institutional theory: interpretation, power relation, and regulation liminality	The interpretations of each organisational actor towards the new halal certification policy in Indonesia are driven by different institutional reasons/logics, resulting in contradictions, even conflicts related to the relationship between organisations implementing the policy
Bashir et al., 2019	Identify the degree to which halal consumers with higher institutional pressures are more expected to purchase halal food products	Halal consumers, South Africa	Structural equation modelling (SEM)	• Attitude • From institutional theory: coercive pressures, normative pressures, mimetic pressures • Purchasing intention • Buying behaviour	All institutional factors have a direct effect on halal consumer intentions and an indirect effect on buying behaviour

Author	Purpose of research	Object of research	Method	Variables	Finding
Suharko et al., 2018	Identify the institutional conformance of the Halal Certification Organisation (HCO) to the development of the halal tourism industry (HTI)	Halal tourism industry, Indonesia and Thailand	Qualitative case study approach-set of interviews has been conducted with some key informants in Majelis Ulama Indonesia (MUI) and Central Islamic Committee of Thailand (CICOT)	• From the institutional theory: three motives — coercive pressures, normative pressures, mimetic pressures-for understanding the dynamic of halal tourism sectors	Adapting to the rapid development of halal tourism industry, the two HCOs provided a halal certificate for Muslim consumers' protection, increased export of goods to a number of Muslim countries and provided halal tourism services to augment the competitiveness of respective halal tourism destination
Ab Talib et al., 2016b	Identify the theoretical background of halal food certificate implementation	N/A	Literature review	• From the institutional theory: coercive (dependence —regulatory pressure), normative (demand —customer pressure), mimetic (uncertain —competitive factor)	Three propositions — the relationship between coercive, normative, and mimetic on halal food certification
Rahman et al., 2020	Identify the central institutional theory that can be used as a primary reference for future scholars as underpinning theory	N/A	Literature review	• From the institutional theory: behaviour, perception, etc.	General review by focusing on the concept of institutions, the characteristics of institutions, and the three key elements discussed in institutional theory
Sumarliah et al., 2023	Identify the intent to adopt a blockchain-facilitated halal traceability (BFHT) scheme in Indonesian firms' halal food supply chain (SC)	Halal food enterprise, Indonesia	Partial least squares structural equation modelling (PLS-SEM)	• From the institutional theory: institutional force — prescriptive, imitative, coercive • Halal-focused approach: procuring materials, manufacturing activities, staffing, warehousing and shipping • Perceived attractiveness: compatibility, complexity, comparative advantages, perceived attractiveness • Adoption intent	The intent to adopt the blockchain-facilitated halal traceability (BFHT) is considerably affected by perceived attractiveness, as perceived attractiveness is considerably affected by institutional forces, which are significantly influenced by halal-focused attitude. Firms that follow a completely halal-focused attitude show higher awareness regarding institutional forces that motivate them to adopt a BFHT

Author	Purpose of research	Object of research	Method	Variables	Finding
Sumarliah et al., 2022	Identify the participation intent in the blockchain-halal fashion traceability (BHFT) system via a joint framework that includes diffusion of innovation theory, institutional theory, and halal-oriented approach	Halal fashion producers, Indonesia	Partial least squares structural equation modelling (PLS-SEM)	• Institutional theory: institutional pressure- normative, mimetic, coercive • Halal-oriented approach: sourcing, manufacturing, staffing, storing and shipping • Diffusion of innovation theory: perceived desirability-compatibility, complexity, relative advantage • Participation intention	The halal-oriented approach is significant in helping halal fashion manufacturing companies value the institutional pressures that support them in blockchain-empowered halal fashion traceability
Tan et al., 2022	Identify the current traceability challenges for the food supply chain in Malaysia to comply with halal requirements. We position these challenges in the context of institutional theory	Food supply chain, Malaysia	Case study- interview with three companies	• Based on institutional theory (coercive, mimetic and normative pressures) and agency theory (agency problem and risk sharing): • Lack of Global Halal Certification system, inaccurate and unauthentic data of halal products, poor regulation of raw materials for halal products, and ineffectiveness of existing traceability system	The technology with smart contract is proposed with inputs from three Blockchain software providers with the aim to create a conceptual framework that integrates both halal processes and technologies to improve traceability of Halal food supply chain from farm to fork
Hew et al., 2020	Identify the intention to participate in a blockchain-based halal traceability system through a united model that consists of a halal orientation strategy, institutional theory, and diffusion of innovation theory	Halal food and beverage manufacturers, Malaysia	Partial least squares structural equation modelling (PLS-SEM)	• From the institutional theory: institutional pressure — normative, mimetic, coercive • halal orientation strategy: materials, production process, staffing, storage and transportation • Perceived desirability: complexity, relative advantage, combability • Intention to participate	First, the halal orientation strategy will be more perceptive towards the institutional pressures that demand them to participate in a traceability system. Second, the manufacturers would evaluate the technological characteristics of the system and subsequently develop their perceived desirability. Third, the manufacturers with favourable perceived desirability shall decide to participate in the system

AUTHOR	PURPOSE OF RESEARCH	OBJECT OF RESEARCH	METHOD	VARIABLES	FINDING
Karbhari et al., 2021	Identify the relevance of applying institutional theory in Shariah governance of Islamic banks	Islamic Banks	Literature review	• Institutional theory: coercive-to attain legitimacy, mimetic-to eliminate uncertainty and normative- mainly from professionalisation	Institutional theory to best serve the development of operational strategies and structures of Islamic banks, including the role, function and power of the various stakeholders, including regulators and those involved in the Shariah governance process of Islamic banks
RBV					
Islam et al., 2024	Identify the underlying Islamic principles to the business theories for producers and policymakers and explain halal marketing by value creation approach for halal stakeholders concerned with halal certification and its implementation	N/A	Literature review	• Best Worst Method (BWM), Gravity Theory, Decision Tree (DT), Theory of Constraints, Classical Secularisation Theory, and Game Theory, fuzzy decision-making trial and evaluation laboratory (DEMATEL), stakeholder theory (ST), Grounded Theory, Theory of Religion, Pareto analysis, Critical Success Factors (CSFs), Resource-based view (RBV) and institutional theory (IT)	Only seven studies consulted the resource-based view (RBV), a strategy theory and the institutional theory (IT) connected to halal. This study further underpinned qualitative Quranic verses to add to the current body of RBV and IT, resulting in halal sustainable competitive advantage and halal certification institutionalisation
Nee & Mohamad, 2022	Identify Scopus database halal logistics and halal supply chain academic literature from 2007 to 2020	N/A	Literature review	• Theory used in research about halal logistics and halal supply chain	Diffusion of Innovation (DOI), Resource-Based View (RBV), Technology–Organisation–Environment (TOE), Technology Acceptance Model (TAM), Theory of Planned Behaviour (TPB), Institutional Theory, Agency Theory and Adaptive Saturation Theory (AST) are the theories that have been applied in various aspects of research in HL and HSC

AUTHOR	PURPOSE OF RESEARCH	OBJECT OF RESEARCH	METHOD	VARIABLES	FINDING
Ab Talib et al., 2016a	Identify a theoretical model for the relationship between halal certification and logistics performance	N/A	Literature review	• Institutional theory: coercive isomorphism-regulation and policies enforced onto firms prior to operation; firms are pressured to secure certification as a means of gaining business legitimacy • RBV: halal is both tangible and intangible resources • Logistics performance: quality, time, cost, and flexibility	The conceptual model: halal certification, could positively influence logistics performance; governmental factors act as the moderator between the halal certification-logistics performance relationship or could directly influence logistics performance
Halal Industry					
Hasan & Pasyah, 2022	Identify the challenges of the Indonesian halal industry in the digital economy era	Halal food and beverage industry, Indonesia	Normative legal research	• Opportunities for the halal product industry in the digital economy era; • The challenges of the Halal Industry in the era of the digital economy; • Legal assurance of halal industry in the digital economy era; • Elements and system of law enforcement and protection of rights (non-legal factors, including culture, the law or regulation itself, the mentality of the officers who enforce the law, the facilities expected to support the implementation of the law, and the legal culture/legal awareness); facility factors used by law enforcement	Halal product industry in Indonesia in the era of the digital economy and efforts to guarantee legal certainty for the halal industry is currently still not implemented optimally

AUTHOR	PURPOSE OF RESEARCH	OBJECT OF RESEARCH	METHOD	VARIABLES	FINDING
Batubara & Harahap, 2022	Identify the strategies for halal industry development implemented by business actors in Indonesia and provide Indonesian Muslims' responses and Sharia compliance to the halal context in their lives	Halal industry, Indonesia	Analytical Network Process	• Internal problem: internal industry-relatively new in Indonesia, marketing, and human resources • External problem: infrastructure, legal standards, and government support • Strategy: halal area development, government policy support, coaching and training, assistance, research and collaboration, and constructing halal concerns through local wisdom	The strategies used to develop halal industry are not appropriate due to internal factors such as lack of standardisation, branding, and limited human resources, and external ones which are the absence of a roadmap for halal industry and less supports from the government. Improving effective government policies and training human resources are among the strategies that might be applied
Salahuddin et al., 2021	Identify a glance over five decades of Malaysian experience in nurturing and commodifying the halal industry	Halal industry, Malaysia	Literature review	• Halal logistics (market outlook, constraints, needs), halal marketing and sales (market outlook, constraints, needs) • Halal operation (market outlook, constraints, needs),	Cost of realignment to policies, risk of asymmetric information, and certification fraud are among the major barriers that hinder starting an operation in a halal setting
Adham et al., 2020	Identify the Muslim-minority context of Taiwan and utilise the Viable System Model (VSM) as the framework to diagnose the current state of Taiwan's halal industry	Halal industry, Taiwan	Viable System Model	• Implementation • Coordination • System monitoring • Intelligence • Policymaking	An absence of a halal industry development policy. This situation then explains why Taiwan lacks formal policymaking and intelligence as well as control and coordination functions
Utomo et al., 2021	Identify and explore the role of Islamic financing in supporting halal industry development in Indonesia	Islamic financing, Indonesia	Partial least square (PLS)	• Islamic financial literacy • Religiosity • Subjective norms, • Attitude • Awareness • Intention	Literacy on Islamic finance, attitude and awareness strongly affect business owners' intention to use Islamic financial products. It was also found that subjective norms significantly influence literacy, attitude, and awareness. However, religiosity does not significantly affect attitude toward Islamic financial products

indicates a gap in research that looks at the broader factors influencing the performance of the halal industry.

2. Absence of a barrier identification framework. None of the existing studies focus on identifying the barriers that prevent the halal industry from maximising its potential. The failure to identify these barriers systematically limits the field's understanding of the factors that inhibit the industry's growth and performance optimisation.

3. Lack of advanced methodologies. As mentioned in the provided research excerpt, none of the prior works utilised integrated ISM-DEMATEL methodologies, which are well-suited for understanding complex relationships among barriers. ISM (Interpretive Structural Modelling) helps create a structured model to identify the relationships among barriers. At the same time, DEMATEL (Decision Making Trial and Evaluation Laboratory) quantifies and visualises each barrier's causal relationships and influence. The absence of these methodologies in the field is a notable research gap.

4. Underuse of institutional and resource-based theories. Although several studies on the halal industry exist, they have not adequately applied the institutional theory (which looks at how institutions, including regulations and cultural norms, influence organisational behaviour) and resource-based theory (which focuses on how organisations use their internal resources to create competitive advantage). The research you are working on emphasises these theories to examine performance barriers, thereby addressing a gap where the application of these theoretical frameworks is limited or underdeveloped.

Connecting considerations to the research gap:

1. Addressing the lack of holistic industry performance studies:

• This research goes beyond the narrow focus on specific elements of the halal industry and aims to provide a holistic assessment of the industry's performance. In doing so, it introduces a fresh perspective that considers the industry as a complex system influenced by various factors. This perspective, missing from the literature, makes it a novel and intriguing study for policymakers and industry stakeholders.

• The connection to the gap is clear: while others may look at subsets or components of the halal industry, this research addresses the full scope of performance evaluation, making it highly relevant for policymakers and industry stakeholders.

2. Systematic Barrier Identification:

• By identifying the barriers to maximising the performance of the halal industry, this research fills a void left by earlier works. The connection here is that no prior studies systematically addressed these barriers, and by doing so, this research advances the academic conversation and provides practical insights, enlightening the audience about the real-world implications of the research.

• The research expands the scope of analysis to encompass the key barriers that hinder the industry's growth, which had previously been overlooked or inadequately explored.

3. Application of Integrated ISM-DEMATEL:

• The application of the integrated ISM-DEMATEL approach is innovative in this context, providing a methodologically rigorous way to identify and evaluate the relationships among barriers. The connection to the research gap is through the absence of such techniques in previous studies, and this research directly fills that methodological gap, instilling confidence in the audience about the robustness of the research.

• This provides a quantitative and structured approach to addressing complex interdependencies among barriers, allowing the research to offer previously unavailable insights into halal industry studies.

4. Combining Institutional and Resource-Based Theories:

• This research makes a theoretical contribution by integrating institutional and resource-based theories to explain the performance barriers of the halal industry. Earlier studies may have used these theories in isolated contexts, but none have applied them in conjunction to analyse the industry's barriers and performance.

• By focusing on these two theories, the research not only fills a theoretical gap but also provides a framework for future researchers to apply these theories to other industries or contexts.

• Overall, the research gap is well-established regarding the limited application of institutional, resource-based theories and halal industry

research in identifying barriers and underusing advanced methodologies (ISM-DEMATEL).

2. RESEARCH METHODS

2.1. BARRIERS TO MAXIMISING HALAL INDUSTRY PERFORMANCE

Although not directly identifying the barriers to maximising the performance of the halal industry, the previous study of the institutional theory and resource-based view in the halal context and the previous study of the halal industry provided insight into choosing several barrier factors (Table 1). This study chose 16 factors as barriers to maximising halal industry performance (Table 2).

2.2. CONTENT VALIDATION

Before processing with the Combined ISM-DEMATEL methodology, a content validation pro-

Tab. 2. Summary of barriers to maximising halal industry performance

UNDERPINNING THEORY OR INSIGHT FROM PREVIOUS RESEARCH		BARRIERS
Three motives from institutional theory (Jaswir et al., 2023; Hewege & Perera, 2020; Iswanto & Koeswinarmo, 2020; Bashir et al., 2019; Ab Talib et al., 2016b Sumarliah et al., 2023; Sumarliah et al., 2022; Hew et al., 2020; Karbhari et al., 2021)	1	The absence of successful enterprises due to their use of halal certification led to a lack of understanding of Indonesian business actors regarding the importance of halal for their business (B1)
	2	The absence of successful enterprises owing to their use of halal certification has led to a lack of halal awareness among Indonesian business actors (B2)
	3	The absence of successful enterprises due to their use of halal certification led to a lack of understanding among business actors regarding the process of applying for halal certification (B3)
	4	The absence of successful enterprises due to their use of halal certification causes them to pay less attention to the existence of halal supervisors in the company, so the number is minimal (B4)
	5	The lack of education and socialisation related to halal certification leads to a lack of customer demand for halal certification (B5)
Resource based view (Nee & Muhammad, 2022) and internal problem of halal organisation (Batubara & Harahap, 2022)	6	The lack of developed technology for halal leads to the lack of support from information and communication technology regarding traceability issues (B6)
	7	The lack of developed technology for halal leads to limited technology to detect the halal status of the products (B7)
	8	The lack of optimal research for the development of substitution/alternative products from non-halal raw materials or additives (B8)
Halal logistic support (Salahuddin et al., 2021)	9	The lack of support from suppliers within a halal guarantee for certain products (for example, gelatine, which is widely used for consumer products; not many suppliers can supply these products with halal guarantees) (B9)
Challenges of halal industry development-government support (Adham et al., 2020; Batubara & Harahap, 2022)	10	The lack of regulatory commitment led to a lack of control and coordination in support of a viable halal industrial ecosystem from different government agencies (B10)
	11	The lack of regulatory commitment led to the absence of a roadmap for the halal industry, and the regulation was not severe enough to be enforced by the government because it was not supported by the ease and low cost of making a halal certification (B11)
	12	Companies lack optimal halal supervisors because there are no sanctions for the absence of halal supervisors (B12)
Halal logistic support (Salahuddin et al., 2021)	13	The lack of infrastructure to support halal logistic implementation (B13)
	14	The lack of support from halal Logistic Service Provider (LSP) (B14)
Challenges of halal industry development-government support (Adham et al., 2020; Batubara & Harahap, 2022)	15	The lack of the number of halal industrial estates that have been operating (B15)
	16	The lack of regulatory commitment led to the obligation for halal certification for food and beverages being too late (it voluntary before 19 October 2019 and mandatory since 17 October 2024) (B16)

cess was carried out on the barriers found. Content validation is a process that provides guarantees on whether the items represent or depict the relevant concept (Zamanzadeh et al., 2015; Sekaran & Bougie, 2016); therefore, content validation will contribute to the improvement of the items through expert panel suggestions and information on the representativeness and clarity of the items (Polit & Beck, 2006). The steps in conducting the content validation can be described as follows (Yusoff, 2019):

- Step 1. Preparation of the content validation questionnaire. This questionnaire used four Likert scales ranging from not relevant to very relevant (1 = not relevant, 2 = somewhat relevant, 3 = relevant, and 4 = very relevant). A cover letter that would include the study's purpose, the barrier's brief description, and its scoring will be included in the content validity questionnaire to ensure that the review panel of experts ensures clarity, understanding, and meeting expectations with respect to the task being undertaken.
- Step 2. Selection of expert panel and distribution of a content validity questionnaire.
- Step 3. Evaluation of each barrier based on the responses of the expert panel. Each barrier was evaluated using the item-content validity index (I-CVI) and scale level (S-SVI). I-CVI is computed as the number of experts giving a rating of "relevant" or "very relevant" for each item (barrier) divided by the total number of experts. Values range from 0 to 1, where I-CVI > 0.79, the barrier is relevant, between 0.70 and 0.79, the barrier needs revisions; and if the value is below 0.70, the barrier is eliminated. According to Lynn (1986), for six to eight experts, the I-CVI value should be at least 0.83. The S-CVI was calculated using the average CVI (S-CVI/Ave) (Zamanzadeh et al., 2015). The S-CVI/Ave was calculated based on the average I-CVI scores across all barriers. Excellent content validity is indicated by S-CVI/Ave of at least 0.9 (Shi et al., 2012).

2.3. Combined ISM-DEMATEL methodology

Combined ISM-DEMATEL is a methodology for system analysis that employs matrix and graph theories to examine the interrelationships among various factors within a system. The utilisation of ISM and DEMATEL methodologies can facilitate the assessment of the magnitude and relevance of barriers to the performance of the halal industry and the hierarchical arrangement of barriers (Manoharan et al., 2022). The structural framework of the combined ISM-DEMATEL methodology is illustrated in Fig. 1.
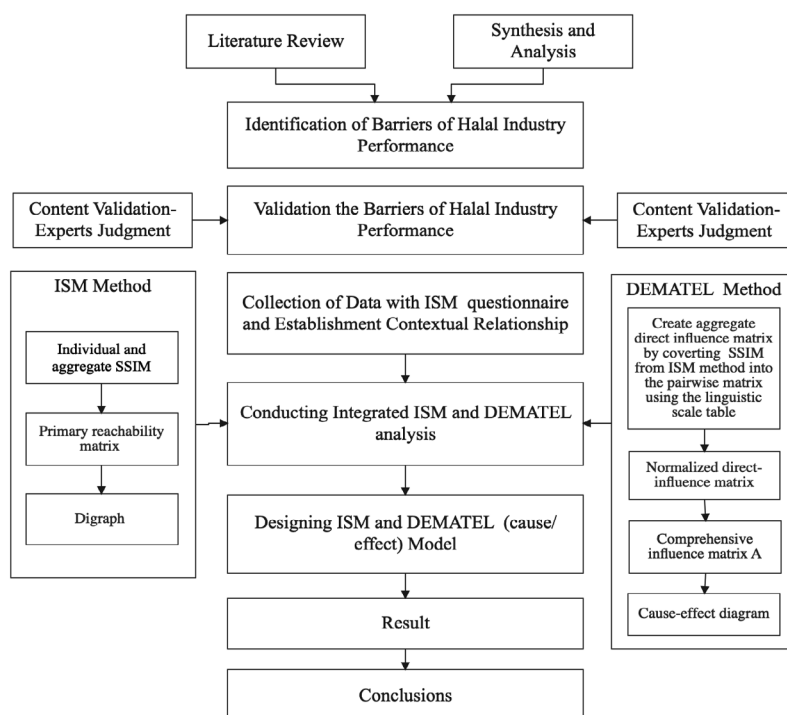

Fig. 1. ISM-DEMATEL integrated framework

Source: elaborated by the authors based on Manoharan et al., 2022.

2.3.1. ISM METHODOLOGY

- Step 1. The integrated approach starts with the case study (in this case, the performance of the halal industry) and a literature review to identify the barrier factors to maximise the performance of the halal industry.
- Step 2. An ISM questionnaire is developed to establish a correlation between every pair of barriers identified in the first phase that has undergone the validation process. The ISM questionnaire requested that each expert evaluate the direct correlation between any two barrier factors using the following symbols: V if factor I affects the emergence of factor J; A if factor J affects factor I; X: If both factors affect one another (two-way effect); and O, if no association exists between the two factors. Based on the questionnaire completed by each expert, an individual and aggregate Structural Self-Interaction Matrix (SSIM) was created. In this case, the aggregate SSIM was calculated based on the majority rule in SSIM (Abdullah et al., 2014; Dhochak & Sharma, 2016; Li et al., 2019; Cai & Xia, 2018; Sushil, 2012).
- Step 3. The primary reachability matrix is developed by transforming the aggregate SSIM into a binary matrix of 1 s and 0 s (symbols X and V are replaced by 1 s, and symbols A and O are replaced by 0 s).
- Step 4. The final reachability matrix is created by using the transitivity rule described by Kannan et al. (2008). The transitivity rule states that if "barrier-1" affects "barrier-2," "barrier-2" affects "barrier-3," then the resultant is "barrier-1" affects "barrier-3".
- Step 5. The barriers are partitioned into different levels from the final reachability matrix based on the reachability and antecedent set. The reachability set is the assembly of the barrier that is affected by other barriers and itself, whereas the antecedent set is the assembly of the barrier that affects other barriers and itself (Warfield, 1974; Kumar et al., 2016).
- Step 6. The digraph, hierarchical model, or structural connections between the barriers are developed based on the results of step 5.

2.3.2. DEMATEL METHODOLOGY

- Step 1. Convert SSIM from the ISM method into a pairwise matrix using the linguistic scale table,

which has values ranging from 0 (no influence) to 4 (extremely high influence), with 1 representing low influence, 2 representing medium influence, and 3 representing high influence. This conversion generates an aggregate direct-influence matrix X for the eight experts. The aggregate direct influence matrix $X=[x_{ij}]_{n \times n}$, which consists of 16 factors as barriers, can be seen in Equation 1 (when i = j, x_{ij} = 0).

$$X = \begin{bmatrix} 0 & x_{12} & \dots & x_{1n} \\ x_{21} & 0 & \dots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \dots & 0 \end{bmatrix} \quad (1)$$

- Step 2. Establish the normalised direct-influence matrix M and after normalisation according to Equation (2). After normalisation, the values of the elements in the matrix M were all between 0 and 1.

$$M = \frac{X}{\max\limits_{1 \le i \le n} \sum_{j=1}^{n} t_{ij}} \quad (2)$$

- Step 3. Establish the comprehensive influence matrix A using (3). "I" denotes the identity matrix. The comprehensive influence matrix A reflects the comprehensive relations among the factors, including direct and indirect relations.

$$A = M(I-M)^{-1} \quad (3)$$

- Step 4. Calculate the influencing degree, influenced degree, centrality and causality. Ri represents the cumulative impact of factor Bi on other factors, which is the summation of all constituent elements in the corresponding row of matrix A. Di represents the overall impact of external influences on factor Bi. The summation of the column elements of matrix A yields this value: the system's component Bi is "mi", the sum of Ri and Di. As shown by the difference between Ri and Di, "ni" represents Bi's pure effect on the other components.
- Step 5. Develop a cause–effect diagram. The centrality m of the horizontal axis vector (Ri+Di) — called "prominence" — shows the factors' significance. The "relation" vertical axis (Ri-Di) represents causality n, which divides elements into cause factors (n > 0) and effect factors (n < 0). Visualising the dataset of (mi, ni) creates a cause-effect diagram that illustrates fac-

tor significance and interrelationships (Tseng, 2009).

2.4. Research respondents

A panel of experts representing the halal industry in Indonesia was selected to participate in this study. Because the results of this study were based on experts' opinions, they were essential to this study. According to Dalkey and Helmer (1963), an expert is knowledgeable about a specific field. Adler and Ziglio (1996) emphasised that the selection of experts must be based on four "expertise" requirements: an expert must have (i) expertise in dealing with relevant problems (in this case, the halal industry in Indonesia, and have at least five years of experience in the halal industry); (ii) willingness and capacity to participate; (iii) time to participate; and (iv) a strong ability to communicate.

In this study, the number of experts for data processing using the ISM and DEMATEL methods followed the rules for the number of experts for the content validity method. Rodrigues et al. (2017) stated that the minimum number of experts was two, and the maximum was 20 for the validation process. Therefore, in assessing the barriers' content validity for this research, eight experts were selected based on the mentioned "expertise requirements" criteria as well as after having preliminary discussion and continuous follow-up: (i) a representative from the Halal Product Guarantee Agency; (ii) two representatives from two companies; (iii) the Deputy Director of the LPPOM Indonesian Ulema Council; (iv) two representatives from the Halal Inspection Agency; (v) staff of the National Sharia Economy and Finance Committee; and (vi) the Head of the Halal Industry Empowerment Center. The panel of experts was asked to offer professional views based on subjective judgment for each barrier to the dimensions of the entire construct through filled-out Content Validity and ISM questionnaires. The questionnaires were distributed to a panel of experts using Google Forms. It took nearly two months to select, approach, inform, and receive responses from the panel of experts. Email invitations with a survey link were sent to eight experts as eligible individuals. The remainder was sent if the survey was not initiated after one week of emailing. After three weeks, eight respondents gave positive responses.

3. Research results

3.1. Result of the content validity method

The results of the content validation method can be seen in Tables 3 and 4. After excluding barriers B6 (the lack of developed technology for halal leads to the lack of support from information and communication technology regarding traceability issues), B7 (the lack of developed technology for halal leads to limited technology to detect the halal status of the products), and B13 (the lack of infrastructure to support halal logistic implementation), the I-CVI and S-CVI/Ave meet satisfactory levels (above 0.83 and 0.90), and thus, the rest of the barriers achieved a satisfactory level of content validity. Content validity caused the number of barriers to be discussed in subsequent data processing to only 13 factors.

3.2. Result of data processing with ISM

In accordance with the framework of the integrated ISM-DEMATEL method, the ISM method was used first, followed by the DEMATEL method. The individual SSIM and pairwise matrix were constructed using the responses eight decision-makers gave in the ISM questionnaire, as explained in the sub-section respondent of the research. In the ISM method, the aggregate SSIM matrix for barriers, as shown in Table 5, was constructed based on the majority rule proposed by Abdullah et al. (2014), Dhochak and Sharma (2016), Li et al. (2019), Cai and Xie (2018), and Sushil (2012).

Then, the SSIM was converted into binary numbers 0 and 1 to get the initial Reachability Matrix, as shown in Table 6. The final reachability matrix was developed from the initial reachability matrix using the transitivity rule (Table 6). The final reachability matrix reflects the driving power and dependence of barriers. Driving power refers to the effectiveness of barriers on others; for each barrier, this score was quantified by summing up the value on the corresponding row in the final reachability matrix. Dependence refers to the extent to which barriers are affected by others. The score was evaluated for each barrier by summing the values in the corresponding column in the final reachability matrix. Subsequently,

Tab. 3. Initial result of the content validation process

BARRIERS	EXPERTS (THE RESULT FROM QUESTIONNAIRE)								EXPERTS (CONVERSION TO BINARY SCALE								EXPERT IN AGREEMENT	I-CVI
	A	B	C	D	E	F	G	H	A	B	C	D	E	F	G	H		
B1	3	3	4	4	4	3	4	4	1	1	1	1	1	1	1	1	8	1,00
B2	2	3	4	3	4	4	4	4	0	1	1	1	1	1	1	1	7	0,88
B3	2	4	3	3	4	3	4	4	0	1	1	1	1	1	1	1	7	0,88
B4	3	4	4	3	4	4	4	4	1	1	1	1	1	1	1	1	8	1,00
B5	2	3	4	3	4	4	4	4	0	1	1	1	1	1	1	1	7	0,88
B6	2	2	4	2	4	3	4	4	0	0	1	0	1	1	1	1	5	0,63
B7	2	2	2	2	4	4	3	3	0	0	0	0	1	1	1	1	4	0,50
B8	2	3	3	3	4	4	3	4	0	1	1	1	1	1	1	1	7	0,88
B9	3	3	3	3	4	3	2	3	1	1	1	1	1	1	0	1	7	0,88
B10	3	4	4	4	4	3	3	4	1	1	1	1	1	1	1	1	8	1,00
B11	3	4	4	3	4	3	1	3	1	1	1	1	1	1	0	1	7	0,88
B12	3	3	2	3	4	3	3	4	1	1	0	1	1	1	1	1	7	0,88
B13	3	4	3	2	4	2	3	3	1	1	1	0	1	0	1	1	6	0,75
B14	3	4	3	2	4	3	4	4	1	1	1	0	1	1	1	1	7	0,88
B15	3	3	3	1	4	3	4	3	1	1	1	0	1	1	1	1	7	0,88
B16	3	4	4	3	4	4	4	1	1	1	1	1	1	1	1	0	7	0,88
																	S-CVI/Ave	0,85
									0,63	0,88	0,88	0,69	1,00	0,94	0,88	0,94		
									Average proportion of barriers judged as relevance across the eight experts									0,85

Tab. 4. Final result of the content validation process

BARRIERS	EXPERTS (THE RESULT FROM QUESTIONNAIRE)								EXPERTS (CONVERSION TO BINARY SCALE								EXPERT IN AGREEMENT	I-CVI
	A	B	C	D	E	F	G	H	A	B	C	D	E	F	G	H		
B1	3	3	4	4	4	3	4	4	1	1	1	1	1	1	1	1	8	1,00
B2	2	3	4	3	4	4	4	4	0	1	1	1	1	1	1	1	7	0,88
B3	2	4	3	3	4	3	4	4	0	1	1	1	1	1	1	1	7	0,88
B4	3	4	4	3	4	4	4	4	1	1	1	1	1	1	1	1	8	1,00
B5	2	3	4	3	4	4	4	4	0	1	1	1	1	1	1	1	7	0,88
B8	2	3	3	3	4	4	3	4	0	1	1	1	1	1	1	1	7	0,88
B9	3	3	3	3	4	3	2	3	1	1	1	1	1	1	0	1	7	0,88
B10	3	4	4	4	4	3	3	4	1	1	1	1	1	1	1	1	8	1,00
B11	3	4	4	3	4	3	1	3	1	1	1	1	1	1	0	1	7	0,88
B12	3	3	2	3	4	3	3	4	1	1	0	1	1	1	1	1	7	0,88
B14	3	4	3	2	4	3	4	4	1	1	1	0	1	1	1	1	7	0,88
B15	3	3	3	1	4	3	4	3	1	1	1	0	1	1	1	1	7	0,88
B16	3	4	4	3	4	4	4	1	1	1	1	1	1	1	1	0	7	0,88
																	S-CVI/Ave	0,90
									0,69	1,00	0,92	0,85	1,00	1,00	0,85	0,92		
									Average proportion of barriers judged as relevance across the eight experts									0,90

based on the final reachability matrix (Table 7), the reachability, antecedent, and intersection sets were identified for each barrier. The barrier for which the reachability and intersection sets are the same is given as the top-level barrier in the ISM hierarchy. This would not help achieve any other barrier above their level. After the top-level barrier was identified, it was discarded from the remaining barriers. This iteration is continued until the levels of each barrier are obtained. In this study, the thirteen barriers, along with their reachability set, antecedent set, intersection set, and levels, are presented in Table 8. The level identification process, or partitioning of these barriers, was completed in eight iterations. The identified levels aid in building the digraph and the final model of the ISM (Mathiyazhagan et al., 2013), as shown in

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Tab. 5. Aggregate SSIM based on the majority rule

	16j	15j	14j	12j	11j	10j	9j	8j	5j	4j	3j	2j	1j
	B16	B15	B14	B12	B11	B10	B9	B8	B5	B4	B3	B2	B1
1i	V	V	V	V	A	A	A	V	A	V	X	X	
2i	A	V	V	V	A	A	A	V	A	V	V		
3i	A	V	V	V	A	A	V	V	A	V			
4i	V	O	O	X	A	A	O	O	A				
5i	V	V	V	V	V	A	V	V					
8i	A	O	O	O	A	A	X						
9i	X	O	X	O	A	A							
10i	V	V	V	X	X								
11i	V	V	V	V									
12i	X	O	O										
14i	A	X											
15i	O												
16i													

Tab. 6. Initial reachability matrix

		1j	2j	3j	4j	5j	8j	9j	10j	11j	12j	14j	15j	16j
		B1	B2	B3	B4	B5	B8	B9	B10	B11	B12	B14	B15	B16
1i	B1	1	1	1	1	0	1	0	0	0	1	1	1	1
2i	B2	1	1	1	1	0	1	0	0	0	1	1	1	0
3i	B3	1	0	1	1	0	1	1	0	0	1	1	1	0
4i	B4	0	0	0	1	0	0	0	0	0	1	0	0	1
5i	B5	1	1	1	1	1	1	1	0	1	1	1	1	1
8i	B8	0	0	0	0	0	1	1	0	0	0	0	0	0
9i	B9	1	1	0	0	0	1	1	0	0	0	1	0	1
10i	B10	1	1	1	1	1	1	1	1	1	1	1	1	1
11i	B11	1	1	1	1	0	1	1	1	1	1	1	1	1
12i	B12	0	0	0	1	0	0	0	1	0	1	0	0	1
14i	B14	0	0	0	0	0	0	1	0	0	0	1	1	0
15i	B15	0	0	0	0	0	0	0	0	0	0	1	1	0
16i	B16	0	1	1	0	0	1	1	0	0	1	1	0	1

Tab. 7. Final reachability matrix

		1j	2j	3j	4j	5j	8j	9j	10j	11j	12j	14j	15j	16j	DRIVING POWER
		B1	B2	B3	B4	B5	B8	B9	B10	B11	B12	B14	B15	B16	
1i	B1	1	1	1	1	0	1	1*	0	0	1	1	1	1	10
2i	B2	1	1	1	1	0	1	1*	0	0	1	1	1	1*	10
3i	B3	1	0	1	1	0	1	1	0	0	1	1	1	1*	9
4i	B4	0	0	0	1	0	0	0	0	0	1	0	0	1	3
5i	B5	1	1	1	1	1	1	1	0	1	1	1	1	1	12
8i	B8	0	0	0	0	0	1	1*	0	0	0	1*	0	1*	4
9i	B9	1	1	0	0	0	1	1	0	0	0	1	1*	1	7
10i	B10	1	1	1	1	1	1	1	1	1	1	1	1	1	13
11i	B11	1	1	1	1	0	1	1	1	1	1	1	1	1	12
12i	B12	0	0	0	1	0	0	0	1	0	1	0	0	1	4
14i	B14	0	0	0	0	0	0	1	0	0	0	1	1	0	3
15i	B15	0	0	0	0	0	0	0	0	0	0	1	1	0	2
16i	B16	0	1	1	0	0	1	1	0	0	1	1	0	1	7
Dependence		7	7	7	8	2	9	10	3	3	9	11	9	11	

Tab. 8. Level partition

No	Reachability Set	Antecedent Set	Intersection Set	Level
12	4j,10j,12j,16j	1i,2i,3i,4i,5i,10i,11i,12i,16i	4ij,10ij,12ij,16ij	
14	9j,14j,15j	1i,2i,3i,5i,8i,9i,10i,11i,14i,15i,16i	9ij,14ij,15ij	I
15	14j,15j	1i,2i,3i,5i,9i,10i,11i,14i,15i	14ij,15ij	
8	8j,9j,16j	1i,2i,3i,5i,8i,9i,10i,11i,16i	8ij,9ij,16ij	
9	1j,2j,8j,9j,16j	1i,2i,3i,5i,8i,9i,10i,11i,16i	1ij,2ij,8ij,9ij,16ij	II
16	2j,3j,8j,9j,16j	1i,2i,3i,4i,5i,8i,9i,10i,11i,16i	2ij,3ij,8ij,9ij,16ij	
4	4j	1i,2i,3i,4i,5i,10i,11i	4ij	III
1	1j,2j,3j	1i,2i,3i,5i,10i,11i	1ij,2ij,3ij	
3	1j,3j	1i,2i,3i,5i,10i,11i	1ij,3ij	IV
2	2j	2i,5i,10i,11i	2ij	V
11	10j,11j	5i,10i,11i	10ij,11ij	VI
5	5j	5i,10i	5ij	VII
10	10j	10i	10ij	VIII

Tab. 9. Aggregate direct-relations matrix

		1j	2j	3j	4j	5j	8j	9j	10j	11j	12j	14j	15j	16j
		B1	B2	B3	B4	B5	B8	B9	B10	B11	B12	B14	B15	B16
1i	B1	0	2	2	3	1	3	1	1	1	3	3	3	3
2i	B2	2	0	3	3	1	3	1	1	1	3	3	3	1
3i	B3	2	1	0	3	1	3	3	1	1	3	3	3	1
4i	B4	1	1	1	0	1	0	0	1	1	2	0	0	3
5i	B5	3	3	3	3	0	3	3	1	3	3	3	3	3
8i	B8	1	1	1	0	1	0	2	1	1	0	0	0	2
9i	B9	3	3	1	0	1	2	0	1	1	0	2	0	2
10i	B10	3	3	3	3	3	3	3	0	2	2	3	3	3
11i	B11	3	3	3	3	1	3	3	2	0	3	3	3	3
12i	B12	1	1	1	2	1	0	0	2	1	0	0	0	2
14i	B14	1	1	1	0	1	0	2	1	1	0	0	2	1
15i	B15	1	1	1	0	1	0	0	1	1	0	2	0	0
16i	B16	1	3	3	1	1	2	2	1	1	2	3	0	0
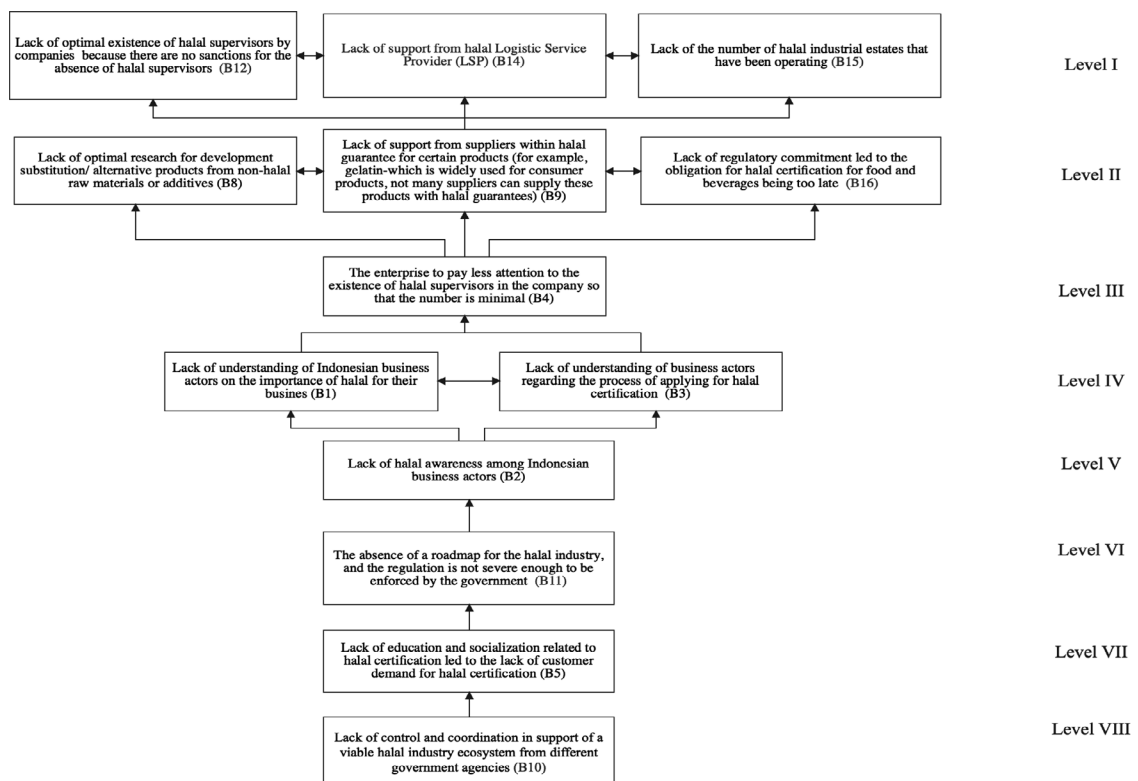
Fig. 2. ISM model of the halal industry barriers

Tab. 10. Normalised direct relationship matrix "M"

| | | 1j | 2j | 3j | 4j | 5j | 8j | 9j | 10j | 11j | 12j | 14j | 15j | 16j |
		B1	B2	B3	B4	B5	B8	B9	B10	B11	B12	B14	B15	B16
1i	B1	0.000	0.059	0.059	0.088	0.029	0.088	0.029	0.029	0.029	0.088	0.088	0.088	0.088
2i	B2	0.059	0.000	0.088	0.088	0.029	0.088	0.029	0.029	0.029	0.088	0.088	0.088	0.029
3i	B3	0.059	0.029	0.000	0.088	0.029	0.088	0.088	0.029	0.029	0.088	0.088	0.088	0.029
4i	B4	0.029	0.029	0.029	0.000	0.029	0.000	0.000	0.029	0.029	0.059	0.000	0.000	0.088
5i	B5	0.088	0.088	0.088	0.088	0.000	0.088	0.088	0.029	0.088	0.088	0.088	0.088	0.088
8i	B8	0.029	0.029	0.029	0.000	0.029	0.000	0.059	0.029	0.029	0.000	0.000	0.000	0.059
9i	B9	0.088	0.088	0.029	0.000	0.029	0.059	0.000	0.029	0.029	0.000	0.059	0.000	0.059
10i	B10	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.000	0.059	0.059	0.088	0.088	0.088
11i	B11	0.088	0.088	0.088	0.088	0.029	0.088	0.088	0.059	0.000	0.088	0.088	0.088	0.088
12i	B12	0.029	0.029	0.029	0.059	0.029	0.000	0.000	0.059	0.029	0.000	0.000	0.000	0.059
14i	B14	0.029	0.029	0.029	0.000	0.029	0.000	0.059	0.029	0.029	0.000	0.000	0.059	0.029
15i	B15	0.029	0.029	0.029	0.000	0.029	0.000	0.000	0.029	0.029	0.000	0.059	0.000	0.000
16i	B16	0.029	0.088	0.088	0.029	0.029	0.059	0.059	0.029	0.029	0.059	0.088	0.000	0.000

Tab. 11. Comprehensive influence matrix "A"

| | | 1j | 2j | 3j | 4j | 5j | 8j | 9j | 10j | 11j | 12j | 14j | 15j | 16j | Total |
		B1	B2	B3	B4	B5	B8	B9	B10	B11	B12	B14	B15	B16	
1i	B1	0.075	0.136	0.138	0.155	0.08	0.156	0.098	0.082	0.083	0.157	0.17	0.151	0.167	1.648
2i	B2	0.128	0.075	0.159	0.154	0.079	0.154	0.096	0.081	0.081	0.155	0.166	0.151	0.111	1.587
3i	B3	0.129	0.105	0.074	0.149	0.078	0.152	0.148	0.08	0.08	0.149	0.164	0.146	0.111	1.565
4i	B4	0.069	0.074	0.076	0.044	0.056	0.044	0.039	0.057	0.057	0.102	0.05	0.037	0.13	0.834
5i	B5	0.19	0.196	0.197	0.186	0.07	0.191	0.181	0.103	0.157	0.189	0.208	0.181	0.201	2.251
8i	B8	0.07	0.073	0.072	0.039	0.054	0.045	0.095	0.054	0.056	0.04	0.05	0.036	0.099	0.782
9i	B9	0.141	0.145	0.093	0.058	0.066	0.12	0.056	0.066	0.068	0.059	0.127	0.058	0.118	1.174
10i	B10	0.194	0.2	0.201	0.188	0.155	0.196	0.186	0.074	0.134	0.164	0.213	0.185	0.204	2.293
11i	B11	0.185	0.191	0.192	0.181	0.098	0.186	0.177	0.126	0.071	0.183	0.202	0.176	0.196	2.165
12i	B12	0.071	0.075	0.077	0.102	0.058	0.046	0.041	0.085	0.059	0.047	0.052	0.041	0.106	0.859
14i	B14	0.071	0.072	0.071	0.038	0.055	0.043	0.094	0.054	0.056	0.038	0.051	0.095	0.07	0.808
15i	B15	0.06	0.06	0.062	0.032	0.049	0.033	0.032	0.049	0.051	0.032	0.095	0.035	0.033	0.621
16i	B16	0.096	0.151	0.153	0.093	0.072	0.125	0.12	0.073	0.074	0.121	0.16	0.064	0.071	1.374
Total		1.479	1.553	1.564	1.418	0.969	1.491	1.361	0.983	1.025	1.436	1.706	1.357	1.618	

Tab. 12. Total relation Matrix, R+D, and R-D for the barriers

BARRIERS	D	R	D+R	D-R	RANK (D-R)	RANK (D+R)	CAUSE / EFFECT
B1	1.648	1.479	3.126	0.169	4	6	Cause
B2	1.587	1.553	3.14	0.034	5	4	Cause
B3	1.565	1.564	3.129	0.001	6	5	Cause
B4	0.834	1.418	2.252	-0.584	10	12	Effect
B5	2.251	0.969	3.221	1.282	2	2	Cause
B8	0.782	1.491	2.273	-0.708	11	11	Effect
B9	1.174	1.361	2.535	-0.188	7	8	Effect
B10	2.293	0.983	3.277	1.310	1	1	Cause
B11	2.165	1.025	3.190	1.139	3	3	Cause
B12	0.859	1.436	2.295	-0.576	9	10	Effect
B14	0.808	1.706	2.514	-0.898	13	9	Effect
B15	0.621	1.357	1.978	-0.736	12	13	Effect
B16	1.374	1.618	2.992	-0.245	8	7	Effect

Fig. 2. The relationship between barriers i and j is indicated by an arrow pointing from i to j.

As described previously, the DEMATEL method was applied to SSIM in this study by transforming the matrix into a pairwise matrix using a linguistic scale (Equation 1). The aggregate direct-relation matrix (matrix X) is presented in Table 9. The normalised direct relationship matrix "M" was formed using Equation (2), which is presented in Table 10. Table 11 shows the comprehensive influence matrix "A". In matrix "A", the sum of individual rows and the sum of individual columns are considered to calculate the (R+D) and (R-D), which are used to plot the digraph, and it also determines the cause and effect relationship of each barrier. The values of (R+D) and (R-D) are also highlighted in Table 12. Figs. 3 and 4 show the causal relationship diagram for the barriers and the revised digraph model for barriers in the halal industry.
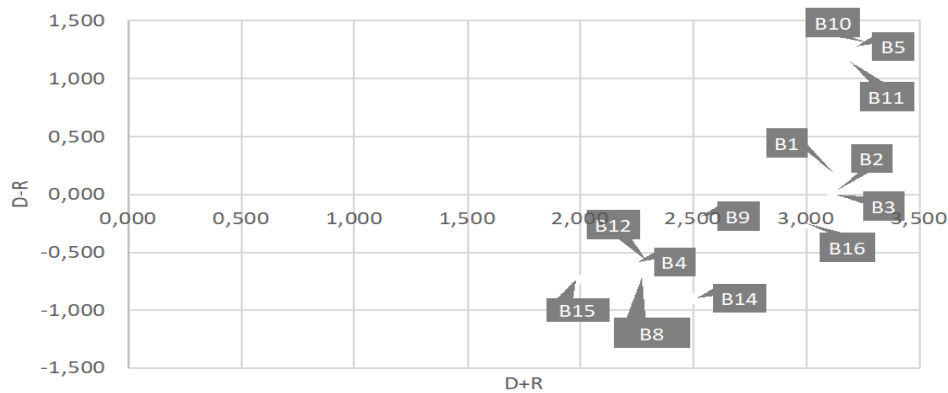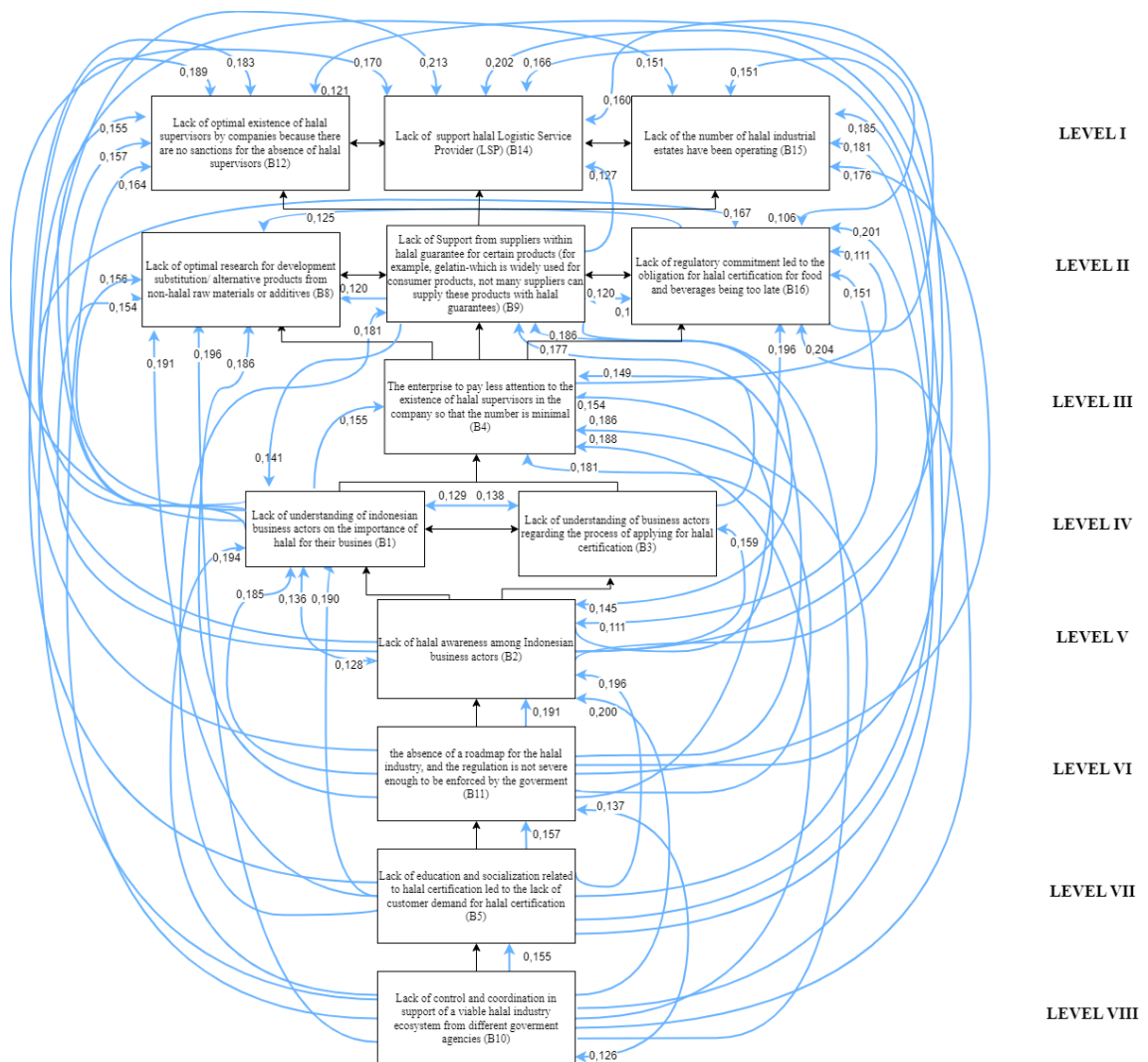
Fig. 3. Causal relationship diagram

Fig. 4. Revised digraph model according to the result from DEMATEL

4. Discussion

The integrated ISM-DEMATEL method is utilised in this study to identify the main barriers to optimising the halal industry in Indonesia and capture the cause–effect relationships between them based on the expert panel's opinions. The suggested ISM model aids in recognising the significance of barriers, visualising the structure of complex causal relationships using matrices or digraphs and identifying interdependence among the barriers. This study provides significant insights into the barriers that are important to both industry and academia.

Figure 2 and Table 7 indicate that "the lack of control and coordination in support of a viable halal industry ecosystem from different government agencies" (B10) is the most influential barrier with the highest driving power and weak dependence power, and since it is a barrier that hinders the maximisation of the halal industry, policymaking requires more focus to reduce the problems and bring more benefits. In fact, coordination is an important aspect in the implementation of the Law of Halal Product Guarantee because it involves many agencies, such as the Ministry of Industry, the Ministry of Trade, the Ministry of Health, the Indonesian Ulema Council, and other Islamic mass organisations (Hasan & Pasyah, 2022). This coordination is also required because the government must implement law enforcement and consumer rights protection for the certification and labelling of halal products via three (three) surveillance systems: preventive supervision, uniqueness, and incidental. A preventive surveillance system for halal food items, including registration, was implemented. This unique surveillance system is intended to actively monitor halal food, medication, and cosmetics, which can significantly influence health, social, and economic aspects. When indicators of a specific case of halal certification or halal labelling are discovered in the field, this method encourages law enforcement to tackle it with appropriate actions depending on the uniqueness of the committed infractions. An incidental surveillance system is a procedure for unannounced inspections conducted by law enforcement on halal food security and safety. Then, the lack of control and coordination in support of a viable halal industry ecosystem from different government agencies caused several things, including "the lack of education and socialisation", 'the absence of a roadmap for halal integrity", the lack of optimal existence of halal supervisors by enterprise", "the lack

of support from halal Logistic Service Providers (LSP)", and "the lack of the number of halal industrial estates that have been operating".

Barriers with a high degree of importance and a high net effect are considered critical for maximising the performance of the halal industry. The (+) score represents the relative importance of each barrier. Therefore, factors with higher scores of (+) may have the highest priority in the ranking of barriers. Based on Table 12, the barrier "the lack of regulatory commitment led to the lack of control and coordination in support of a viable halal industry ecosystem from different government agencies" (B10) is ranked first based on the degree of importance, followed by "the lack of education and socialisation related to halal certification that led to the lack of customer demand for halal certification" (B5) and "the lack of regulatory commitment led to the absence of a roadmap for the halal industry, and the regulation is not severe enough to be enforced by the government because it is not supported by the ease and low cost of making a halal certification" (B11). This finding is consistent with the results of the ISM digraph.

Fig. 3 shows the causal relationship diagram, which provides information on the most significant barriers to maximising the halal industry and their level of influence. The feedback collected from the eight experts was displayed in the form of a visual impact map to classify the drivers and barriers into cause-and-effect groups. Fig. 3 presents that the barriers "the lack of regulatory commitment led to the lack of control and coordination in support of a viable halal industry ecosystem from different government agencies" (B10), "the lack of education and socialisation related to halal certification led to the lack of customer demand for halal certification" (B5), "the lack of regulatory commitment led to the absence of a roadmap for the halal industry" (B11), "the lack of understanding of Indonesian business actors on the importance of halal for their business" (B1), "the lack of halal awareness among Indonesian business actors" (B2), and "the lack of understanding of business actors regarding the process of applying for halal certification" (B3) are the causal factors; whereas the barriers "pay less attention to the existence of halal supervisors in the company so that the number is minimal" (B4), "the lack of optimal research for development substitution/alternative products from non-halal raw materials or additives" (B8), "the lack of support from suppliers within halal guarantee for certain products" (B9), "the lack of optimal existence of halal supervisors by companies" (B12), "the lack of

support from halal LSP" (B14), "the lack of the number of halal industrial estates that have been operating" (B15), and "the obligation for halal certification for food and beverages being too late" (B16) belong to the effect group. Fig. 4 shows the revised digraph model for the barriers in the Halal Industry. This figure depicts the relationship between barriers and the magnitude of the value of the relationship between these barriers.

In this study, barriers were divided into causal/influential/driving and affected/dependent groups. From the standpoint of the ISM Model (digraph), the lack of control and coordination in support of a viable halal industry ecosystem from different government agencies (B10) is the most influential barrier, with a high degree of importance, and belongs to the cause factor. This barrier requires immediate attention and needs to be eliminated, and policymaking in the halal sector has to keep its priority. Control and coordination could be essential to handle the three priorities in ranking barriers from the standpoint DEMATEL, namely, "the lack of education and socialisation related to halal certification led to the lack of customer demand for halal certification" (B5), "the lack of understanding of business actors regarding the process of applying for halal certification" (B3), and "the lack of halal awareness among Indonesian business actors" (B2).

This study provides some theoretical contributions in the field of the halal industry, such as:

- Proposes a framework (which is based on the integrated ISM-DEMATEL method) to identify and rank barriers to maximising the performance of the halal industry in Indonesia that could be implemented for identifying and ranking the halal industry barriers in other countries.
- Identifies and raises awareness of critical barriers, the driving and dependence powers of the barriers, and dominant barriers to maximising the performance of the halal industry in Indonesia.
- Proposes guidelines to managers or decision-makers of the halal industry to maximise those industries by discovering the most significant barriers that impact each other.

This study has practical implications for the halal industry. Even though Indonesia is one of the countries with the most significant number of Muslims, in several aspects, its performance is still not optimal or lagging compared to other Muslim-majority countries. Some barriers may cause an inability to achieve optimal conditions. Since this study applied the ISM

and DEMATEL with the help of the expert panel's opinions, it can provide insights into multiple policy-making to determine the relationship between the barriers and focus on the critical barriers to obtain more benefits, increase performance, and increase the efficiency of resource allocation. Moreover, after analysing the barriers, the given framework model is better and effectively selects a programme related to the critical barrier. Then, in line with the most influential barrier, the lack of control and coordination in support of a viable halal industry ecosystem from different government agencies, the government must update the coordination process, standard codes, and procedures and adhere to their implementation. Coordination among government agencies to support the halal industry can enhance the number of halal certifications and generate a rigorous roadmap for the halal industry. Indeed, through a clear roadmap agreed upon by all policymakers, a clear division of tasks and indicators of achievement can be identified. Thus, improving halal performance is not an issue with unclear authority or overlapping powers but with well-divided portions of responsibility. Then, in line with the next level of priority barriers (the lack of education and socialisation related to halal certification that led to the lack of customer demand for halal certification, and the lack of regulatory commitment led to the absence of a roadmap for the halal industry, and the regulation is not severe enough to be enforced by the government), one of the important programs that should be well-measured attainment on the roadmap is halal literacy for the community and enterprise, including the procedure to obtain the halal certificate, the importance of the community to provide factual support for the halalness of a product, and the kind of sanctions for enterprises who do not make an actual declaration of the halalness of their products procedure to get halal certificates. The programme's success was monitored using a periodic survey.

CONCLUSIONS

A descriptive picture was drawn regarding the barriers to maximising halal industry performance. An extensive literature survey identifies various barriers related to halal industry performance. Referring to the institutional theory and RBV in the context of halal research and previous research related to the halal industry, this study succeeded in identifying 16 barriers. After the validation process, only 13 barriers

were considered relevant and used in the subsequent data processing. Then, a structural model and cause–effect diagram were developed for 13 barriers using the integrated ISM-DEMATEL methodology) to determine the critical barriers. The barrier "the lack of control and coordination in support of a viable halal industry ecosystem from different government agencies" is the most influential barrier with the highest driving power and weak dependence power. These barriers should be the focus to be resolved to handle the next level of caused barriers ("the lack of education and socialisation related to halal certification that led to the lack of customer demand for halal certification" and "the lack of regulatory commitment led to the absence of a roadmap for the halal industry, and the regulation is not severe enough to be enforced by the government").

This study has several limitations. It depended on the expert panel's opinions to validate and identify the relationship between barriers. There may be different barriers for other halal-industry regions. The judgment bias in understanding the barrier is also a concern because the panel experts depended on the given data and had to decide in this context. However, this barrier relationship does not always provide definite results. This limitation inhibits the generalisability of the outcomes. In the future, the relationship between barriers can be tested with the fuzzy ISM, fuzzy DEMATEL, rough ISM, or rough DEMATEL approaches, as a fuzzy and rough approach may offer insights into the significance of barriers and the performance ratings of alternatives concerning barriers. In addition, there is no international comparison of the barriers to the halal industry, which could be an opportunity for future research. Moreover, the relationship between barriers from this study could be used to test the model generated by the integrated ISM-DEMATEL methodology by applying the Structural Equation Modelling (SEM) technique.

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Mobile digital technologies as an integrator of the logistics of transport services in a Smart City

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A B S T R A C T

The modern world is socio-technological with a city-centric exemplification. Literature studies and reports have identified an empirical research gap. It relates to the poor identification of the relevant construct components pertaining to digital mobile technology solutions that support urban transport services from the users' perspective. Filling this gap involved distinguishing a research problem related to insufficient identification of the desired application components as representations of mobile technology solutions in the context of the urban transport services' uptake. The article mainly aims to diagnose and evaluate the use of mobile digital technologies to support the logistics of transport services from the perspective of Smart City residents in accordance with the concept of sustainable development. The specific objectives were a theoretical objective, defined as the development of a theoretical model for the creation and management of public transport services resulting from the needs of Smart City residents, and an empirical objective, defined as the verification of the impact made by components of the digital mobility solutions construct on the choice of urban transport services. A nomothetic approach was used based on triangulation of results obtained from mixed studies. The source basis for qualitative research was bibliographic data obtained from the Scopus and Web of Science (WoS) databases, monographs, reports and other netographic sources. They were verified and analysed using the bibliometric technique of word occurrence and co-occurrence analysis (co-word analysis) based on critical content analysis. VOSviewer software was used to conduct the qualitative part of the study. In turn, the source base for quantitative research was city residents, who were surveyed using the CAPI (Computer Assisted Personal Interview) online survey technique. IBM SPSS Statistics software was used to analyse the data. The research indicates the necessity to use mobile digital technologies for managing urban transport services' logistics in the spirit of Society 5.0.

K E Y   W O R D S

mobile technologies, digitalisation, Smart City, logistics of services, transport

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Introduction

Technological evolution is inherently related to the evolution of social and community relations. (Cantwell & Vertova, 2004). The history of the ancestors (homo habilis) of modern humans (homo sapiens) started about 3 billion years ago and was marked by the creation and use of the first tools and the formation of social hominid groups. The socio-cultural evolution oscillating around the tools, methods and techniques available to and used by people has led to the existential transformation of humanity from nomadic tribes living in the spirit of nature to techno-

logical and digital nomads (Basalia, 1999). According to e-numerativity, the evolution started with a society based on hunting and gathering (1.0), to the agrarian (2.0), the industrial (3.0), the information (4.0), and the super-intelligent collaborative digital society (5.0) (Deguchi, 2020).

The cohesion of social groups, the development of language, and the improvement of communication methods, along with the organisational division and specialisation of work and the creative design of inventions, allowed people to improve and subordinate the world. Such inventions as the wheel, wagons, boats, the printing press, calculating machines, and steam engines led to an environmental revolution. The ecosystem in which people functioned transformed, resulting from the absorption of green areas for crops and the infrastructure of buildings and roads. A sedentary lifestyle and increasingly advanced technologies resulted in people creating settlement units, i.e., cities characterised by high development intensity, little agricultural land, and a population working outside agriculture (Papalia, 2007).

At the turn of the 19th and 20th centuries, the global population was 1.7 billion, and it took another half a century to increase it to 2.5 billion. In 1987, the world population reached 5 billion. It took 12 years for it to exceed another billion, reaching 6 billion in 1999. It took another 12 years to exceed 7 billion. The current population, according to the UN, is over 8 billion, and it will exceed 9.7 billion in 2050. Today, the number of Earth's inhabitants is twice as high as it was 50 years ago (Latos, 2019). Currently, over 500 million people live in cities with a population of 10 million or more. In 2030, it will be 730 million. Globally, it is now over half (55 %) of humanity. It is estimated that in 2050, 41 cities will have a population of over 10 million, 63 — a population of 5 to 10 million, while the number of cities with a population of 1–5 million will increase to 558, and those with 0.5 to 1 million will be 731 (Madej & Sumara, 2019). Therefore, it is expected and extremely valuable to think about the solutions that will help city inhabitants to live in such conditions, considering their living, working, and leisure. It means the need for new ideas for public services, such as transport, healthcare, and administration. This is one of the reasons why the authors chose the topic for this research.

Urbanisation, as a specific process indicating an increased number of people living in cities in relation to the total population, has contributed to migration transformations for centuries. Urbanisation has resulted in an increasing population density per square kilometre. Such a large number of people meant and still means great creative potential and great expectations, as well as great threats (Spencer et al., 2009).

Old technologies that have contributed to the current development of cities are necessary for their continued survival and development in the future, especially considering the specificity of the so-called urban lifestyle related to the interface of nature and technology, recognised as a sub-model of civilisation with laws, language, folklore, traditions and an existential model identified with the improvement of individual-collective coexistence. The Smart City concept (ChuanTao et al., 2015) is an exemplification of such an approach. In the spirit of digital technology, the concept fits into the idea of a super-intelligent collaborative digital Society 5.0, where combining physical space (the real world) and cyberspace creates conditions for a comfortable and satisfying life for the inhabitants of these super cities, thanks to new, mobile digital technologies operating on ICT layer combined with IoT, AI, big data, cloud computing, machine learning and deep learning. Here, old or classical technologies are supported by new digital solutions (Deakin, 2013; Kumar, 2017; Šulyová & Kubina, 2022; Kinelski, 2022).

In the course of evolution, technological solutions have contributed to the propagation of anthropocentrism, which considers a human to be the centre of all reality, or even technocentrism, a concept that accepts technology as the main value in the development of civilisation, moving away from the biocentric approach with a human as a part of nature without the central position in the world. The Smart City concept is an aberration of such thinking. "Smart" as a concept is broad and ambiguous in itself (Baraniewicz-Kotasińska, 2020). In relation to cities, the meaning is narrowly identified using terms such as intelligent, innovative, cognitive and creative. In a broader sense, a Smart City is a city that contributes to meeting the needs of its inhabitants, using the benefits of modern technologies while not limiting the development opportunities of future generations (Kanter & Litow, 2009). Considering this definitional aspect of Smart City, relating to care for future generations, it emphasises the element of sustainability of the so-called Smart Growth included in Agenda 21. Technology-based development should consider the environmental ecosystem and treat humans and technologies as its parts rather than something above them. This is the essence of the aberration. Humans need nature to survive and function because they are

living individuals. Technology alone is insufficient for humans as their survival depends on the natural environment. Therefore, another component, "Sustainable", can be added to the "City" concept, emphasising the importance of the environmental aspect. Therefore, a "Sustainable City" (Khansari et al., 2013) bases its functioning not so much on technology but on respect for nature. To sum up, metropolises can be called "Smart Sustainable Cities" if they combine innovative technology applications with the natural habitat, integrating stakeholders and providing all interested parties an opportunity to develop without reducing such opportunities for future generations (Höjer & Wangel, 2014). As the Smart City concept includes the assumption of environmental sustainability, it will be used in the further part of the article to maintain the coherence of the argument.

Based on the descriptors defined by the SRF — the Center of Regional Science of the Department of Spatial Planning of Vienna University of Technology, a Smart City has a smart economy, smart environment, smart mobility, smart people, smart living and smart governance (European Smart Cities). This multidimensional characteristic provides several connections related to residents whose domain of activity is movement. Smart mobility is the component that integrates, unifies and bonds the entire Smart City concept. For the concept to become a reality, it is necessary to guarantee the efficient operation of the city's functional areas, including the mobility of residents in terms of migration and circulation, i.e., their physical transfer in space. In this respect, new technologies play an important role, especially in the area of communication and transport, which represent a holistic approach to urban logistics (Dembińska et al., 2018).

The importance of ensuring the effectiveness of activities while reducing the degree of environmental degradation in meeting the transport needs of city residents sets new trends in the creation and use of new technologies. Including digital technologies in the fabric of urban logistics means digitising information supporting the management of transport services. Travel planning and its implementation inherently involve the use of digital technologies (Taniguchi et al., 2016; Szpilko et al., 2023a). In this approach, it becomes important to create such technical and operational solutions for sustainable digital mobility that will be based on ecological methods and means of transport thanks to interdisciplinarity combining the concepts of transport management, spatial development, respect for the natural environment

and safety of residents (Allen & Browne, 2010). The layer of digital space created by digital mobile applications plays an important role in this process.

The article's main objective is to diagnose and evaluate the use of mobile digital technologies to support transport services logistics from the perspective of Smart City residents according to the sustainable development concept. The specific objectives were theoretical, defined as the development of a theoretical model for the creation and management of public transport services resulting from the needs of Smart City residents, and empirical, defined as the verification of the impact made by the components of the digital mobility solutions construct on the choice of urban transport services. Achieving the main objective and specific objectives required the use of mixed research methods. Qualitative methods were used first, followed by quantitative methods.

To realise the aim of the study, the authors decided on a three-stage research programme to objectively assess the level of use of digital mobile technologies that support logistics transport services in a Smart City. The research programme includes complementary qualitative and quantitative methods. Fig. 1 presents the research programme by stages, stating their purpose, references to research questions, associated hypothesis, data collection methods, and used analysis methods.

To diagnose the current state of scientific achievement on the Smart City topic and the use of mobile digital technologies to support the transport services' logistics, qualitative research methodologies were used, including a search and query of Scopus and Web of Science (WoS) databases for the occurrence and co-occurrence of terms within the subject scope under study and a critical content analysis covering the body of literature. The following research questions formed the basis for starting the research procedure for the qualitative part:

- RQ1. What is the essence of modern city logistics, and what system and process technology challenges must the transport services' logistics meet in serving Smart City residents in the 21st century?
- RQ2. What is the manifestation of logistics technologisation in managing the representation of the communication and transport construct of the Smart City community?

The literature review helped define an empirical research gap, which indicated poor recognition of relevant construct components of digital mobile technology solutions supporting urban transport

STAGE 1

Method: qualitative
Purpose: diagnosis of the current state of scientific achievement
References to research questions: RQ1, RQ2
Associated hypothesis: N/A
Data collection methods: search of Scopus and Web of Science (WoS) databases
Type of analysis: occurrence and co-occurrence of terms, critical content analysis.

STAGE 2

Method: quantitative
Purpose: diagnosis and assessment of the availability of mobile digital technology solutions to support the transport services' logistics in selected cities in Poland from the perspective of Smart City residents.
References to research questions: RQ3, RQ4, RQ5
Associated hypothesis: H1, H2
Data collection methods: CAPI online survey
Type of analysis:
- the distributions of the variables in the contingency tables
- χ^2 test of independence between selected variables (Cramer's v coefficient)
- Bartell's test of sphericity
- KMO coefficient
- correlation matrix based on χ^2 coefficient

STAGE 3

Method: conclusions and summary
Purpose: development of a theoretical model for the creation and management of public transport services resulting from the needs of Smart City residents.
References to research questions: N/A
Associated hypothesis: N/A
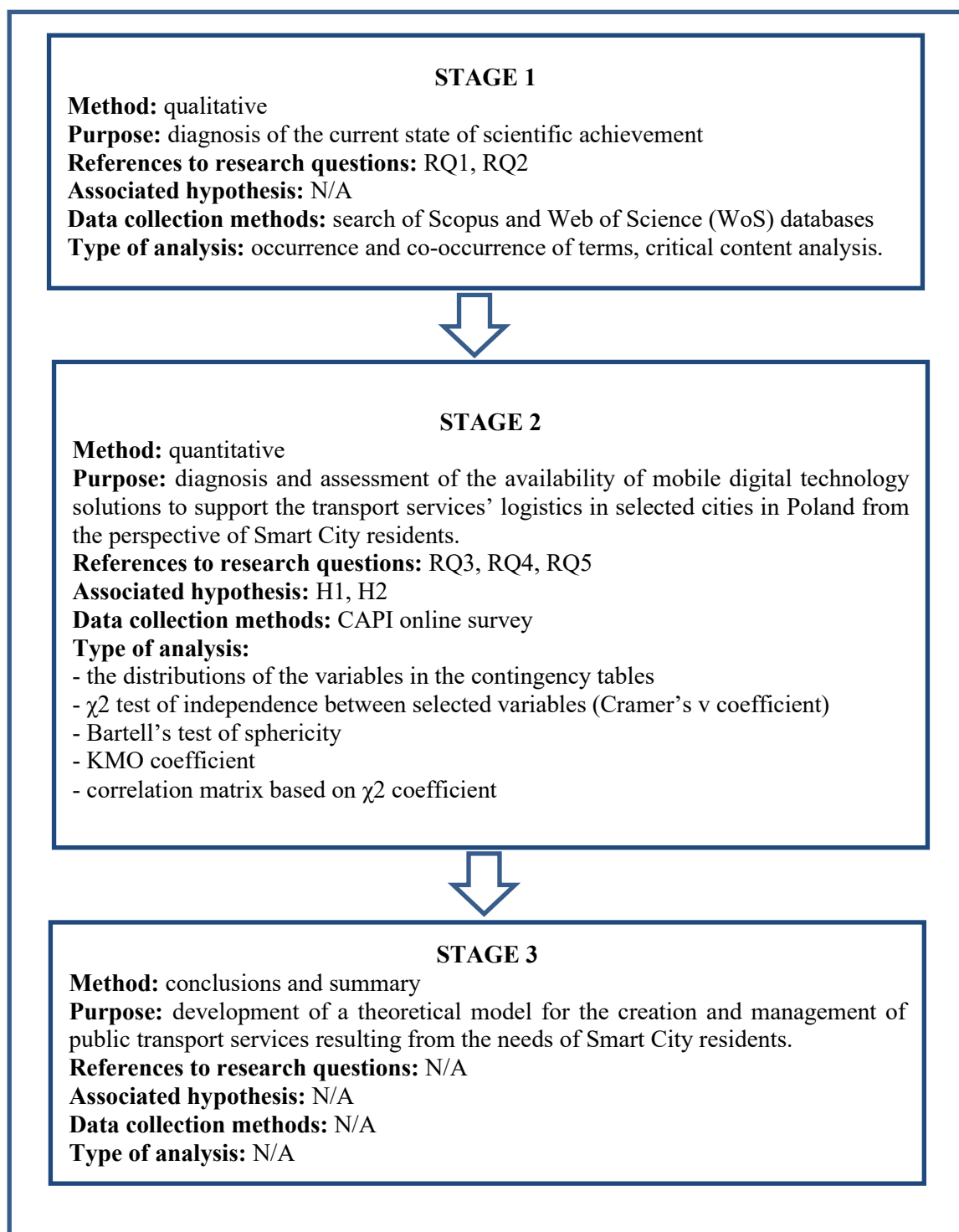**Data collection methods:** N/A
Type of analysis: N/A

Fig. 1. Research programme

services from the users' perspective. The definition of this gap was based on formulating specific questions for a research model based on quantitative research methodology:

- RQ3. What is the current availability of digital solutions informing people about transport services in cities in accordance with the idea of sustainable development?
- RQ4. How important are digital information sources in providing and updating information about changes in public transport services for residents?
- RQ5. What technological solutions in the area of communication and information should be disseminated in urban transport services for residents to be consistent with the idea of sustainable development of a smart city?

Filling this gap involved creating a quantitative research model for an identified research problem regarding insufficient identification of desirable application components as a representation of mobile technology solutions used for disseminating public transport services. Also, research hypotheses were formulated and the study population and the unit of study were identified. Then, the sampling method was defined, the survey implementation method was selected, the survey instrument was constructed, methodologies for the collected data analysis were selected, and hypothesis testing was formed. This approach combined the strengths of qualitative and quantitative methods and obtained research material to complement the existing theoretical output and to identify practical recommendations. The approach has the following strengths: maintaining due research care and obtaining the end result in compliance with the scientific discourse. Its shortcomings, especially in the quantitative part, are a limited surveyed population of a few Polish cities and the methodology of non-random selection of units to the sample, which only allows suppositions about possible regularities.

The article, in particular the conclusions and recommendations, provides a better understanding of the role and importance of the use of digital mobile technologies in the implementation of logistics processes of transport services in cities. Considering the ongoing processes of virtualisation and technologisation and the broadly understood digital transformation of many socio-economic areas of cities, the coming years will be marked by the necessity of digital technologies to be present everywhere, including and, perhaps, primarily, in logistics processes, and especially in communication and transport processes.

This is important because, according to preliminary estimates, in 2050, 75 % of the world's population will live in cities. Therefore, the guarantee of efficient and sustainable urban travel, i.e., movement within urban agglomerations, is becoming a priority both in terms of creating new models and the practice of operational applications.

1. Literature review

The population migration to cities forced authorities to adapt to a new situation. So far, the natural growth of the urban fabric has not been sufficient, giving rise to new problems. It is especially visible in crowded city centres, where congestion problems hinder the movement of residents (Kauf et al., 2018). However, urbanisation problems, especially in developing cities, can be divided into categories (Winkowska et al., 2019) related to social and sociological problems, technical infrastructure, and the environment and logistics. Of course, in the context of new concepts, such as ESG (environment–social–governance) (Pollman, 2022), all these elements influence each other, making it difficult to isolate one area of interest. However, research prompted an attempt to indicate how logistics activities can support residents, also in the context of other problematic areas.

An important aspect of the logistics approach is to ensure the appropriate flow of people and goods, which is the essence of logistics. Hence, the concept of urban logistics focuses on providing a transport system that meets the expectations of all stakeholders, including residents, enterprises, service providers, city managers, etc. (Neghabadi et al., 2019; Bjørgen & Ryghaug, 2022; Przybylska et al., 2023). Such a transport system should consider the mobility of residents individually (Caban, 2021) and collectively (Ceder, 2019). Another important issue is securing the supply of goods and services, which involves developing a system that facilitates access of large vehicles to the city or ensuring deliveries from satellite warehouses around cities (Moore, 2019; Mepparambath et al., 2021).

Mobility in cities changed under the influence of the Industry 4.0 concept when people started to think about creating "thinking" digitalised cities. This is how the Smart City concept was born, including many components, such as smart economy, smart mobility, smart environment, smart people, smart living, and smart governance (Winkowska et al.,

2019). However, researchers indicate that a uniform definition of a Smart City is not possible, and although the name itself potentially refers to the use of modern technologies, the focus should also be placed on elements related to the sustainable management of city resources with the participation of its inhabitants to achieve their well-being (Tomaszewska, 2021). Certainly, modern IT systems are supportive, facilitating the management of data generated in the city's ecosystem (Szum, 2021).

The COVID-19 pandemic added a new dimension to urban logistics, which made home deliveries, collection points (Sułkowski et al., 2022), and even safe public transport (Rasca et al., 2021) more important. More attention is paid to ensuring that transport services can be considered ecological, which requires appropriate technological solutions (Kiba-Janiak et al., 2021; Kunnapapdeelert et al., 2022). In addition, attention is paid to the sustainable development goals implemented by governments of various countries, including in the EU (Shrestha & Haarstad, 2023). From the perspective of residents, mobility is still treated as one of the most important elements of choosing a place of residence as it affects job possibilities, the availability of public services (schools, kindergartens, and shopping), and gives a sense of freedom from a sociological point of view (Wawer et al., 2022).

Digital mobile technologies play an important role in the Smart City concept, contributing to improved efficiency and sustainable development of urban areas. Mobile applications are a key element of digital mobile technologies in the Smart City context. These applications allow city residents to monitor traffic, purchase tickets, access information on public transport delays and failures, and plan routes, considering multiple transport modes. They help residents use various transport services more effectively, increasing public transport availability and reducing road congestion (Janoskova et al., 2021). Another important element is data transmission, monitoring and analysis systems, particularly BI and processing large data sets, such as Big Data (Hussain et al., 2019). Thanks to the GPS (Global Positioning System) technology, the possibilities offered by wireless data transmission in 5G mobile networks (Gohar & Nencioni, 2021) and sensors mounted on transport means, and, in particular, the IoT concept (Bauer et al., 2021) cities can track the movement of vehicles and passengers in real-time. This enables traffic management, quick response to failures and better planning of transport infrastructure. Moreover, the

analysis of data from various sources allows for more accurate decisions to be made, increasing the efficiency of transport systems. Digital mobile technologies are an indispensable element of the Smart City concept, influencing the efficiency and availability of transport services. Mobile applications facilitate the use of various transport means, while monitoring and data analysis systems enable better traffic management and planning of transport infrastructure. In this context, it is also very important to maintain appropriate experiences for mobile application users (Diamantaki et al., 2015). Developing these technologies is key to creating more sustainable and smarter cities, improving the residents' quality of life and reducing the negative impact of transport on the environment (Barr et al., 2021).

2. Research methods

The considerations in the theoretical analysis (based on qualitative research methodologies), covering the scientific achievements so far, became the basis for the practical verification of the scope pertaining to the use of digital mobile technologies to support the transport services logistics provided in selected cities in Poland (based on the quantitative research methodology).

A study was made at the turn of April and May 2023, focusing on the research issue of diagnosing and assessing the availability of solutions in mobile digital technologies supporting the transport services logistics in selected Polish cities from the perspective of Smart City residents. The subject of the measurement was the residents' knowledge, attitudes, and opinions in selected Polish cities regarding the use of applications representing digital mobile technologies that support the logistics of public transport services. Such subject definition led to a descriptive and explanatory study, which required to prepare the characteristics of the information construct pillars defining the availability of public transport services and demonstrating the validity of introducing possible improvements in the implementation and applicability of mobile digital technologies for representing applications as support for the logistics of transport services dedicated to Smart City residents.

The study's assumptions were implemented based on the inductive proof methodology using two research hypotheses:

H1: Residents who have knowledge about mobile digital solutions are more willing to and more often

use various forms of digital information sharing regarding the transport services logistics, i.e., mobile digital applications .

H2: Residents who appreciate digitalisation for providing information about the transport services logistics use various public transport forms much more often.

Information from city residents was required to verify the hypotheses. It was assumed that the study population would consist of Polish residents over the age of 15 who lived in the city during the six months before the study. The decision to test a part of the population was made due to limitations in the availability of potential subjects, time and the research budget. Consequently, the minimum sample size was determined.

In the calculation processes, the sample was comprised of Polish residents who were 15–64 years old as of 31 December 2022. According to the Central Statistical Office, the number of such residents amounted to 14,472,409 (Statistics Poland, 2023). It was assumed that the fraction of the proportion value including people using public transport was 0.4 compared to 0.6 of people not using it (Gadziński & Goras, 2019), and the assumed level of random error will be of the order of 5 % with a confidence level of 0.95.

A formula was used to calculate the minimum sample size:

$$n_{min}=NP(\alpha^2 \cdot f(1-f))/NP \cdot e^2 + \alpha^2 \cdot f(1-f) \qquad (1)$$

where:
n_{min} means the minimum sample size,
NP — size of the study population,
α — confidence level for the results,
f — fraction size,
e — assumed maximum error.

After calculations, the minimum sample size was n_{min} = 369 units. To examine the determined number, the diagnostic survey method was used with the CAPI (Computer Assisted Personal Interview) Internet survey technique. The research tool was a questionnaire consisting of 17 closed questions, including nine based on the Rensis Likert scale of attitudes, which was prepared in a digital version and placed on the https://www.ebadania.pl/ platform. A link to the questionnaire was placed on social networking sites in local groups devoted to urban issues. For the technical selection of sample units, the method of non-random sampling of typical units

with snowball elements was used, which means that the study could include people registered on social media in urban groups who meet the conditions for participation in the study. They could send a request to other people who could take part in the study, provided they also met the participation conditions. The advantage of this approach was the increase in the number of study participants, yet the disadvantage was the inability to supervise who completed the questionnaires. This measurement method means the study is fragmentary, deterministic, and representative of the selected study population.

Respondents could complete a questionnaire shared on social media for two weeks. Ultimately, 1,278 completed questionnaires were obtained, which is three times more than initially expected. The obtained data were anonymised and coded in IBM SPSS Statistics. Then, they were verified and validated to check and assess the suitability of the material for statistical processing. After passing this stage, the material could be subjected to a proper three-stage analysis.

In the first analysis stage, data is aggregated into tables, distributing the values of answer variants obtained from basic and specific questions. Then, in the second stage, the representativeness of the sample was verified using a consistency test based on the χ^2 statistic written:

$$\chi^2 = \sum_{i=1}^{r} \frac{(n_i - np_i)^2}{np_i} \qquad (2)$$

where:
p_i — the probability that feature X will take a value belonging to the range of class "i",
np_i — the number of units that should be in the i-th interval.

Assuming that the statistics have a χ^2 α distribution with k = (r - 1), where: k is the number of degrees of freedom and r is the number of class intervals. In turn, the empirical value of the χ^2 statistic is calculated from the data obtained from the study. The form of a critical set: P $(\chi^2 < \chi^2_\alpha) = \alpha$ where χ^2_α is the critical value determined from the χ^2 distribution tables for k = r - 1 degree of freedom and p = α. The values obtained from the study sample for the variables gender, age, and place of residence were compared with the distributions characterising the population. Thus, the representativeness of the sample for the surveyed population of Polish city residents was confirmed (Table 1).

Tab. 1. Verification of the tested sample against the population based on the χ^2 significance test.

VARIABLE	VALUE χ^2 REAL	VALUE χ^2_α THEORETICAL	TEST REALIZATION $\chi^2 < \chi^2_\alpha$
Sex	0.385	3.841	concordance
Age	10.299	12.592	concordance
Place of accommodation	3.028	11.070	concordance

1 a α — confidence level

In the third analysis stage, a reference was made to answers to the basic questions and metrics, compiling the results in the form of contingency tables and verifying the possibility of a relationship between the selected variables using the χ^2 independence test in the form:

$$\chi^2 = \sum_i^r \sum_j^s \frac{(n_{ij} - \tilde{n}_{ij})^2}{\tilde{n}_{ij}} : \chi^2_{(r-1)\cdot(s-1)} \qquad (3)$$

where:
nij — empirical conditional numbers resulting from the contingency table,
$\tilde{n}_{ij}$ — theoretical conditional numbers that would appear in the array if the features were independent.

The V-Cramér coefficient calculated from the formula was adopted as a verifier confirming the existence of the relationship:

$$\mathcal{V} = \sqrt{\frac{\chi^2}{n \cdot min(r-1, k-1)}} \qquad (4)$$

where:
$\mathcal{V}$ — is the V-Cramér coefficient between two variables,
χ^2 — χ^2 test result for a pair of variables,
n — number of observations,
r — number of levels of one variable,
k — number of the second variable,
min (r-1, k-1) — the smaller value of the two (r-1) or (k-1) is selected.

This three-stage procedure allowed for obtaining material to verify the hypotheses, the results of which are presented in the research results section. However, for the purposes of this article, the authors developed only those questions that were consistent with the main thread of the article.

3. RESEARCH RESULTS

To confirm the level of interest in the topic of mobile technologies in the context of transport in a Smart City, a qualitative study was conducted within existing databases of scientific publications. The source basis for qualitative research was bibliographic data obtained from two interdisciplinary databases, Scopus and Web of Science (WoS), regarding scientific publications in the area of mobile digital technologies used in the Smart City concept. For the query to the Scopus and Web of Science databases, a common search phrase was established, "Mobile technologies in Smart City transport", which was literally used for the query in the Web of Science database, and for the query to the Scopus database, the phrase was appropriately fragmented. Due to the very specific research area, no publication time limits were set in the search results regarding the field or scientific discipline. The analysis focused on scientific articles, monographs and book chapters. Queries from the above databases made it possible to analyse the occurrence and co-occurrence of words (co-word analysis) using the VOSviewer software. The analysis was carried out considering all connections between co-authors and citations between publications, and the minimum level of keyword occurrences was set to three, which resulted in the extraction of 28 keywords characteristic of the search phrase. The figure below (Fig. 2) shows the visualisation of the network of occurrence and strength of connections of keywords appearing in articles related to digital mobile technologies in Smart City transport.

As a result of the query with the given search and analysis parameters, 208 publications were identified in the Web of Science database and 476 in the Scopus database, which were subjected to analysis of the occurrence and co-occurrence of words (co-word analysis) using the VOSviewer software. The time horizon for the co-occurrence of keywords for a given search phrase covered the years 2003–2023. The analysis indicates that the most frequently occurring words and key phrases in the analysed scientific publications are: "smart city" ("smart cities"), "information and communication", "mobile phone", and "internet of things". Additionally, a strong correlation (distances on the link map) was observed between the phrases "smart city" and "information and communication" and "internet of things", and a smaller correlation with the phrase "mobile phone". In the
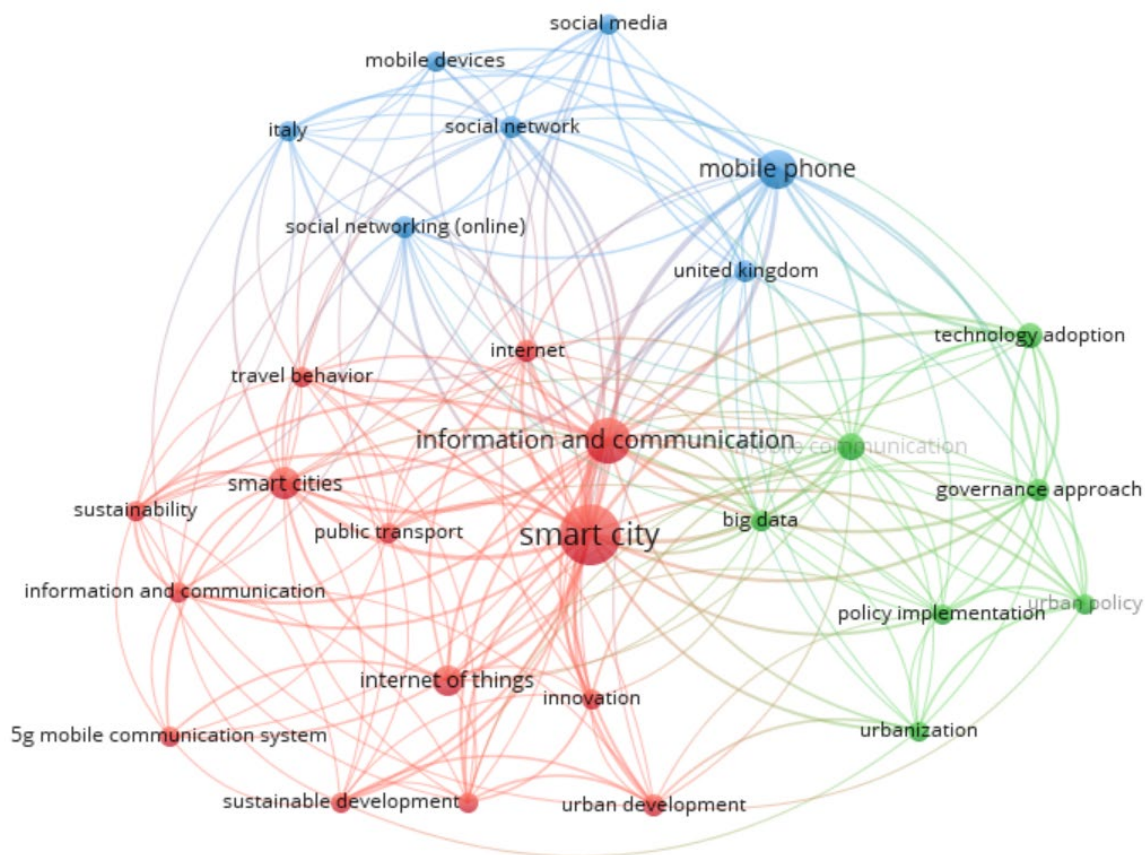
Fig. 2. Results of keyword co-occurrence analysis for the phrase "Mobile technologies in Smart City transport"

Tab. 2. Solutions for the digital availability of transport services in selected Polish metropolises in 2023

VARIABLE	GENDER			AGE			PLACE OF ACCOMMODATION		
	χ^{2A}	P^B	V^c	χ^2	P	V	χ^2	P	V
Public Wi-Fi access	2.367	0.305	0.046	96.033	0.001	0.207	50.220	0.001	0.150
Smart City platforms that provide information about activities in the city	32.752	0.001	0.201	77.958	0.001	0.219	64.662	0.001	0.200
Personalised messages	16.361	0.001	0.121	72.298	0.001	0.180	77.141	0.001	0.186
Mobile applications for finding available parking spaces	26.600	0.001	0.181	148.020	0.001	0.302	146.403	0.001	0.301
Mobile sharing applications (carsharing/ bikesharing)	43.220	0.001	0.195	163.851	0.001	0.269	149.174	0.001	0.256
Mobile applications for planning public transport trips and purchasing tickets	28.187	0.001	0.154	101.570	0.001	0.207	215.906	0.001	0.301
E-commerce mobile applications enabling ticket purchase transactions	16.298	0.001	0.116	160.362	0.001	0.258	96.998	0.001	0.201
Mobile application for communication tracking and delay visibility	17.260	0.001	0.127	112.791	0.001	0.230	80.468	0.001	0.195

[a] χ^2 — test value at α=0,05 [b] p — asymptotic significance [c] The strength of the relationship calculated using V-Cramer

context of the conducted query, what is quite characteristic is the weak representation and strength of connections of keywords related to the social area, including platform and application. Such results became the basis for conducting research on the use of mobile digital technologies to fill the research information gap, which, based on the literature review, was formulated as poor recognition of the relevant components of the digital construct of mobile technology solutions to support urban transport services from a user perspective.

Quantitative research conducted at the turn of April and May 2023 allowed the authors to diagnose the current state of knowledge and identify the potential for the availability of mobile digital technologies to support the logistics of public transport services in selected Polish cities from the perspective of Smart City residents. The research describes the profile of the surveyed population, the distances and ways of moving respondents in urban space, and information solutions in the area of mobile digital technologies that support residents in decision-making processes in the field of urban travel logistics. This approach ultimately allowed the authors to build a model proposal in the form of a model application construct as a representation of solutions in the area of mobile digital technologies supporting the logistics of transport services in cities from the customer's perspective.

The study conducted in May and April 2023 involved 1,278 people from five metropolitan areas such as Cracow (20.3 %), Lodz (10.0 %), Poznan (13.1 %), Warsaw (43.2 %), and Wroclaw (16.4 %). The vast majority of respondents indicate that having knowledge of the essence of the Smart City concept, the cities in which they live can be called Smart City (70.0 %). The majority of respondents were working people (72.4 %), compared to those studying and not working (11.0 %), teaching and working (15.1 %), and retirees (1.5 %). Most respondents indicated that they were fans of new technologies (84.5 %) compared to people who were sceptical about new technologies (15.5 %). Regardless of their attitude towards new technologies, respondents indicated that they were familiar with the phrase new technologies and understood its meaning (36.6 %), they knew the phrase and understood the need to use new technologies (31.0 %), and they knew the phrase and actively participated in the processes of implementing new technologies (21.1 %). Only several respondents indicated that they had never heard the phrase "new technologies" (2.8 %).

Residents of urban agglomerations participating in the study indicated that when moving around the city, they move within a radius of up to 1 km (24.0 %) or travel within the city covering distances from 1 to 5 km (12.1 %), from 5 to 10 km (35.8 %), from 10 to 15 km (8.5 %), from 15 to 20 km (9.3 %) or above 20 km (10.4%). Respondents declared that they most often cover the distance to their destination on foot (19.7 %) or using transport infrastructure such as their own car (22.5 %), tram (23.9 %), bus (19.7 %), bicycle/scooter (5.6 %), train (4.2%) or shared car (4.2 %).

When moving around the city, residents have the opportunity to use digital solutions supporting the logistics of individual and collective transport services. Among the available solutions, respondents indicate that three groups of solutions are available to them. The first group consists of general digital solutions such as Wi-Fi, Smart City platforms and applications with personalised messages. The second group are applications dedicated to users of individual and public transport. The third group of solutions are digital solutions integrally related to mass public transport.

When analysing the availability of applications as digital solutions supporting transport services, the first look should be at the solutions available to everyone, including those who live in the city. Such solutions include public Wi-Fi access, Smart City platforms and applications with personalised messages. Thus, most respondents (87.3 %) are aware of the possibility of access to public Wi-Fi as a digital communication solution in a given city, and just over half (58.0 %) use it. There is no relationship between Wi-Fi use and gender. Considering age, this digital solution is more often used by people aged 35–44 (19.3 %) and 25–34 (9.8 %) and residents of Warsaw (18.2 %), Krakow (13.0 %), and Lodz (10.5 %). Another solution is Smart City platforms, which enable the provision of information about activities in the city and ensure communication with residents. Such solutions are relatively little known to respondents. Only slightly more than half of the respondents (63.4 %) are aware that such a solution exists in their city, and even fewer respondents use it (40.0 %). This solution is used more often by women (22.4 %) than men (17.5 %), people aged 35–44 (18.4 %) and residents of Cracow (12.3 %) and Warsaw (10.0 %). Applications that send personalised messages are important for city residents. Such solutions are known to the majority of respondents (87.3 %), and just over half of the respondents use them (59.7 %).

Such solutions are used more often by men (33.6 %) than women (26.1 %), people aged 35–44 (18.4 %) and residents of Warsaw (20.3 %) and Cracow (14.5 %). The use of general digital solutions available to everyone and which can potentially be used by everyone is weakly dependent on gender, age and city, which is consistent with the basis of their availability and universality and which is confirmed by the $\chi2$ independence test with the strength of the relationship determined by V-Cramer (Table 2).

Another group of digital solutions are applications supporting urban transport logistics from the point of view of individual and public transport users. Such applications that enable the search for free parking spaces in a given city are known to more than half of the respondents (63.4 %). However, they are used by only one in four respondents (24.4 %). This solution is used more often by men (15.8 %) than women (8.6 %), people aged 35–44 (12.5 %), and residents of Cracow (5.4 %) and Wroclaw (7.1 %). Another digital solution available to residents is applications involving "sharing means of transport", such as "carsharing" and "bikesharing". These solutions are known to the majority of respondents (88.7 %). And here, as in the case of parking space applications, there are few users (23.1 %). This solution is used more often by men (16.9 %) than women (16.4 %), people aged 35–44 (15.0 %) and residents of Cracow (10.5 %) and Warsaw (6.5 %). The use of such digital solutions, considering the user of individual personal and public transport, is weakly dependent on gender and moderately dependent on age and city, which is confirmed by the $\chi2$ independence test with the strength of the relationship determined by V-Cramer (Table 2). In turn, the last group of digital solutions are those that are integrally related to mass public transport. First of all, these are mobile applications that are used to plan public transport trips and purchase tickets. According to respondents' declarations, such solutions are available to them (93.0 %), and they are willing to use them (80.3 %). This solution is used more often by women (42.7 %) than men (37.5 %), people aged 25–34 (18.9 %) and 35–44 (21.6 %), and residents of Warsaw (31.0 %) and Cracow (21.1 %). Another digital solution available to residents in the field of public transport is applications enabling online ticket purchase transactions. These solutions are known to the majority of respondents (94.4 %), and they use them equally often (73.1 %). This solution is used more often by men (38.3 %) than women (34.9 %), people aged 35–44 (22.3 %) and 55–64 years (14.8 %) and residents of each agglomeration, mostly in Warsaw

(26.8 %), Cracow (16.1 %), and Lodz (13.1 %). The last solution integrally related to public transport is mobile applications that enable tracking of communication means and their delays. The majority of respondents (83.1 %) are aware of the existence of such solutions in the city. And over half of the respondents (61.0 %) use them. Such solutions are used more often by women (32.8 %) than men (28.2 %), people aged 35–44 (15.1 %) and 25–34 (14.5 %) and residents of every agglomeration, mostly in Warsaw (23.6 %), Cracow (15.7 %), and Wroclaw (9.2 %). To sum up, the use of digital solutions supporting mass public transport is weakly dependent on gender and moderately dependent on age and city, which is confirmed by the $\chi2$ independence test with the strength of the relationship determined by V-Cramer (Table 2).

Among the available solutions, respondents admit that they use applications supporting urban travel from smaller towns to a city operating within an agglomeration based on suburban railway infrastructure and solutions, applications supporting the selection of public transport means and purchasing tickets. It should be added that not all applications are available in all cities. Most often, respondents indicated the use of applications, such as jakdojade.pl (73.2 %), koleo.pl (59.2 %), and portalpasazera.pl (43.7 %). Somewhat often, respondents indicated that they used such solutions as mmpk.info (36.6 %), mobilet.pl (25.4 %), and bilkom.pl/ (23.9 %). The respondents were least likely to mention such applications as skycash.com (19.7 %), buslive.pl (18.3 %), and kiedyprzyjedzie.pl (15.5 %). When assessing the indicated applications on a scale from -3 (lowest rating) to +3 (highest rating), the respondents rated the following as the highest: koleo.pl ($\bar{x}$ - 20.85 points), mobilet.pl ($\bar{x}$ - 20.54 points), kiedyprzyjedzie.pl ($\bar{x}$ - 16.83 points), and portalpasazera.pl ($\bar{x}$ - 16.83 points), and the lowest ratings were given to jakdojade.pl ($\bar{x}$ - 1.41 points), mmpk.info ($\bar{x}$ - 1.39 points), and buslive.pl ($\bar{x}$ - 0.59 points).

Due to the above evaluations of the application, the authors believe that it was worth examining the components of the application's utility construct that should be included in the construction of a model digital solution supporting the logistics of transport services for the population in the city, so that it meets the expectations of potential individual users.

For this purpose, a question with 15 answer options was constructed based on a multi-part nominal scale, where each variant was assigned an ordinal

scale based on Rensis Likert scaling. Analysing the obtained results, it was found that the most important functional components for application users due to their answer "definitely yes" were the intuitive ticket purchasing module (77.5 %), the ability to quickly search for connections (66.2 %), remembering fixed routes (64.8 %), updating information in real-time and indicating delays (64.8 %), and optimising routes using various transport means (63.4 %). According to the respondents, the functional components that are slightly less important in the construct are information about the location of stops (59.2 %), combining various forms of communication (59.2 %), and indicating transfer hubs such as "park & ride". The least important are intuitive graphic visualisation (45.1 %), the ability to read information on various media (43.7 %), and image scalability (36.6 %). However, the utility components of marginal importance for respondents who are users of the application are indications of sustainable means of transport (electric/hybrid transport) (18.3 %), indications of the score for choosing low-emission transport — promotional

discounts/bonuses in fees for using public transport (18.3 %), showing the carbon footprint created when choosing a given means of transport (9.9 %) and the possibility of voice support in the native language and foreign languages (the most common) (9.9 %).

By analysing the potential relationships between the components of the application's utility construct and factors describing the population, the following information was obtained. Namely, the intuitive ticket purchasing model as a component of the application's utility construct is slightly more important for women (48.5 %) than men (45.9 %), people aged 35–44 (24.4 %) and residents of the agglomeration of the cities of Warsaw (33.8 %) and Cracow (20.2 %). In turn, the ability to quickly search for connections is slightly more important for women (48.5 %) than men (45.9 %), people aged 35–44 (23.2 %) and residents of the agglomeration of Warsaw (33.9 %) and Cracow (20.3 %). Similarly, remembering fixed routes is slightly more important for women (45.9 %) than men (38.6 %), people aged 25–34 (20.1 %) and residents of the agglomerations of Warsaw (29.6 %) and

Tab. 3. Expectations that should be met by the components of the utility construct of digital mobile applications in urban transport services

Variable	Gender			Age			Place of accommodation		
	χ^{2A}	P^B	V^C	χ^2	P	V	χ^2	P	V
Ability to quickly search for connections	21.032	0.001	0.128	173.976	0.001	0.213	303.325	0.001	0.281
Intuitive ticket purchasing module	5.946	0.051	0.068	106.257	0.001	0.204	83.362	0.001	0.181
Image scalability	46.847	0.001	0.191	231.953	0.001	0.213	179.002	0.001	0.187
Ability to read information on various media (desktop/smartphone)	57.529	0.001	0.212	248.364	0.001	0.220	220.525	0.001	0.208
Possibility of voice control in the native language and foreign languages (the most common)	106.875	0.001	0.289	327.839	0.001	0.253	179.958	0.001	0.188
Intuitive graphic visualisation	24.593	0.001	0.139	84.617	0.001	0.149	188.694	0.001	0.222
Real-time information updates and delay indication	43.569	0.001	0.185	76.823	0.001	0.173	93.024	0.001	0.191
Memorising fixed routes	37.291	0.001	0.171	199.159	0.001	0.197	235.880	0.001	0.215
Indication of transfer hubs, e.g. "park & ride" / bus – train	4.705	0.195	0.061	319.888	0.001	0.289	412.569	0.001	0.328
Optimisation of travel routes using various means of transport (travel time/cost)	105.124	0.001	0.287	123.755	0.001	0.156	252.264	0.001	0.222
Combining various forms of communication	56.256	0.001	0.210	130.077	0.001	0.160	362.398	0.001	0.266
Location of stops	40.094	0.001	0.177	78.628	0.001	0.143	205.795	0.001	0.232
Scoring for choosing low-emission transport — promotional discounts/bonuses in fees for using public transport	78.869	0.001	0.248	140.505	0.001	0.166	106.712	0.001	0.144
Showing the carbon footprint created when choosing a given means of transport	64.681	0.001	0.225	283.188	0.001	0.272	189.368	0.001	0.222
Indications of sustainable means of transport (electric/hybrid transport)	55.979	0.001	0.209	99.654	0.001	0.161	156.472	0.001	0.202

[a] χ^2 — test value at $\alpha=0.05$ [b] p — asymptotic significance [c] The strength of the relationship calculated using V-Cramer

Cracow (19.7 %). Similarly, updating information in real-time and indicating delays is slightly more important for women (48.8 %) than men (47.0 %), people aged 35–44 (24.5 %) and residents of the agglomeration of the cities of Warsaw (32.7 %) and Cracow (20.3 %). Also, the optimisation of travel routes using various means of transport (travel time/cost) is slightly more important for men (47.1 %) than women (43.0 %), people aged 35–44 (22.7 %) and residents of the Warsaw agglomeration (30.2 %) and Cracow (18.7 %).

In turn, the component of stop location is slightly more important for women (45.4 %) than men (43.3 %), people aged 35–44 (22.2 %) and residents of the agglomeration of Warsaw (31.3 %) and Cracow (18.4 %). Similarly, combining various forms of communication is slightly more important for women (41.9 %) than men (32.5 %), people aged 35–44 (20.6 %) and residents of the agglomerations of Warsaw (30.0 %) and Cracow (18.0 %). However, indicating transfer hubs, e.g. "park & ride"/ bus–train, is slightly more important for women (43.4 %) than men (38.4 %), people aged 35–44 (21.8 %) and residents of the Warsaw agglomeration (28.5 %) and Cracow (19.9 %).

The next group of components indicates that intuitive graphic visualisation is slightly more important for women (41.1%) than men (35.0%), people aged 35–44 (19.3%) and residents of the agglomeration of Warsaw (27.3%) and Cracow (19.2%). Similarly, the ability to read information on various media (desktop/smartphone) is slightly more important for women (41.2 %) than men (24.9 %), people aged 35–44 (19.8 %) and residents of the Warsaw agglomeration (26.8 %) and Cracow (16.9 %). As well as image scalability is slightly more important for women (35.25 %) than men (32.4 %), people aged 35–44 (17.4 %) and residents of the agglomeration of Warsaw (22.6 %) and Cracow (13.8 %).

As for the last group of components, the indication of sustainable means of transport (electric/hybrid transport) is slightly more important for women (24.9 %) than men (14.5 %), people aged 35–44 (10.7 %) and residents of the agglomeration of the cities of Łódź (11.4 %) and Warsaw (10.9 %). Similarly, the score for choosing low-emission transport — promotional discounts/bonuses in urban transport fees is slightly more important for men (28.5 %) than women (23.6 %), people aged 35–44 (12.1 %) and residents of the Warsaw agglomeration (16.7 %) and Cracow (12.0 %). In turn, showing the carbon footprint created when choosing a given means of transport is slightly more important for women (18.7 %) than men (9.7 %), people aged 35–44 (20.6 %) and residents of the agglomeration of Cracow (9.5 %) and Lodz (7.8 %). Similarly, the possibility of voice service in the native language and foreign languages (the most common) is slightly more important for women (13.9 %) than men (10.0 %), people aged 35–44 (6.9 %) and residents of the Warsaw agglomeration (10.1 %) and Cracow (6.2 %).

To sum up, the analysis of the application's operational components from the point of view of the statistical verification procedure indicates that they are weakly dependent on gender, apart from the lack of dependence in the case of the components: the intuitive ticket purchase model and the indication of transfer hubs, e.g., "park & ride"/bus, and moderately dependent on age and city, which confirms χ^2 independence test with the strength of the relationship determined by V-Cramer (Table 3). By specifying the dependencies between the components of the utility construct of applications supporting the logistics of transport services in cities and defining the aggregation pillars for the utility components, it was decided to process the data using factor analysis allowing for the identification of potential connections between the components, which will allow for the identification of dependency regularities. The boundary conditions for the analysis were:

- K–M–O marginal statistics,
- Bartlett's test of sphericity,
- correlation matrix based on the χ^2 coefficient,
- Oblimin simple rotation with the elimination of coefficients below 0.4.

After processing the data in SPSS, the value of the K-M-O marginal statistics was obtained at the level of 0.708, which proves the adequacy of the sample selection and is the basis for aggregating components into pillars and creating a model. This approach is confirmed by Bartlett's test of sphericity, where the approximate value of the χ^2 statistic was 9491.341 with a significance level of <0.001. On this basis, a matrix was proposed that includes four pillars of the application's utility construct that should be included in a model digital solution supporting transport services in the city so that it meets the expectations of potential individual users (Table 4).

The identified four pillars of the utility construct in building a model digital solution supporting transport services in the city can be appropriately described:

- pillar 1 — interactive communication,
- pillar 2 — proactive transaction,
- pillar 3 — modular logistics,
- pillar 4 — sustainable progression.

Tab. 4. Results of factor analysis of the construct components of digital mobile applications in urban transport services

VARIABLE	PILLAR 1	PILLAR 2	PILLAR 3	PILLAR 4
Ability to quickly search for connections	0.841			
Intuitive ticket purchasing module	0.670			
Image scalability	0.666			
Ability to read information on various media (desktop/smartphone)	0.569			
Possibility of voice control in native language and foreign languages (the most common)		0.890		
Intuitive graphic visualisation		0.794		
Real-time information updates and delay indication		0.741		
Memorising fixed routes			0.803	
Indication of transfer hubs, e.g. "park & ride" / bus–train			0.801	
Optimisation of travel routes using various means of transport (travel time/cost)			0.787	
Combining various forms of communication			0.714	
Location of stops			0.633	
Scoring for choosing low-emission transport - promotional discounts/bonuses in fees for using public transport				0.920
Showing the carbon footprint created when choosing a given means of transport				0.902
Indications of sustainable means of transport (electric/hybrid transport)				0.598

[Usable component]
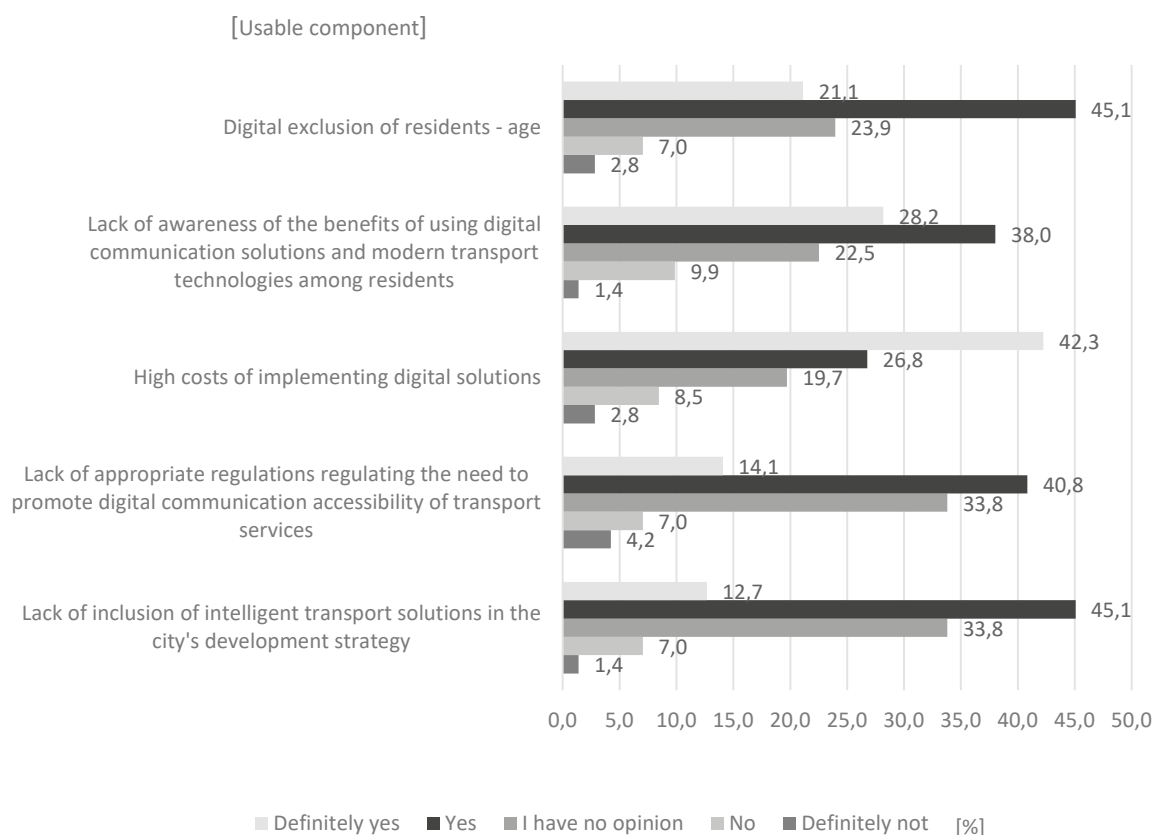
Fig. 3. Barriers to the implementation of solutions in the field of digital accessibility of public transport services [%]

Such a design of individual application components in line with users' expectations is important because, for many respondents (87.3 %), mobile digital solutions are currently the basic information and functional tools enabling transport services in the city. Although not everyone always uses available application solutions as tools for accessing public transport services, it is worth ensuring that such solutions appear and become popular. However, you should be aware that implementing modern technological solutions in cities is not easy. Very often, there are barriers to implementing intelligent digital solutions supporting the availability of public transport services.

Among the potential barriers, respondents indicate the high costs of implementing digital solutions (69.0 %), which often constitute a significant block in the digitisation of cities. According to respondents, another matter is the lack of awareness of the benefits of using digital communication solutions and modern transport technologies among residents (66.2 %), which translates into a low level of support for the implementation of such solutions and their adoption. Another factor that rather often inhibits the digitalisation of cities is the digital exclusion of residents due to age (66.2 %). Older people are less susceptible to using innovative solutions. Important factors hindering the digitalisation of cities may also be the failure to include intelligent transport solutions in the city's development strategy (57.7 %) and the lack of appropriate regulations regulating the need to promote digital communication accessibility of transport services (54.9 %). These barriers may potentially contribute to the slowdown in the process of digitising cities. It is worth being aware of this and introducing actions to prevent or eliminate such barriers.

To sum up, despite the potential barriers that may arise when implementing innovative technological solutions designed to support the logistics of transport services, it is worth looking for the best possible solutions in the field of mobile digital solutions because they are an important tool supporting the functioning of city residents in their everyday functioning.

4. Discussion of the results

As a result of the analysis, the research hypotheses were confirmed. Therefore, the answer to hypothesis H1 is "Yes, residents who have knowledge about existing mobile digital solutions are more willing to use various forms of digital sharing of information about the logistics of transport services, i.e., mobile digital applications, more often than others". People who are aware of various possible applications and the facilities associated with them are much more willing to use them when planning their trips around the city. It can be seen in other research, like in Seul, where the combined efforts of different stakeholders helped to improve an integrated platform for transit services (Lee et al., 2022). The same research pointed to the need for greater trust in the technology and support from governance. But the biggest challenge is the cooperation and trust between local communities and local governance (Spicer et al., 2023). The trust issue is also an element of another study conducted to determine the factors that influence residents and public servants following the Smart City concept (Habib et al., 2023). However, the idea of using new technologies to move around the city does not have to apply only to its residents but also to tourists (Chuang, 2023) using smart tourism service (STS). The use of artificial intelligence can be used to improve this type of solution (Elharoun et al., 2023; Szpilko et al., 2023b), and data can be collected, for example, using signals from mobile networks (Yang et al., 2023), and then, based on the analyses, it will be possible to share as appropriate information as possible for specific people. The research says that the possibilities of different technologies are wide, and it is up to the residents and local governance to implement the solution, which would be responsive but also give a chance for development and optimisation (Kolhe et al., 2023).

Similarly, a positive answer can be indicated in the form of "Yes, residents who appreciate digitalisation in terms of providing information on the logistics of transport services use various forms of public transport much more often than others", which means a positive verification of the H2 hypothesis. It can be seen that city residents are increasingly using public transport for various reasons, e.g., lower ticket prices (Wallimann et al., 2023) or the possibility of combining public transport with individual transport (Kosmidis & Müller-Eie, 2023). The research shows a possible correlation between the technology used and the residents' attitude towards travelling around the city (van Lierop & Bahamonde-Birke, 2023). With the increasing interest in new technologies and the availability of applications, including in the field of planning trips around the city, travelling by public transport is becoming much easier than travelling individually. Also, there is a possibility of much greater interest in on-demand mobility services,

which can be an alternative to public transport services, a bit faster, cheaper, and more eco-friendly (Geržinič et al., 2023; Gkavra et al., 2023). Different forms of city transport suggest that it would be attractive for the technological solutions to combine all these options (Gokasar & Karaman, 2023).

This makes the city potentially more attractive as a modern and friendly place. High efficiency and effectiveness of the people's flow in transport processes is currently one of the basic areas of city management. The use of applications as information, communication, and operational tools can be an important stimulus for implementing the strategies of modern and innovative cities aimed at implementing the Smart City idea. This can also be the next step in developing cities as innovative and attractive places for living and working (Marchesani et al., 2023). Technology development in the context of city management depends on access to new innovative solutions. If city managers want to attract new investors and implement new solutions, they need to stay open-minded. This demonstrates the importance of the presented study and the possibilities for future research.

CONCLUSIONS

Considering the research results, it should be assumed that the future of cities will depend on the creation of opportunities that will be available to residents and visitors. Although the analysis of the occurrence and strength of connections in scientific publications indicates a relatively small share of keywords and phrases related to social media, it should be assumed that due to the mobile and context-dependent location-dependent nature of the operation of transport applications in the Smart City concept, the share of solutions based on social media will be growing. The rising interest in mobile solutions supporting travel management prompts a closer look at the functionality of such applications.

To meet the needs of city users, which were pointed out in the quantitative research, a model for creating and managing transport services in terms of the components of a digital mobile application was proposed (Fig. 4). The model consists of four pillars, also resulting from the described research: I — interactive communication, II — proactive transaction, III — modular logistics, IV — sustainable progression.

The information and communication pillar assumes the appearance of the application, which should primarily meet the criterion of accessibility, i.e., scalability and the ability to adapt to various operating systems. It is also a requirement regarding accessibility for various social groups, including those with disabilities.

The transactional pillar would concern the possibility and choice of transport services by providing data on transport connections or purchasing tickets.

The logistics pillar would concern journey planning and combining various forms of public transport in the city. It would also be possible to include functionality related to combining public transport with individual transport means, e.g., scooters and bikes for rent. It is important to build a personal profile to enable search optimisation.

A sustainable approach requires users to know their impact on the environment, hinting at possible actions to reduce their negative impact on the environment.

The uniqueness of this model results from its structure. It considers the communication form, transaction methods, possibilities of combining transport means, and the possibility of choosing branches and means of transport with a lower impact on the environment. In the eyes of respondents, these elements are increasingly important for their decisions. Therefore, the authors believe that managers of public transport services or IT companies providing mobile services in the context of urban transport should consider the issues of using and ensuring the availability of information on low-emission means of transport.

Research shows that city residents pay increasingly more attention to living conditions and require them to be more health-friendly. The concept of healthy cities (Thompson et al., 2023) is becoming more popular. Therefore, local authorities and public transport managers should consider the issue of appropriate selection of transport means and take care of the infrastructure for other, more ecological choices, e.g. bicycles. Another important aspect is ensuring the quality of available digital services related to the provision of information on the current state of urban transport. The availability of such applications should certainly be greater, especially since more and more people use public transport and mobile devices to plan routes.

The limitation of the research was obtaining answers from residents of only five Polish metropolises (Cracow, Lodz, Poznan, Warsaw, and Wroclaw).
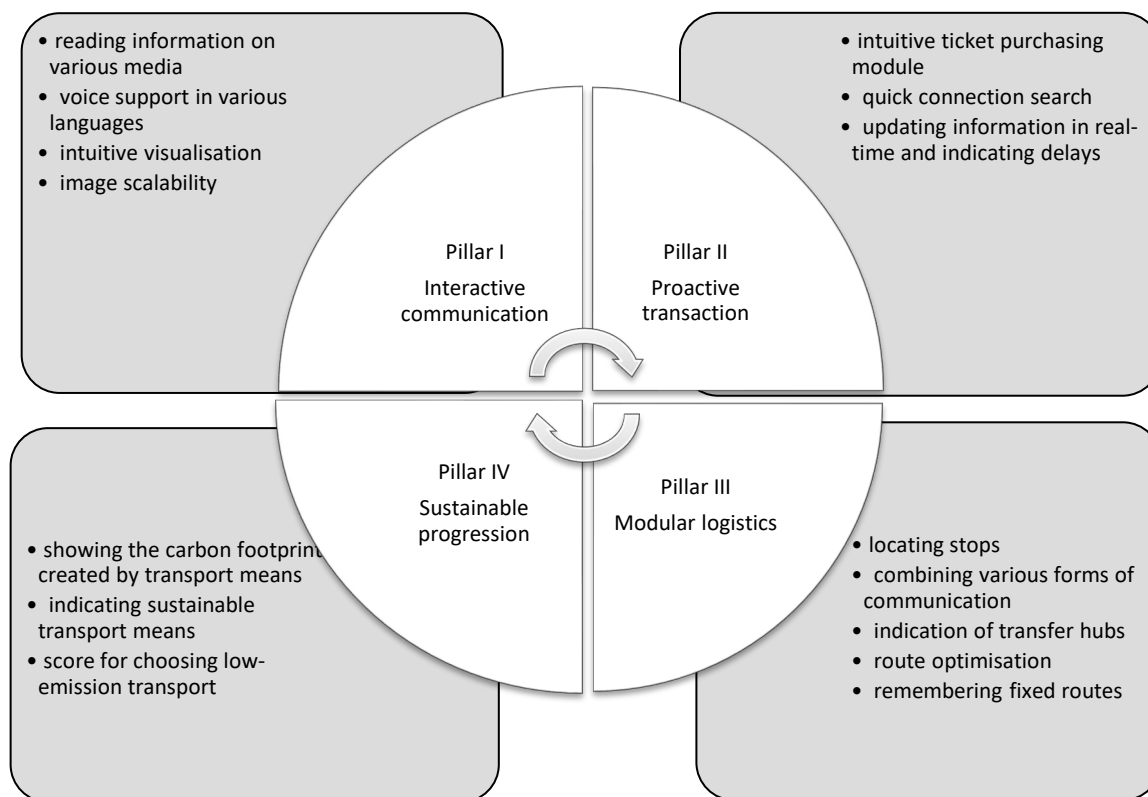
- reading information on various media
- voice support in various languages
- intuitive visualisation
- image scalability

Pillar I
Interactive communication

- intuitive ticket purchasing module
- quick connection search
- updating information in real-time and indicating delays

Pillar II
Proactive transaction

Pillar IV
Sustainable progression

Pillar III
Modular logistics

- showing the carbon footprint created by transport means
- indicating sustainable transport means
- score for choosing low-emission transport

- locating stops
- combining various forms of communication
- indication of transfer hubs
- route optimisation
- remembering fixed routes

Fig. 4. Model for creating and managing transport services as a component of a digital mobile application

The research could be extended to include agglomerations such as Tricity or the Silesian agglomeration, where transport services are much more extended, and it would be expected to examine the state of public transport services in these cities and check the applicability of the results, but also to examine the state of public transport services in these cities.

The proposed model can also be extended and changed with additional functionalities in individual pillars so that it is as flexible as possible and adapts to the capabilities of specific cities. Certainly, in the future, a good solution would be to create one application model for different cities, but due to the large differences in topography and communication systems, this will be extremely difficult.

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International Society for Manufacturing,
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FIVE USER TYPES OF AUTONOMOUS DRIVING IN HUNGARY

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A B S T R A C T

One of the most socially impactful innovations of the near future will be the proliferation of self-driving vehicles, which will have a major impact not only on the passengers in the vehicle but on all road users and even on society as a whole, transforming cityscapes. This study aims to contribute to the social acceptance of self-driving vehicles. As society is not unified in its attitude towards self-driving vehicles, the authors believe that successful social acceptance requires different messages to be delivered to different types of consumers. This research segmented consumers based on their acceptance of self-driving technology, thereby providing a basis for targeted communication in the future. Cluster analyses were used on a sample of 517 Hungarian consumers to identify five segments based on attitudes towards self-driving vehicles. The analysis identified five distinct segments of consumers: (1) tradition-loving dismissers, (2) open-minded adventurers, (3) uncertain optimists, (4) distrustful sceptics, and (5) abstentious observers. These segments can be targeted with differentiated communication strategies. This paper contributes to the literature on self-driving technology acceptance by providing a detailed segmentation of the consumer market, highlighting the importance of targeted communication to enhance technology adoption. It offers a novel approach by focusing on specific consumer segments rather than society in general. By identifying the needs and characteristics of different consumer segments, marketers can develop more effective communication strategies to promote the acceptance of self-driving technology. Using a more targeted marketing approach instead of mass-marketing may result in a smoother spread of innovation and maximise social welfare benefits from technological advancements.

K E Y   W O R D S

autonomous vehicles, sustainable mobility, smart mobility, EGD, technology acceptance

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INTRODUCTION

The 21st century is full of revolutionary changes and radical innovations. New products, technologies, and services appear daily and are integrated into everyday lives with significant impacts. Self-driving technologies are perhaps the most outstanding of these innovations and will greatly affect daily lives and habits throughout human civilisation. Self-driving technologies will affect people's lives regardless of whether they are drivers, cyclists, or pedestrians (Cohen et al., 2020).

The technological development of self-driving vehicles is in the stage of mass street testing: self-driving vehicles can be seen tested in road traffic in nearly 200 cities around the world, where they are part of everyday traffic and the lives of citizens. The advancement of self-driving technology is also indicated by the fact that 53 institutions have already procured road test licenses in California.

In recent years, social scientists have begun to more intensively study how advances in self-driving technology relate to societal preparedness. Research related to consumer acceptance of self-driving vehicles has found heterogeneous attitudes towards self-driving vehicles and a high frequency of extremist views by identifying the most rejecting groups: women, the elderly, the less educated, and those living in rural areas (Schoettle & Sivak, 2014; Kyriakidis et al., 2015; König & Neumayr, 2017; Hulse et al., 2018; Liljamo et al., 2018; Havlíčková et al., 2019; Rovňák et al., 2022; Szpilko et al., 2023; Raue et al., 2019; Wang et al., 2020).

It was also observed that most respondents offered an opinion even though they had little information about the technology (Keszey, 2020). In addition, the level of acceptance and the amount of information were directly proportional (Lukovics & Gábor, 2021).

The international literature agrees that the question is not whether self-driving vehicles will come into general use but when (Grindsted et al., 2021). From a social point of view, it is important to make this transition as smooth as possible. In the diffusion of innovation, however, researchers have shown that the complexity of innovation is inversely proportional to the speed of adoption (Csizmadia, 2017) because if acceptance requires a great deal of new information and different ways of thinking, the spread of innovation is slower and has a higher likelihood of rejection.

Rogers's (2003) well-known theory, the diffusion of innovation, demonstrates that consumers respond differently to new technologies and have different personal characteristics. Piskóti et al. (2013) stated that the key to successful innovation is focusing on customer benefits and effective market penetration. Customer benefits will always be relevant, recognisable, and easy to communicate. Vágási (2002) also emphasised that well-identified consumer preferences and needs play a significant role in success.

It is also important to note that Rogers (2003) perceived the diffusion of innovation as a communication process in which information about technology reaches members of society through specific channels. This communication process can come to fruition effectively if well-targeted messages about the technology are delivered to consumers. The theory defines diffusion as a communication process with four key elements: innovation, communication channels, time, and a social system (Miller, 2015; Dearing & Cox, 2018). This process involves reducing uncertainty about an innovation through information exchange (Rogers, 1964). The central assumption of the study described in this article is that just as the effectiveness of communication, in general, is enhanced by segmenting the target market, so it should be done in the self-driving vehicle market.

This study aims to classify Hungarian consumers into homogeneous groups and determine their main characteristics. The relevant literature on self-driving technology acceptance is reviewed first to achieve the research purpose. Next, the methodology is presented, including the use of mathematical-statistical methods, such as factor and cluster analyses. The Results section identifies and describes the five distinct consumer segments. Personas were set up for the formed segments, and each of them was characterised. Finally, the Discussion and Conclusion sections analyse the implications of research findings and summarise the study's contributions. Research results may serve as important inputs for differentiated marketing communications that indirectly contribute to a smooth societal transition to self-driving technologies.

1. LITERATURE REVIEW

Generally, models examining technology acceptance try to explain the intention to use as a dependent variable with various independent variables (Davis, 1989). The two best-known models — the technology acceptance (TAM) and unified theory of acceptance and use of technology (UTAUT) model — and their adaptations examine nearly a dozen such independent variables. Of these factors, the international literature identifies "perceived ease of use" as a significant influencing factor (Davis, 1989; Venkatesh & Davis, 2000). Using the technology acceptance model, Buckley et al. (2018), Panagiotopolous and Dimitrakopoulos (2018), and Xu et al. (2018) found that perceived ease of use plays a direct role in predicting consumer behaviour. Based on the UTAUT model, expectations (regarding performance and effort) and experience are key factors that influence behavioural intention and, through this, actual usage as well (Venkatesh

& Davis, 2000; Venkatesh et al., 2003, 2012). Deb et al. (2017) have shown that men have more positive attitudes than women towards autonomous vehicle[1] technology. Results differ by age because while Liu et al. (2019) concluded that respondents of the younger generation have a more positive attitude than members of the older generation, Hartwitch et al. (2018) found a strong positive attitude in the case of the older generation towards the acceptance of autonomous vehicle technology. This strong positive attitude may be influenced by the fact that before the survey, Hartwitch et al. (2018) invited respondents to experience the feeling of travelling in a self-driving vehicle using a simulator.

Panagiotopoulos and Dimitrakopoulos (2018) have shown that people exhibiting high confidence in self-driving vehicles are less affected by social norms than those with low confidence. According to various surveys, trust varies from generation to generation. Gold et al. (2015) concluded that the older generation has higher confidence, while Bansal et al. (2016) found that members of the older age group could be characterised by lower levels of confidence. Age may also be related to risk-taking. Liu et al. (2019) have shown that perceived risk appears more strongly in the older generation than in the younger generation, which was explained by changes in risk tolerance with age. Generally perceived risk has a strong negative effect on acceptance, so as perceived risk increases, people's intention to use the technology decreases.

Kyriakidis et al. (2015) found that people using a driving support system are likelier to adopt self-driving vehicles. This means that people's past behaviour may influence their future willingness to accept.

Experience (which is a key factor in the TAM and UTAUT models) is strongly connected with awareness. With more experience or information about a new technology, people tend to become more familiar with its potential benefits, strengthening trust and leading to a smoother adoption process (Lukovics & Gábor, 2021; Páthy, 2019). In this context, it is important to note that society comprises groups with

different characteristics, expectations, attitudes, and knowledge. Identifying these groups is crucial for developing an appropriate communication strategy.

Only several articles in the international literature are related to consumer segmentation concerning autonomous vehicles (Audi, 2019; Berrada et al., 2020; Rahimi et al., 2020). Audi (2019) and Berrada et al. (2020) identified five groups after examining different factors and characteristics of the respondents. These researchers surveyed respondents' opinions on self-driving vehicles, their concerns, and how informed they were about self-driving vehicles (Audi, 2019; Berrada et al., 2020). In contrast, Rahimi et al. (2020) identified three user classes based on respondents' modality style and attitudes.

As discussed above, the adoption of self-driving vehicles is influenced by a number of factors (as indicated by the TAM and UTAUT models). Some researchers (Audi, 2019; Berrada et al., 2020; Rahimi et al., 2020) have already identified different consumer groups based on factors mentioned in technology acceptance models and other characteristic issues (e.g., modality style). This study aims to provide a deeper insight into Hungarian respondents' attitudes towards autonomous vehicles, their intention to try them, and how informed they are (awareness) about the topic to classify them into homogeneous groups. The segmentation is based on a survey (variables in Table 3) covering four main topics: attitude, intention to use, acceptance of changes, and awareness.

2. RESEARCH METHODS

The research aimed to identify distinct segments within the general population; therefore, quantitative research was conducted based on an online questionnaire with 16 questions. The Google questionnaire was used to examine the attitudes, expectations, and awareness of the Hungarian sample regarding self-driving vehicles and classify them into homogeneous groups with the help of factor and cluster analyses.

The online questionnaire formed the basis of quantitative research. It was published on the social media platform with the largest user base, Facebook (Statista, 2024), which is suitable for conducting public surveys in scientific studies (Kalimeri et al., 2020). The platform's advertising tools allow researchers to target specific demographics, behaviours, and interests, making it particularly useful for reaching niche and hard-to-reach populations (Iannelli et al.,

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[1] The diverse array of pertinent technologies has sparked intricate — and sometimes conflicting — classifications of vehicle automation. Among these, the International Society of Automotive Engineers' (SAE) 5 Levels of Driving Automation represent the emerging descriptive consensus (SEA, 2014; ITS, 2015): 1. Driver assistance, 2. Partial automation, 3. Conditional automation, 4. High automation, and 5. Full automation. These levels are descriptive rather than prescriptive and focus on technical rather than legal distinctions. The study described in this article defines autonomous driving as encompassing Levels 4 and 5, and research subjects were informed accordingly.

Tab. 1. Distribution of age groups in the sample

Age group	N
17 or younger	5
18–20	89
21–29	213
30–39	48
40–49	88
50–59	49
60 or older	25
Sum	**517**

Tab. 2. Values of KMO and Bartlett's test

KMO index		0,888
Bartlett's test	Sig. Value	0,000

Tab. 3. Rotated factor weight matrix

Questions involved in the study (variables)	Factors			
	1	2	3	4
1. Suppose that you have the opportunity to test a self-driving vehicle on a CLOSED TEST ROAD. Would you try it?	0.847			
2. Would you like to try a self-driving vehicle?	0.798			
3. Suppose that you have the opportunity to test such a vehicle in TRAFFIC. Would you try it?	0.781			
4. How much would you like to try a self-driving vehicle in traffic with a driver sitting in the driver's seat who could take control of the vehicle at any time?	0.723			
5. When would you try a self-driving vehicle for the first time?	0.615			
6. Do you consider self-driving vehicles to be safe?		0.760		
7. How true are the following feelings when you think of self-driving and self-driving vehicles? 1 — not true at all; 5 — very true [I'm optimistic]		0.749		
8. Do you think that self-driving vehicles would have a positive effect on our daily lives?		0.747		
9. How true are the following feelings when you think of self-driving and self-driving vehicles? 1 — not true at all; 5 — very true [I'm curious]		0.62		
10. How interested are you in self-driving vehicles?		0.606		
11. How happy would you be with the following changes (brought about by the use of self-driving vehicles)? 1 — I would not be happy at all; 5 — I would be very happy [There would be fewer accidents on the roads.]			0.885	
12. How happy would you be with the following changes (brought about by the use of self-driving vehicles)? 1 — I would not be happy at all; 5 — I would be very happy [There would be more parking spots.]			0.885	
13. How happy would you be with the following changes (brought about by the use of self-driving vehicles)? 1 — I would not be happy at all; 5 — I would be very happy [The transport system would be more predictable and the number of delays would be reduced.]			0.867	
14. How happy would you be with the following changes (brought about by the use of self-driving vehicles)? 1 — I would not be happy at all; 5 — I would be very happy [The time spent on driving would be free.]			0.619	
15. How informed do you feel yourself in connection with self-driving vehicles?				0.878
16. How often do you read about self-driving vehicles?				0.856

2018; King et al., 2014). In the first part of the questionnaire, questions focused on driving and driving license; the second part asked questions about self-driving vehicles; and in the last part, questions were posed about the demographic characteristics of the respondents. The questionnaire was available on Facebook from 22 September 2020 to 11 October 2020. During this period, 517 respondents took part in the survey. In terms of demographic characteristics, the sample comprised 62.3 % female and 37.7 % male respondents. The age distribution is illustrated in Table 1 below.

The IBM SPSS statistical program was used to evaluate the responses received during the quantitative research and to define the segments. Factor analysis and cluster analysis were applied for data analysis and group formation (Harman, 1961; Mulaik, 1972; Jain et al., 1999).

Tab. 4. Mean values of factors in each cluster

Clusters and their characteristics Intention to Test		Factors			
		Intetntion to test	Attitude	Accepting Changes	Awareness
1	Cluster size	44	44	44	44
	Mean	-0.31	-0.45	-2.39	0.15
2	Cluster size	107	107	107	107
	Mean	0.62	0.17	0.26	1.37
3	Cluster size	166	166	166	166
	Mean	0.68	0.32	0.10	-0.63
4	Cluster size	130	130	130	130
	Mean	-1.09	0.57	0.25	-0.19
5	Cluster size	70	70	70	70
	Mean	-0.33	-1.78	0.42	-0.32

The factor analysis used 16 variables[2]. The correlation matrix of the variables and the values of the Bartlett's test and KMO index (Harman, 1961; Horn & Engstrom,1979) was examined to explore the applicability of the method.

Based on the values in Table 2, the variables are suitable for creating factors, as the KMO value is above 0.7, and the result of Bartlett's test is also adequate.

Based on the Kaiser criteria, those with an eigenvalue above 1 were retained among the resulting principal components. Four factors were identified that retained 70.281 % of the amount of information in the original 16 variables, reaching a minimum of 60 %.

Table 3 lists the questions ("items") involved in the study and the factors that were created. Varimax rotation, the rectangular rotation method of IBM SPSS, was used to reduce the number of high-weighted variables per factor. This method is suitable for determining values and using the factors further in cluster analysis (Hunyadi, Mundruczó & Vita, 2000). Items in the first factor were mainly related to testing of self-driving vehicles, so they were named "Intention to Test". The second factor contained items related to the respondents' presuppositions, feelings, and attitudes, so the second factor was named "Attitude". The third factor included items about the acceptance of changes generated by self-driving vehicles, so this factor was called "Accepting Changes". The last factor covered items about respondents' awareness and how informed they were about self-driving vehicles, so the fourth factor was named "Awareness".

After the factor analysis, the next step was cluster analysis. The four factors were used, which were obtained from the factor analysis. Before the analysis, three important preparatory steps were performed: handling outliers, standardising variables, and examining multicollinearity (Haitovsky, 1969; Kim, 2019).

From the two-step cluster analysis, the system separated five clusters based on the variables included in the study (Table 4): Cluster 1 = 8.5 %, Cluster 2 = 20.7 %, Cluster 3 = 32.1 %, Cluster 4 = 25.1 %, and Cluster 5 = 13.5 %. The average attitude (mean = (−0.45)) and willingness to try (mean = (−0.31)) of the first cluster are low, but their average awareness (mean = 0.15) is relatively high compared with the other clusters. Despite this, this group does not really like changes (mean = (−2.39)) compared with the average for the whole population. The members of this cluster also have a much more negative opinion about self-driving cars than members of the other four clusters. The members of the second cluster have a positive attitude on average (mean = 0.17), a high willingness to try (mean = 0.62), they receive changes very well (mean = 0.26), and this cluster is the best informed (mean = 1.37) about self-driving vehicles. The third cluster also has a positive attitude on average (mean = 0.37), and changes are well received by them also (mean = 0.10). The average value of their intention to test (mean = 0.68) is very close to that of the second cluster, but their level of awareness (mean = (−0.63)) is lower. The members of the fourth group have a positive attitude (mean = 0.57) but a relatively low intention to try (mean = (−1.09)). They receive changes well (mean = 0.25), but they are not very informed (mean = (−0.19)) about the topic compared to the other clusters. The fifth cluster has a negative

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[2] The list of the 16 variables can be found in Table 3.

attitude on average (mean = (−1.78)), a low willingness to try (mean = (−0.33)) and a low level of awareness (mean = (−0.32)). Despite these, they are quite open to changes (mean = 0.42)).

3. RESEARCH RESULTS

After performing the cluster analysis, cross-tabulation analyses (the summary results are given in Table 5) were used to identify the segments in greater detail. The formed segments can be characterised as follows:

- Segment 1 — Traditional dismissers: 59.1 % of the segment is female, and 40.9 % is male. The majority is 40–49 years of age, but this segment also has the highest proportion of members who are 60 and above. This group proved to be the most pessimistic about self-driving vehicles. In addition, 54.4 % of the cluster said they were not interested in self-driving at all, and 65.9 % said they would definitely not buy such a vehicle. The group members are not passionate about novelties, and would only try self-driving vehicles if they were already completely widespread. Moreover, most of the segment was completely against using self-driving cars. More than 80 % would not sit in such a vehicle even when tested in traffic. A significant proportion does not consider self-driving vehicles safe at all. This group is the most distrustful and the least curious among the segments. The most positive reception was related to the statement, "There would be fewer accidents on the roads".

- Segment 2 — Open-minded adventurers: Men (72 %) and young people dominate this segment. Most belong to the 21–29 year age group, but a large proportion comprises 18- to 20-year-olds. Of the group, 58.9 % are students. Generally, members of the segment have no worries about self-driving vehicles and proved to be both the most optimistic and the most interested. The majority would also like to buy such a vehicle for themselves in the future. Most are very open to novelties and like to share their experiences with others. They would be among the first to try out a self-driving vehicle. More than 80 % of the segment would try them out in traffic, and more than 50 % without (an emergency) driver. Most of the group's respondents are excited to use self-driving vehicles in traffic and consider them safe.

This group is the least distrustful and the most curious.

- Segment 3 — Uncertain optimists: This segment contains the highest proportion of women (79.5 %) and is predominated by respondents aged 21–29 and 18–20. They are not really concerned and have a relatively optimistic opinion about self-driving vehicles. The members are interested in the topic but not as much as the members of the second segment. The majority are not sure if they would buy such a vehicle for themselves, but they would think about it. They like to gather information about novelties before they try them out, so they would only sit in such a vehicle if others had already done so. They would like to try self-driving vehicles even in traffic. If they had to sit in a vehicle without a driver, they would think more about it than would members of the second segment, but based on the answers, they would still try it out. Members of the group are positive about change, but they would be most pleased to see a reduction in pollution. Like the second segment, they are curious but a little less trusting.

- Segment 4 — Distrustful sceptics: This segment has a higher percentage of women (69.2 %), and most of the segment is aged 21–29 and 30–39. They are less optimistic and less interested in self-driving vehicles than members of the third segment. They are more worried and probably would not buy a self-driving vehicle for themselves. Typically, they would only try such a vehicle if many people had already done so, and many positive reviews might make them more interested. They might try a self-driving vehicle in traffic, but only with an emergency driver. The group can be best characterised by neutral feelings regarding the use and safety of self-driving vehicles. Most people in this group are positive about the topic but have doubts. A significant percentage do not want to see self-driving vehicles in traffic and do not yet see the point in having them. Most could not decide how safe self-driving vehicles were or did not consider them safe. This group typically receives change well, but they would be most pleased with reduced pollution and more green zones in cities. They are not curious and do not trust this technology.

- Segment 5 — Abstentious observers: This segment is best characterised by females (62.9 %)

Tab. 5. Segments and their characteristics

QUESTIONS	SEGMENTS				
	1. TRADITION-LOVING DISMISSERS	2. OPEN-MINDED ADVENTURERS	3. UNCERTAIN OPTIMISTS	4. DISTRUSTFUL SCEPTICS	5. ABSTENTIOUS OBSERVERS
GENDER RATIO	59.1 % female	72 % male	79.5 % female	69.2 % female	62.9 % female
AGE GROUP	40–49 60+	18–20 21–29	18–20 21–29	21–29 30–39	40–49 50–59
RATIO OF STUDENTS AND WORKERS	77.3 % worker	58.9 % student	54.8 % student	50 %–50 %	75.7 % worker
ARE THEY WORRIED?	Not really	Not at all	Not really	More than the 3. (yes)	Not really
ARE THEY OPTIMISTS?	Not at all	They are the most optimistic	Yes	Less than the 3.	Not really
ARE THEY INTERESTED IN SELF DRIVING?	Not at all	They are the most interested	Somewhat	Less than the 3.	Somewhat
WOULD THEY BUY SUCH A VEHICLE?	No	Yes	Maybe yes	Probably not	They do not know
WHEN WOULD THEY TRY A SELF-DRIVING VEHICLE?	Only if they are already considered widespread	Among the firsts or shortly after their appearance	If they have enough information	If a lot of people have tried it	If they have enough information
WHAT IS THEIR ATTITUDE TOWARDS THE USE OF SELF-DRIVING VEHICLES?	They absolutely reject the use of self-driving vehicles	They are excited	Positive, but they have reservations	Neutral	Positive, but they have reservations
WOULD THEY TRY SUCH A VEHICLE IN TRAFFIC?	No	Yes, of course	Yes, of course	Maybe yes	More than the 4
WOULD THEY TRY SUCH A VEHICLE WITHOUT A DRIVER?	No	Yes, of course	Maybe yes	Probably not	More than the 4
DO THEY CONSIDER SELF-DRIVING VEHICLES SAFE?	Not really	Yes, of course	Yes, they are probably safe	They do not know	Neutral feelings
ARE THEY DISTRUSTFUL?	They are the most distrustful	Not at all	Yes, but not to a great extent	Yes, they are distrustful	Not at all
ARE THEY CURIOUS?	Not at all	They are the most curious	They are really curious	No	They are moderately curious
ACCEPTING CHANGES	There would be fewer accidents on the roads	They would be happy with all the changes	Reduction of environmental pollution	Reduction of environmental pollution and more green areas	They receive changes neutrally

and people aged 40–49 and 50–59. They are not optimistic, but they are not worried either. They would only try the vehicles if others had already done so and if they had enough information about the technology. They would be more likely to try out such a vehicle than members of the fourth segment. Most members have a positive opinion about the topic but have doubts or neutral feelings about it, too, and they are also concerned about vehicle safety. They receive change just as well as the members of segment 4. They are moderately curious and not distrustful at all. So, although they would try this novelty if they had enough information about it, they do not yet have an opinion on this topic that is clearly negative or positive. Based on this, abstentious behaviour is coupled with some curiosity.

Overall, the sample can be divided into five groups (segments). For a better overview, the characterisation of the segments is summarised in Table 5.

As a research result, segments were successfully identified for which targeted communication can

contribute to widespread societal acceptance of self-driving technology. Below, communication suggestions for each segment are summarised:

- Traditional dismissers: As they have a strong negative opinion and say they would certainly not sit in such a vehicle, it may be worth emphasising the benefits of "other self-driving vehicles". This segment has the highest proportion of those who do not have a driving license. If members of the group become more accepting over time, the emphasis could be placed on the benefits of travelling by a self-driving vehicle for the elderly or those who do not have a driving license (or car). The goal here is not to encourage trying self-driving technology but to ensure they do not become active barriers to spreading the technology. The communication of factual information through mass media may be appropriate.

- Open-minded adventurers: This young, interested, and mostly male group can be reached through social media with messages that provide up-to-date information, a chance to try out the technology, and some technical details. "Self-driving ambassadors" may come from this segment.

- Uncertain optimists: These young women can be reached mainly through social media with educational content that enhances their sense of safety and raises awareness of the positive environmental impacts of self-driving vehicles. Involving influencers can also be effective in convincing this target group. It is worth noting that car-sharing is quite common among members of this group.

- Distrustful sceptics: Personal communication and the convincing role of the previous two segments play key roles in this segment. Uncertainty and mistrust must be reduced here. As they are sceptical and have low risk-taking appetites, they are likely to use this innovation only if it is already widespread. As passive players (pedestrians, transporters, etc.), they will be less affected by this technology. However, their attention can be drawn to the fact that that they can also indirectly benefit from it (e.g., parcel delivery, food delivery, and blood transport).

- Abstentious observers: In their case, the goal is to increase awareness and emphasise the benefits through mass media. The goal is to tilt neutral feelings in a positive direction. Because safety is important to them, and they are curious to some extent, the goal can be achieved with gradual involvement (providing the possibility to test).

4. DISCUSSION OF THE RESULTS

The study aimed to identify consumer segments of autonomous vehicles by utilising an online survey based on the factors of the Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology (UTAUT) model. The survey comprised 16 questions, from which four distinct factors were composed: intention to test, attitude, accepting changes, and awareness.

In alignment with previous studies, such as Audi's driver classification (2019) and the research by Berrada et al. (2020), this study revealed five distinct consumer groups. These groups ranged from open-minded adventurers, who exhibit high enthusiasm and readiness to test and accept autonomous vehicles, to traditional dismissers, who demonstrate an extremely low level of awareness and a negative attitude towards the changes brought by this technology.

Berrada et al. (2020) asked people in Palaiseau (France) about their socio-demographic issues, mobility habits, and use of autonomous vehicles, then applied hierarchical cluster analysis to segment their sample. The study by the Audi research team (2019) surveyed respondents' opinions, knowledge, and concerns about self-driving vehicles in nine countries across three continents and revealed how users could be grouped according to the factors studied. Rahimi et al. (2020) examined people mainly from Florida and hypothesised that individuals' decisions towards autonomous vehicles vary by their modality style. The researchers used a latent class clustering analysis model and identified three distinct user classes.

Comparing the five consumer segments identified in our research with the findings of other researchers (Audi, 2019; Berrada et al., 2020), some similarities can be found in the characteristics of certain groups:

- Open-minded adventurers have a very positive attitude towards autonomous vehicles and are eager to try new technologies. This segment is similar to the "tech-savvy passengers" and "status-oriented trendsetters" groups identified by the Audi research team (2019) and shares characteristics with the "explorers" group identified by Berrada et al. (2020).

- Uncertain optimists have a positive attitude and are curious about this new technology, though not as much as open-minded adventurers. This segment is similar to the "open-minded co-pilots" identified by Audi (2019), and Berrada et

al. (2020) described "early adopters" in a similar way.

- Distrustful sceptics are unsure about the safety of self-driving vehicles or do not consider them safe. This segment is not curious and does not trust this technology, similar to the "suspicious drivers" group identified by Audi (2019) and the "sceptics" identified by Berrada et al. (2020).
- Abstentious observers do not know much about autonomous vehicles and are characterised by abstention coupled with a little curiosity, similar to the "safety-oriented reluctant" group (Audi, 2019) and the "late adopters" identified by Berrada et al. (2020).
- Traditional dismissers do not consider self-driving vehicles safe at all; they are the most distrustful and would never try an autonomous vehicle. Berrada et al. (2020) identified a similar group called "conservatives", but the Audi research team (2019) did not describe such a rejecting segment.

Rahimi et al. (2020) focused on their respondents' modality style, segmenting and describing their sample based on this criterion.

Identifying these segments highlights the diverse consumer landscape and the necessity for targeted communication strategies in the field of autonomous vehicles. Providing appropriate information to the proper groups could help facilitate a smoother adoption process. For instance, increasing awareness, providing more information, and offering hands-on testing opportunities could convert sceptics and uncertain consumers into more accepting and engaged users.

Conclusions

The spread of self-driving technologies may be a defining trend of the 21st century and increasingly seems limited not by technical but by social constraints. So far, only a narrow circle of society is affected by self-driving technology, typically innovative-type consumers who are curious and have a positive attitude towards self-driving. If this technology becomes more widespread, groups not necessarily open to it will inevitably be confronted with self-driving vehicles and their effects. The primary goal of the research was to identify segments and attitudes towards self-driving vehicles that could later serve as a basis for developing educational and communication materials for technology diffusion. As the results are based on an online survey of an unrepre-

sentative population, it is important to remember the limitations of this method. In particular, individuals' attitudes can change significantly during an actual test drive and, moreover, attitudes are often influenced by emotional factors that can be explored in only a limited way through a questionnaire. Additionally, a limitation of the study is that the data collection occurred relatively distant from the time of publication. However, this may be mitigated by the fact that there have been no significant changes in the deployment of autonomous vehicles in Hungary since the data collection, suggesting that attitudes may not have changed significantly. Nevertheless, the five identified segments may guide future marketing research and marketing communication activities.

The main managerial implication of the study is to draw the attention of decision-makers to the need to prepare for and support social dissemination of self-driving technologies, for which appropriate, targeted communication is very important. To achieve this goal, it is essential to identify the groups that should be approached in different ways to support them with different messages and channels so they may see the spread of self-driving technology as an opportunity and not a threat. According to the research results, this goal can be achieved by providing groups that are more open to self-driving (open-minded adventurers; uncertain optimists) with detailed insights into the possibilities offered by this technology while systematically building confidence in those who may be distracted. The study offers an excellent opportunity for further exploration by delving deeper into the defined theoretical segments. Practical creation of the five user types could be pursued, allowing for a more profound qualitative or quantitative investigation of each group's characteristics. This approach could lead to deeper insights into consumer attitudes towards accepting autonomous vehicle technology. This is undoubtedly a long process; the present research seeks to take the first steps as an early guide.

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SUSTAINABLE DEVELOPMENT OF SMART CITIES THROUGH MUNICIPAL WASTE INCINERATORS: THE EXAMPLES OF ARTIFICIAL INTELLIGENCE IN TECHNOLOGICAL ENTREPRENEURSHIP

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A B S T R A C T

The article aims to analyse AI's use for optimising management processes in urban waste incineration plants, making them consistent with the implementation of the sustainable development goals SDG #11 and SDG #12. The triangulation of research methods was chosen to achieve the most reliable research outcomes. The case study was the selected qualitative method. Among the available techniques, two were selected: Computer-Assisted Web Interviewing (CAWI) and in-depth interviews, both of which were employed to gather the necessary data. Scientific research analysed the AI-based technologies used by individual incinerators. The analysis encompassed trends in waste incineration plants utilising AI for sustainable development in smart cities, particularly for achieving SDG#11 and SDG#12, focusing on leveraging AI to enhance environmental outcomes. The effect of using AI in municipal waste incineration plants for SDG#11 and SDG#12 can be applied to other entities implementing the principles of sustainable development in smart cities. The identified trends underscore the importance of adopting and implementing integrated policies and plans that address inclusion, resource efficiency, climate change mitigation and adaptation.

K E Y   W O R D S

technology entrepreneurship, sustainable development, artificial intelligence, AI, SDGs, smart city

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INTRODUCTION

The article presents selected aspects of implementing the principle of sustainable development of smart cities through AI in municipal waste incinerators. Moreover, it focuses on using artificial intelligence to mitigate urban problems, especially air pollution, waste management, and sewage treatment. The analysis focused on the activities of waste incineration plants in the context of achieving SDG#11 goals (Sustainable Cities and Communities) and SDG#12 (Responsible Consumption and Production).

Compared to other research methods, the case study provides the richest array of techniques and tools for data collection. Among the available techniques, two were selected: Computer-Assisted Web Interviewing (CAWI) and in-depth interviews, which were employed to gather the necessary data. The research sample comprised all nine municipal waste incineration plants located in Poland at the time of conducting the survey. These initiatives focus on improving waste management processes, reducing emissions, and contributing to cleaner urban environments, which are in line with the broader objectives of sustainable development and smart city infrastructure optimisation.

The focus on Polish cities in achieving the SDGs reflects their critical role in the global sustainability agenda, emphasising the need for innovative approaches to urban planning and management that prioritise both environmental and social sustainability (Cubric, 2020; Šulyová & Kubina, 2022). Decision support tools for the sustainable development of smart cities are increasingly utilising AI to optimise these processes and ensure higher living standards for the inhabitants of Polish smart cities (Chui et al., 2018; Paiva et al., 2021; Szpilko et al., 2020).

1. LITERATURE REVIEW

The discussion focuses on relationships between AI and rapid advancements in municipal waste incinerators and sustainable development (SD). The aim is to understand whether AI can influence the production of municipal waste incinerators to achieve sustainable resource management according to the Sustainable Development Goals (SDGs) outlined in the United Nations' 2030 Agenda. Table 1 illustrates the scope of AI definition in the chosen publications.

The first Analytical Engine was developed in the 1830s by Ada Lovelace and Charles Babbage. Lovelace created what is considered the first operational program for calculating Bernoulli numbers on Babbage's machine, thereby setting the standard for contemporary artificial intelligence and machine learning (AI) systems. Although Lovelace was enthusiastic about the Analytical Engine's potential to generate conclusions that the human mind could not achieve, she argued that the machine was incapable of producing original ideas. The Dartmouth Research Project defined AI as the problem of "making a machine behave in ways that would be considered intelligent if human behaviour were like this" (McCarthy et al.,

1955). AI must be understood as the ability of a system to act intelligently and to do so in increasingly broader domains (Ertel et al., 2018; Chen et al., 2021; Gupta et al., 2023; Moravec et al., 2024), accurately interpreting external data and using these insights to achieve specific goals and tasks through flexible configurations (Jha et al., 2017; Kaplan et al., 2019; Lévesque et al., 2022). AI is a distinct concept from the Internet of Things (IoT) and Big Data, although interconnected. Artificial Intelligence (AI) transformed the mechanisms of generating and utilising information for decision-making processes (Mikalef et al., 2017; Subotic et al., 2021; Wu et al., 2021; Lazaroiu et al., 2022) and revolutionised business operations (Yigitcanlar et al., 2020; Wang et al., 2021), impacting trade practices and management across various sectors (Wirtz et al., 2019). These sectors are now offering increasingly competitive and sustainable products or services (Govindan et al., 2019; Garbuio et al., 2019; Wirtz et al., 2019). Currently, the synergy between artificial technologies and human intelligence is anchored in algorithms designed to assist managers in making informed decisions. This has initiated a cultural shift wherein a vast array of data, connections, and interactions become integral to the standard management protocols within organisations (Sievers et al., 2021). Such mathematical models facilitate managerial tasks by providing well-catalogued and organised information repositories. Previous research has even indicated that, in many instances, these algorithmic models outperform human decision-making capabilities. Sousa and Rocha (2019) proposed a developmental model for the requisite skills — innovation, leadership, and management — for disruptive business managers, given AI's application in business intelligence processes.

Current research on sustainable entrepreneurship based on artificial intelligence is also significant (Subotić et al., 2021). Many industries have been "touched" by the development of artificial intelligence (Bibri, 2020; Wang et al., 2020). Wynsberghe (2021) defined the term "sustainable artificial intelligence" as a way of using artificial intelligence to enable societies to achieve their sustainable development goals. Artificial intelligence is integrated with environmental and energy systems, as well as other innovative technologies, to facilitate sustainable development (Vinuesa et al., 2020).

This trend could assist enterprises in identifying the nexus between innovation and sustainability (Stone et al., 2016), aiming to incorporate AI into

Tab. 1. Scope of AI definition in the chosen publications

AUTHORS AND TITLE OF PUBLICATIONS	SCOPE OF AI DEFINITION
McCarthy et al. (1955)	as the problem of "making a machine behave in ways that would be considered intelligent if human behaviour was like this"
Nilsson (1983)	must be understood as the ability of a system to act intelligently and to do so in increasingly broader domains
Taddy (2018)	in many instances, these algorithmic models outperform human decision-making capabilities
Mikalef et al. (2017)	transformed the mechanisms of generating and utilising information for decision-making processes
Stone et al. (2016)	objective of incorporating AI into decision-making in municipal waste incinerators
Sousa et al. (2019)	developmental model for the requisite skills with AI's application in business intelligence processes
Schneider et al. (2019)	revolutionised business operations, impacting trade practices and management across various sectors
Subotić et al. (2021)	sustainable entrepreneurship based on artificial intelligence is also significant
Wynsberghe (2021)	defines the term "sustainable artificial intelligence" as a way of using artificial intelligence to enable societies to achieve their sustainable development goals
Vinuesa et al. (2020)	AI-like applications are integrated with environmental and energy systems and other innovative technologies to facilitate sustainable development

decision-making in municipal waste incinerators to fulfil the Sustainable Development Goals (SDGs). The business sector is pivotal in the strategy to achieve the United Nations' Sustainable Development Goals by 2030, as it is a primary driver of economic growth. In reality, municipal waste incinerators of any size production are capable of developing more responsible business models, thereby providing a critical impetus towards the implementation of Sustainable Development Goals (SDGs) through investments in technological innovations and the engagement of multiple stakeholders. Innovation serves as the lifeblood of business operations because, through cutting-edge technologies, it is feasible to implement sustainable models of production and consumption that align perfectly with the objectives of the UN 2030 Agenda, particularly with SDG#12 (responsible consumption and production — ensuring sustainable consumption and production patterns). The integration of new social and environmental demands with the company's standard, in alignment with neoclassical economic theory (Skowronek et al., 2015, Stawasz, 2016; Winkowska et al., 2019), necessitates the protection of ecosystems and individuals, as well as the assurance of social equity (Stubbs et al., 2008, Walicka et al., 2015, Czemiel-Grzybowska, 2022).

Subjects of smart cities that heavily rely on information and communication technologies have been realised in various countries (Alifi & Supangkat, 2016; Yamakami, 2017; Szpilko et al., 2023; Baali et al., 2022). AI continues to revolutionise management, energy generation, and consumption within smart cities, underscoring its far-reaching implications for

entrepreneurship development (Muhammad et al., 2019; Pramod et al., 2023).

1.1. RESEARCH GAPS

The systematic literature review identified research gaps regarding the nexus of sustainable technological entrepreneurship and AI for the years 2000–2023. The following thematic groups were addressed in publications and research gaps in the context of linking AI with sustainable development of technological entrepreneurship (Table 2).

Results presented in this article on Artificial Intelligence-based Decision Support Systems in urban resource management were selected for scientific research from the identified research gaps (Czemiel-Grzybowska, 2023). The topic was analysed in detail: the use of artificial intelligence to mitigate urban problems, especially air pollution, waste management, and sewage treatment. The analysis was conducted of the activities of waste incineration plants in the context of achieving SDG#11 goals (Sustainable Cities and Communities) and SDG#12 (Responsible Consumption and Production).

The aim was to address the literature gap by responding to the following research questions:

(1) What are the areas of AI application in municipal waste incinerators within the context of sustainable development of smart cities?

(2) What are the trends in activities of waste incineration plants using AI for sustainable development in smart cities, particularly in achieving SDGs, especially goals SDG#11 (Sustainable Cities and

Tab. 2. Research gaps in the field of AI and technological entrepreneurship

Common thematic areas of articles	Issues addressed within the areas	Identified research gaps in individual publication topics
1. Sustainable consumption	• sustainable construction, • water management systems with AI • agriculture 4.0, • sustainable energy sources, • the convergence of the Internet of Things and artificial intelligence in urban resource management, • evaluation of renewable energy technologies, • smart campuses, • energy optimisation	Ad.1. The use of artificial intelligence technology to make buildings more ecological and to increase the sense of responsibility among their inhabitants towards sustainable development
2. Artificial Intelligence-based Decision Support Systems in urban resource management		Ad.2. The use of artificial intelligence to mitigate urban problems, especially air pollution, waste management, and sewage treatment
3. Forecasting models		Ad.3.1. The use of artificial intelligence in transportation in the context of traffic forecasts or public transport planning
4. Economic and process issues		Ad.3.2. Analysis of the relationships between climate change and artificial intelligence in the aspect of the emergence of the field of "climate informatics"
		Ad.3.3. The use of artificial intelligence in transportation in the context of traffic forecasting or public transport planning
5. Automated systems		Ad.4. The impact of artificial intelligence and other ecological technologies on the working conditions of farmers and farm operators
6. Convergence with digital technology		Ad.5. Challenges faced by artificial intelligence algorithms and models in assessing renewable energy solutions
		Ad. 6. The potential of artificial intelligence for practical learning and training for various stakeholders, including farmers, residents, and employees

Source: elaborated by the author based on Czemiel-Grzybowska (2023, p. 126).

Communities) and SDG#12 (Responsible Consumption and Production), involve integrating AI to enhance efficiency and sustainability.

2. Research methods

In selecting the research methodology, the aim was not solely to adhere to scientific rigour but also to identify an optimal approach that ensures an objective, rational, organised, systematic, and structured scientific process (Campbell, 1966). Consequently, a triangulation of research methods was chosen to achieve the most reliable research outcomes. The case study was a selected qualitative method. Although this approach is characterised by strict requirements, it allows for considerable flexibility. Patton (1985) highlights that the strength of such a method lies in its ability to grasp the uniqueness of the situation, the nature of the specific phenomenon, its context, and its interactions with other elements rather than in attempting to predict future occurrences. Similarly, Yin (2009) advocates for the use of the case study method to gain a profound understanding of the phenomenon under investigation. Compared to other research methods, the case study provides the richest array of techniques and tools for data collec-

tion. Among the available techniques, two were selected: Computer-Assisted Web Interviewing (CAWI) and in-depth interviews, which were employed to gather the necessary data.

The research was conducted using the CAWI method. This quantitative research method allows for the administration of a prepared survey. The information from the survey was then supplemented with data from direct interviews. The sample was selected by including all municipal incinerators in operation as of January 15, 2024. In the first stage, surveys were sent out for completion. In the second stage, based on the survey results, in-depth interviews were conducted. The research model is presented in Fig. 1.

The research sample comprised all nine municipal waste incineration plants located in Poland at the time of conducting the survey. The survey included a metric identifying the municipal waste incineration plant in terms of location, processing capacity (size), thermal power, and electrical power (Table 3).

The survey questionnaire was sent to respondents via email. Based on the responses received from the survey, follow-up questions were prepared for the in-depth interview. The questionnaire consisted of an introduction outlining the purpose of the study, 20 survey questions, including some open-ended ques-
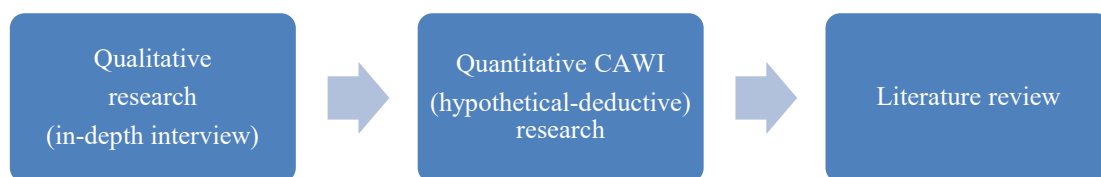
| Qualitative research (in-depth interview) | → | Quantitative CAWI (hypothetical-deductive) research | → | Literature review |

Fig. 1. Model research

Tab. 3. Research sample

WASTE INCINERATION PLANT AND THE YEAR OF COMMISSIONING	ESTIMATED PROCESSING CAPACITIES (MG/R.)	PERCENTAGE SHARE IN THE TOTAL PROCESSING CAPACITIES	THERMAL CAPACITY (MWT)	ELECTRIC POWER (MWE)
Warsaw waste incineration plant (2001)	40 000	3.0	9.1	1.4
Konin waste incineration plant (2015)	94 000	7.0	15.5	4.4
Białystok waste incineration plant	120 000	9.0	17.5	6.1
Bydgoszcz waste incineration plant	180 000	14.0	14.0	14.0
Krakow waste incineration plant	220 000	16.0	27.7	9.2
Poznan waste incineration plant	210 000	15.0	34.0	15.0
Szczecin waste incineration plant	150 000	11.0	32.0	9.4
Rzeszow waste incineration plant	100 000	7.0	16.5	4.6
Zabrze waste incineration plant	250 000	18.0	bd	bd
ALL	1 364 000	100	x	x

tions, and a conclusion with a demographic section. The survey was directed at the management of the incineration plants. The goal of the survey technique was to gather comparative data on the performance of each incineration plant in terms of processing capacity, primary data for each plant, insights into absorption capacity for new technologies, operational challenges and limitations in the field, and competitive advantages. The purpose of the in-depth interview technique was to identify development conditions specific to each entity, determine the level of maturity, and assess growth prospects based on new technologies.

Approximately 450 waste incineration plants are operational across Europe. Poland currently has 157 facilities for the mechanical-biological treatment of municipal waste, including nine municipal waste incineration plants. In 2021, the utilised processing capacities for municipal waste in Poland remained at the same level as in 2020, which was 45 %. Municipal waste incineration plants, as in 2020, did not utilise their permitted capacities. The amount of municipal waste approved for thermal treatment in decisions accounted for about 19 % of the produced municipal waste. Municipal waste incineration plants in 2021 only converted a mere 8 % of the produced municipal waste. Countries advanced in ecology and health protection, such as Germany, the Netherlands, and the Scandinavian countries, have been utilising thermal waste disposal for years. Polish waste incineration plants dispose of municipal waste, i.e., household-originated waste. Currently, efforts are made to ensure that only non-recyclable and non-segregable waste is sent to incinerators. This approach prevents the destruction of recoverable materials, allowing their reuse. Additionally, incineration plants provide a safe method for disposing of solid waste from sewage treatment facilities. Table 3 presents the

characteristics of the research sample, which includes all municipal incineration plants in Poland.

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3. Research results

The proliferation of sustainable development of smart cities involves the harmonisation of all three dimensions (economic, environmental, and social), which are "indissolubly connected and interdependent". Numerous scholars have demonstrated that the outcomes of SDGs are contingent upon the interactions among human, technical, and natural systems. It is crucial to ascertain whether and how the introduction of AI contributes to the SDGs.

All municipal incineration plants are making efforts to automate and forecast their flows and processes (Fig. 2). However, particularly sensitive processes are being forecasted using artificial intelligence. In the in-depth interviews, four out of nine respondents indicated that improvements to the system could be achieved by the AI application designed to identify proximity to the temperature of 1100°C, which is critical for waste containing over 1 % chlorinated organic compounds calculated as chlorine. One of the incineration plants stated, "this is a critical value for us". Subsequently, five out of nine respondents highlighted improvements through the AI application that identifies the approach to the temperature level of 850°C, which is crucial for wastes containing less than 1 % chlorinated organic compounds, calculated as chlorine (threshold level).

However, only two out of the nine respondents pointed to the use of AI application as a significant factor in improving processes that detects the dwell time of flue gases in the chamber — the minimum combustion time is two seconds at an oxygen content of at least 6 % (threshold level).

In the in-depth interviews, respondents highlighted both current and future possibilities for the application of AI in municipal incineration plants, aimed at optimising operations and achieving Sustainable Development Goals (SDGs). The proposals were systematically categorised into three heuristic categories. Respondent 1 stated, "The use of AI in data management: secure cloud storage with the capability of automatic sharing with stakeholders (regulatory bodies) — this facilitates bringing data control closer to the data entry point, as well as storage in a distributed ledger that enhances the activation of smart contracts (data control contracts)". Respondent 2 noted, "The use of AI in data tokenisation allows for the registration, storage, sharing, and transfer of digital assets using blockchain technology. Through tokenisation, it is possible to track the status of intangible objects and smart contracts, enabling the monitoring and comparison of data flows in real-time". Respondent 3 highlighted the future application of AI in "the reorganisation of inter-organisational work processes through smart contracts, aimed at reducing coordination efforts". This includes automating the elimination of unnecessary (unused) tasks by employing intelligent process variants, followed by optimising the sequence or parallel execution of tasks carried out by smart contracts. Respondent 4 emphasised the importance of AI in managing a portfolio of processes, stating that "strategic alignment is essential to connect data management processes with process management and the BPM platform". Respondent 5 indicated that "AI enables the future automation of monitoring activities on the BPM platform, starting from the control of quantity and quality parameters of individual incoming transports, through segregation, incineration, and the removal of sold recoverable materials (plastic, glass, metals), including energy. Respondent 6 pointed out that "AI will accelerate the elimination and remediation of inefficiencies and bottlenecks, and through innovative exploitation, it will identify areas for performance improvement as well as competency gaps". Respondent 7 observed that "the use of AI enables the identification of informational gaps in processes, supplementing previously 'fragmentary' data with comprehensive information by redesigning the flow of information". Respondent 8 highlighted "the demand for process risk analysis using AI, particularly in areas involving sensitive data subject to stakeholder scrutiny. The expectation in this domain is for automatic updates of risk factors". The final respondent, Respondent 9, indicated that "automated sorting — AI-driven robotics can
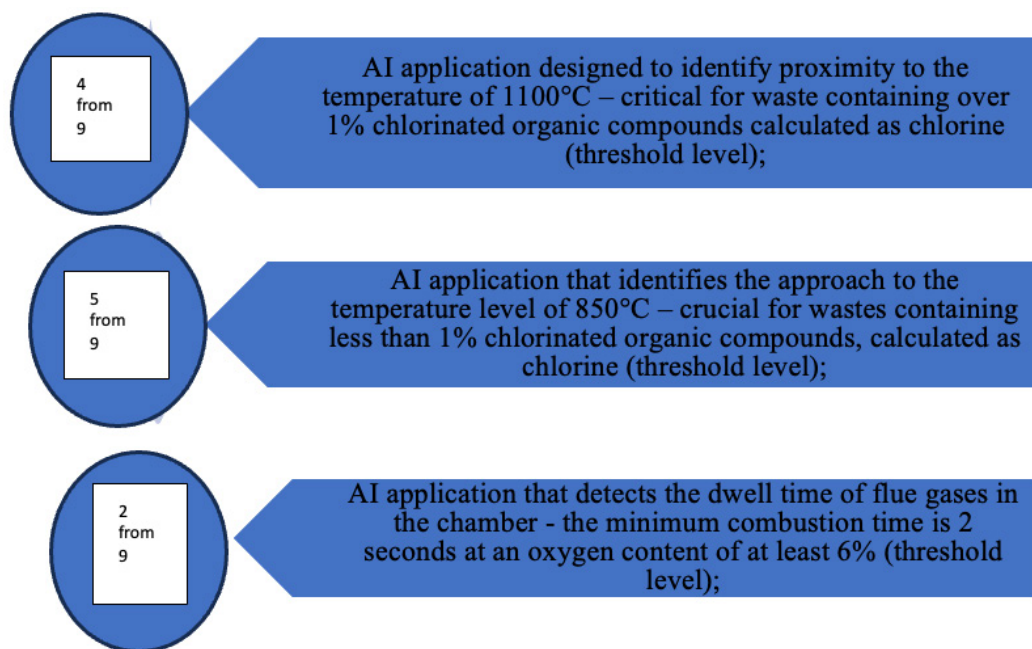
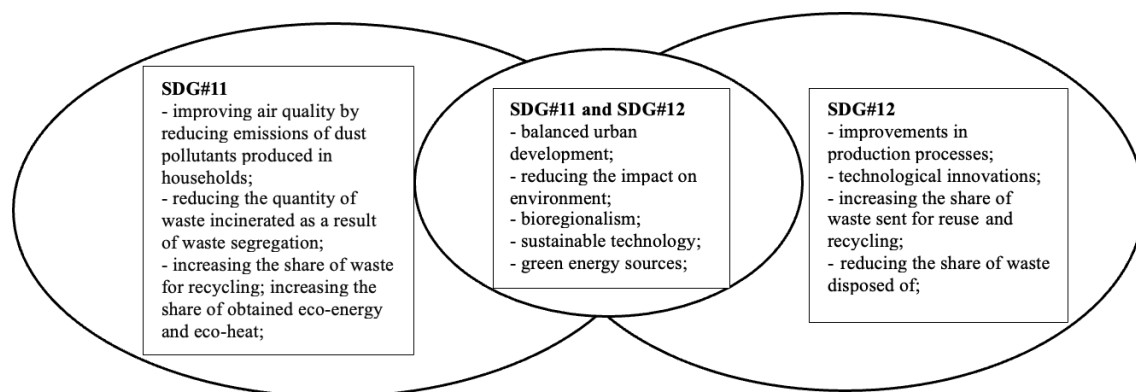Fig. 2. AI applications in all municipal waste incineration plants

Fig. 3. What is the effect of using AI in municipal waste incineration plants for SDG#11 and SDG#12?

improve the efficiency of waste sorting before incineration, ensuring that recyclable materials are separated, thereby reducing the volume of waste that needs to be incinerated. Data Analytics with analysing waste composition data using AI can help in better understanding waste generation patterns, leading to more effective waste management strategies". Every respondent pointed out that incorporating AI in incineration plants offers a pathway to significantly improve operational efficiency, reduce environmental impact, and enhance the overall sustainability of waste management processes, thereby supporting multiple SDGs simultaneously.

Areas of AI application in municipal waste incinerators within the context of sustainable development of smart cities can include optimisation of combustion processes: AI can analyse data related to the composition of waste and combustion conditions to optimise combustion processes, reducing the emission of harmful substances and increasing energy efficiency (Fig. 3, based on the surveys and in-depth interviews). In the framework, waste management like AI systems can assist in sorting waste and deciding on the best methods for its processing, increasing the recovery of recyclable materials and minimising the amount of waste directed to incineration.

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Another area where AI is used can include maintenance and diagnostics. AI can support maintenance programs by predicting failures and assisting in diagnosing problems, increasing the reliability and operational efficiency of incinerators. One important aspect of AI use in waste incinerators is integration with urban systems. AI can aid in the integration of incinerators with other urban systems, such as energy management, waste transportation, and urban infrastructure, promoting a holistic approach to city management. The use of AI in these areas can contribute to more sustainable and efficient waste management in smart cities while minimising the environmental impact.

In municipal waste incineration plants, AI neutralises risks by optimising thermal processes to minimise the formation of dioxins and furans, employing predictive maintenance to prevent equipment failures, and refining emission control systems to enhance the capture and neutralisation of hazardous pollutants like mercury and nitrogen oxides, thereby ensuring compliance with stringent environmental regulations and contributing to public health and safety.

The trends in sustainable development activities of smart cities using AI involve various strategies and practices, especially in the context of achieving SDG#11 (Sustainable Cities and Communities) and SDG#12 (Responsible Consumption and Production). Key areas of focus include the development of frameworks for assessing city sustainability, which,

although predating the SDGs, align with common sustainability principles. However, challenges remain in integrating and implementing coherent, city-specific values, principles, goals, and solutions that encompass not only infrastructure, housing, mobility, and technology but also social well-being in urban contexts. The interconnectedness of social and environmental sustainability is strongly emphasised, recognising that the majority of actions leading to global challenges, such as climate change and loss of biodiversity, originate in cities. Therefore, the achievement of the SDGs will largely be determined by actions taken within cities, necessitating locally relevant, applied, and quantitative methodologies to monitor progress toward sustainability both locally and globally. SDG#11 (Sustainable Cities and Communities) highlights the critical link between the quality of life in cities and the management of natural resources. The trend towards urbanisation brings increased pressure on the environment and a higher demand for basic services, making cities particularly vulnerable to the impacts of climate change and natural disasters. Building urban resilience and making cities resource-efficient is essential for mitigating these risks and ensuring sustainability. This includes providing access to safe and sustainable transport systems, enhancing inclusive and sustainable urbanisation, and reducing the adverse per capita environmental impact of cities.

AI can be utilised in municipal waste incineration plants in areas such as optimising furnace designs for better combustion efficiency, improving air-injection systems for complete combustion, and enhancing flue-gas recirculation to reduce emissions. AI can also support the control of auxiliary burners to maintain optimal furnace temperatures and assist in advanced air-pollution control techniques for removing particulates, acid gases, dioxins, and mercury.

Managers added that municipal waste incineration plants should employ AI applications in advanced predictive analytics for pre-emptive maintenance scheduling, thermodynamic modelling for optimising combustion efficiency, spectroscopic analysis for real-time emission monitoring, machine learning algorithms for adaptive control of incineration parameters, and robotic sorting systems integrated with computer vision for enhanced waste segregation, thereby improving operational efficiency, reducing environmental impact, and ensuring compliance with stringent environmental standards.

These initiatives focus on improving waste management processes, reducing emissions, and contrib-

uting to cleaner urban environments, which are in line with the broader objectives of sustainable development and smart city infrastructure optimisation. For more detailed insights, it would be beneficial to refer to specific studies or reports in this field.

4. DISCUSSION OF THE RESULTS

The volume of municipal waste generated in Poland is increasing annually. The high-calorie fraction of the waste constitutes approximately 22 % of the total mass of municipal waste. This source of heat can locally lead to reduced heating prices or supply, for example, the tram network of a large metropolis. Incineration plants can locally reduce heating prices and be competitive with coal (Serban et al., 2020).

Waste incineration is inherently associated with the generation of by-products, namely slag and ashes, produced in the flue gas cleaning process. However, all Polish incineration plants are equipped with facilities to neutralise ashes and slag. This involves adding specific chemical compounds designed to neutralise the effects of incineration by-products.

In the course of these in-depth interviews, incineration plant managers highlighted various waste management approaches optimised through the application of AI technology (Ullach et al., 2020; Singh et al., 2020; Rani et al., 2021). These approaches include storage, use in construction, or filling in mining excavations. All managers reported that municipal waste incineration plants are fully ecological tools that complement recycling efforts (Park et al., 2020; Ragab et al., 2023). Unlike landfills, a municipal waste incineration plant neutralises waste without emitting toxic fumes, halting the release of foul odours and preventing groundwater contamination. In doing so, it aligns with the objectives outlined in SDG#11 (Sustainable Cities and Communities) and SDG#12 (Responsible Consumption and Production).

Polish municipal waste incineration plants are generating increasingly higher levels of electrical and thermal energy production year after year. The incineration process occurs at a temperature of 1100 degrees Celsius, releasing substantial amounts of heat that facilitate the production of electricity, heat, and steam. The energy derived from waste is primarily used for the plant's own needs, but an increasing proportion is sold to the public grid (Navarro-Espinoza et al., 2022; Lopez-Blanco et al., 2023). The revenue from energy significantly accelerates the payback of the incineration plant's initial costs and

subsequently allows for the generation of increasing profits from operations (Muhammad et al., 2019; Ma et al., 2020). Managers emphasised that municipal waste incineration plants are a much better and more ecological alternative to landfills, which not only fail to resolve the waste problem but also pose serious threats to the environment and human health (Kamel et al., 2019; Golinska-Dawson et al., 2023).

The identified trends underscore the importance of adopting and implementing integrated policies and plans that address inclusion, resource efficiency, climate change mitigation and adaptation, and resilience to disasters (Ortega-Fernandez et al., 2020; O'Dwyer et al., 2019). The focus on Polish cities in achieving the SDGs reflects the critical role they play in the global sustainability agenda, emphasising the need for innovative approaches to urban planning and management that prioritise both environmental and social sustainability (Cubric, 2020). Decision support tools for the sustainable development of smart cities are increasingly utilising AI to optimise these processes and ensure higher living standards for the inhabitants of Polish smart cities (Chui et al., 2018; Paiva et al., 2021).

CONCLUSIONS

The article discussed the role of AI in enhancing the efficiency and sustainability of municipal waste incinerators within smart cities, contributing to the achievement of SDG#11 and SDG#12. The research emphasises the potential of AI in optimising waste management processes, thereby reducing emissions and improving energy recovery, which in turn supports more sustainable urban environments. The use of AI in municipal waste incineration plants contributes to SDG#11 (Sustainable Cities and Communities) by optimising waste management, thus improving urban environmental quality and public health. By enhancing combustion efficiency and emission controls, AI supports cleaner air and less environmental pollution. For SDG#12 (Responsible Consumption and Production), AI helps in achieving more efficient waste-to-energy conversion, reducing landfill usage, and promoting recycling and sustainable waste management practices, aligning with the goal of sustainable management and efficient use of natural resources.

For further research, it is recommended to explore more integrated AI applications across different waste management processes, assess the long-

term impacts of AI-enhanced waste incineration on urban sustainability, and investigate the scalability of these technologies in diverse urban settings. Additionally, studies could focus on the socio-economic implications of adopting AI in waste management, including job creation, public acceptance, and policy frameworks to support technological integration.

Trends in waste incineration plants utilising AI for sustainable development in smart cities, particularly for achieving SDG#11 and SDG#12, focus on leveraging AI to enhance environmental outcomes.

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FACTORS AFFECTING SUSTAINABLE CLOTHING PURCHASE INTENTIONS: EVIDENCE FROM INDONESIA

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ABSTRACT

The purpose of this study is to contribute to the debate over whether the Theory of Planned Behavior, in conjunction with several other variables, can increase purchase intention for sustainable clothing in Indonesia. A survey questionnaire was used to collect data. A total of 502 responses were received from Indonesians who are sustainable clothing customers. Among the variables examined using SEM, only perceived consumer effectiveness and subjective norm were shown to have a positive-significant effect on Indonesians' purchase intentions, whereas the remaining variables, including the moderated variables, had no effect. The findings of this study will assist industry professionals in developing strategies for more effective customer communication aimed at promoting desirable purchasing behaviour.

KEY WORDS

Theory of Planned Behaviour, sustainable consumer behaviour, purchase intention, sustainable clothing, Indonesia, SEM

INTRODUCTION

With the use of non-renewable resources exceeding the renewable, a shift in customer product preferences to more sustainable (greener) products (D'Souza et al., 2006) has been noted in many countries, including several developing states (Chua et al., 2016). This shift has also been supported by the escalation of interest by industries, researchers, and practitioners in sustainability, as mentioned by Kim et al. (2015) and Song and Ko (in Kong et al., 2016). In recent years, a considerable interest in the social and environmental issues of clothing has led to a more

socially and environmentally responsible alternative in the entire phase of its supply chain (Dickson et al., 2009; Goworek et al., 2012; Park & Kim, 2016). Hence, sustainable clothing emerges as an inclusive act where sweatshop-free production is encouraged and more environmentally friendly materials are used (Chang & Watchravesringkan, 2018; Goworek et al., 2012; Harris et al., 2016; Joergens, 2006; McNeill & Moore, 2015). This type of clothing is being encouraged and produced worldwide, including in Indonesia and other Southeast Asian neighbouring countries (Singapore, Malaysia, Thailand, Vietnam, and more). In Indonesia, numerous ready-to-wear clothing labels have embraced conscious consumerism by adopting healthy business practices; they are starting to pave the way towards slow fashion, a movement that promotes environmentally friendly manufacturing processes and equitable treatment for all parties involved (Amandari & Wirengjurit, 2019). However, this phenomenon is not supported by research. According to Hasan et al. (2021), sustainable consumption is associated with general traditional practises of society in developing countries, such as Indonesia, where citizens have a moral obligation to live modestly without wasting resources (such as clothing). Citizens in developed countries can lead a life of luxury, associated with waste of money, food, and clothing, and a more independent and free life. Indonesia is a developing country with sustainable clothing mostly available in urban areas where citizens represent the lifestyle particular to a developed country, making it interesting to delve deeper into this topic. The number of sustainable clothing purchase intention studies in Indonesia is limited compared to those conducted in neighbouring countries. Hence, a better understanding of potentials and threats may contribute to the development of the business segment.

Research on green product purchase intentions shows several positive effects of certain variables on sustainable clothing. A study by Kang et al. (2013) on students in the US, the People's Republic of China, and South Korea showed a positive effect of several variables, such as perceived consumer effectiveness, attitude, and subjective norm, having an influence on purchase intentions for sustainable textiles and apparel. Zheng and Chi (2015) also investigated a study with a similar object. They showed that perceived consumer effectiveness, attitudes, and subjective norms influence the buying intention of US consumers of environmentally friendly apparel. However, no research examines factors that can affect Indonesians' likelihood of buying sustainable clothing, specifically as studied by Kang et al. (2013).

This study focuses on how the Theory of Planned Behaviour (TPB) and several other constructs influence sustainable clothing purchase intention. Similar studies have been conducted widely, especially on consumers in several countries, using several variables. However, most adopt Ajzen's Theory of Reasoned Action (TRA) and TPB. In addition to these variables, several additional variables are also used as predictors of purchase intention. It is found that by including these variables, the TPB's predictive power can be increased (Yadav & Pathak, 2016). The variables are somewhat varied, such as the values adopted by consumers for several variables that are pretty specific in certain contexts, such as environmental knowledge and awareness in relation to the purchase intention of sustainable products and services, also known as "green purchase intention" (Joshi & Rahman, 2015; Kang et al., 2013; Paul et al., 2016). The methods commonly used in previous studies are regression, without referring specifically to the type of regression used, and structural equation modelling (SEM) employed in this study to obtain more comprehensive results than using regression. The sample in previous studies does not refer to definite boundaries and is generally only limited by the age and residence location of the respondent.

The purpose of this study was to determine the effect of attitude towards purchase (ATT), subjective norm (SN), perceived behavioural control (PBC), environmental concern (EC), sustainable clothing knowledge (SCK), perceived consumer effectiveness (PCE), and past behaviour (PB) on purchase intention (PI) for sustainable clothing in Indonesia, as well as the extent to which PBC, EC, and SCK each jeopardise the relationship between ATT and PI for sustainable clothing. For the research and discussion of this topic to be more focused with a predetermined scope, it is determined to limit the study object to the intention of purchasing sustainable clothing in Indonesia, namely clothing items like t-shirts, shirts, blouses, and the like, skirts and pants that use organic materials and whose producers have concerns about a sustainable production process. As the SEM method with Confirmatory Factor Analysis (CFA) is believed to provide a more robust analysis of the proposed research model and a more accurate methodological assessment tool than regression (Bollen, 1989; Bullock et al., 1994; Jöreskog & Sörbom, 1989), it was used to achieve the research objectives. This research is expected to address a knowledge gap in empirical

research on the purchase intention of sustainable products in Indonesia.

This paper is divided into five sections: theory and hypotheses formulation, research methodology, results and discussion, research implications and conclusion and recommendation for stakeholders and future investigation.

1. Literature review

1.1. Purchase intention (PI)

Attitudes and judgments from customers and several external factors can influence customer purchase intentions and become critical factors in predicting customer behaviour. PI can be used to gauge a customer's likelihood of buying a product; the higher the purchase intention, the greater their intention to buy the product. According to Schiffman and Kanuk (in Chi et al., 2011), purchase intention implies that customers will gather information, evaluate alternatives, and make decisions based on their prior experiences, preferences, and environmental factors. Purchase intention can be used as an important indicator in predicting customer behaviour. Customers with a favourable intent to buy will form a positive brand commitment, encouraging them to be more likely to buy from a company.

The variables used in this study were modified from the TPB (Ajzen, 1991), stating that a person's intended behaviour is based on attitudes towards that behaviour and subjective norms whose influence is moderated by perceived behavioural control. In this case, the conduct is a person's intention to purchase sustainable clothing. The use of TPB as a conceptual framework has also been found in prior works on green product purchase behaviour (e.g., Albayrak et al., 2013; Arifani & Haryanto, 2018; Kang et al., 2013; Mufidah et al., 2018; Paul et al., 2016; Sparks & Shepherd, 1992; Yadav & Pathak, 2016; Zheng & Chi, 2015; Dabija et al., 2022). Until now, there have been few new findings to better understand the factors affecting consumer buying behaviours towards sustainable clothing or eco-friendly products. This study also uses several additional variables in addition to the three predictors. The incorporation of these concepts into the initial TPB construct has enabled the TPB to increase its explanatory power at various levels for consumers' buying intentions towards eco-friendly products (Zheng & Chi, 2015). As a result, this study integrates them into TPB to create a more

robust model to understand consumers' buying intentions for sustainable clothes.

1.2. Attitude towards purchase (ATT)

Attitude towards behaviour (ATT) can be interpreted as how a person likes or dislikes an object or specific behaviour psychologically (Eagly & Chaiken, 2007). According to the TPB, the more favourable an individual's attitude towards a particular behaviour is, the more likely the person will engage in that behaviour (Ajzen, 1991). Numerous previous studies on sustainable products and attitudes towards environmentally-related behaviour support the claim that attitudes towards environmentally friendly behaviour and purchase intentions have a positive relationship (Albayrak et al., 2013; Barber et al., 2009; Diamantopoulos et al., 2003; do Paço & Raposo, 2009; Ellen et al., 1991; Flamm, 2009; Mostafa, 2009; Yadav & Pathak, 2016). So far, no study has looked at the relationship between attitudes towards a behaviour (in this case, purchasing) and purchase intentions for sustainable clothing in Indonesia, nor have there been studies that look at the relationship between the attitude towards behaviour and buying intentions for environmentally friendly products that are very specific to particular contexts. Prior research has found that purchasing attitudes were positively related to the purchase intention of eco-friendly products (Arifani & Haryanto, 2018; Arli et al., 2018; Chin et al., 2018; Mufidah et al., 2018). As a consequence, the attitude towards the purchase is considered a worthy and exciting variable to be studied, so the hypothesis is set as follows:

H1: ATT positively affects a consumer's PI towards sustainable clothing.

1.3. Subjective norm (SN)

Combining the perceived expectations of people considered important by a person forms an SN so that the person is motivated to fulfil these expectations (Ajzen & Fishbein, 1973). A person unsure of the consequences of certain behaviours tends to seek support from others (Bratt, 1999). Thus, if a person believes that other people they consider important (family, friends, and significant others) want them to perform a behaviour, thus spurring them to fulfil that desire, the behaviour will be more likely to be carried out (Ruiz de Maya et al., 2011; Yadav & Pathak, 2016). Additionally, previous research has reported that SN constitutes a significant predictor of buying intention

(Harland et al., 1999; Kaiser & Gutscher, 2003; Sparks & Shepherd, 1992). Research conducted by Arifani and Haryanto (2018) found that SN was also a predictor that affected Indonesian consumers' intentions to buy green products. Yet, no study has been found that discusses how this predictor affects the purchase intention for sustainable clothing in Indonesia. It becomes interesting to study, and based on several previous studies, the hypothesis is set as follows:

H2: SN positively affects consumer's PI towards sustainable clothing.

1.4. Perceived behavioural control (PBC)

Ajzen (1991) defined PBC as an individual's perception of the ease or difficulty of engaging in certain behaviours. PBC indicates the extent of effort made and the willingness to try to perform a behaviour (Lee, 2008). The greater the consumer's perception of behavioural control over the encountered obstacles, the greater the consumer's intention to buy sustainable products (Ko & Jin, 2017; Nguyen et al., 2017; Tanner & Wölfing Kast, 2003; Yadav & Pathak, 2016; Kovacs, 2021). Contrary to this, a study by Zheng and Chi (2015) shows that PBC does not significantly affect a person's intention to buy sustainable clothing in the United States. Apart from its direct effect on PI, current research has also revealed that PBC may positively moderate the relationship between consumer attitudes and PI. A study conducted by Kim and Chung (2011) stated that an increase in PBC would result in a stronger positive relationship between ATT and PI.

H3: PBC positively affects consumer's PI towards sustainable clothing.

H4: PBC positively moderates the relationship between a consumer's ATT and PI towards sustainable clothing.

1.5. Environmental concern (EC)

Hu et al. (2010) stated that EC is how a person cares about problems related to the environment and their efforts to solve them and show their contribution to providing solutions. The increasing public awareness of the environment is the basis for using the environmental concern variable in this study. Finding out consumers' views on environmental issues and how they are reflected in buying sustainable goods or services is a perfect start to better understand a country's responses to the green concept

(Chan & Lau, 2000). According to Hines et al. (1987), environmental concern is fundamental in environmental research, an important factor and a main variable in the consumer decision-making process to buy sustainable products (Diamantopoulos et al., 2003; Mostafa, 2009). A study by Fraj-Andrés et al. (2009) showed that many customers are concerned about sustainability, so companies that do not address environmental issues by providing environmentally sustainable goods may lose their credibility. More specifically, increased environmental awareness significantly increases the intention to buy certain environmentally sustainable products (Lee et al., 2014; Pagiaslis & Krontalis, 2014; Sang & Bekhet, 2015). Several other studies support the finding that environmental awareness significantly affects consumers' purchasing attitudes towards sustainable products and services (Han et al., 2009; Hartmann & Apaolaza-Ibáñez, 2012), which also further influences buying intentions.

H5: EC positively affects consumer's PI towards sustainable clothing.

H6: EC positively moderates the relationship between a consumer's ATT and PI towards sustainable clothing.

1.6. Sustainable clothing knowledge (SCK)

When someone cares about the environment, their knowledge can influence their buying attitudes and behaviour (Scott & Vigar-Ellis, 2014). Understanding environmental issues can affect a person's intention to purchase sustainable products (Ali & Ahmad, 2016; Rokicka, 2002; Yadav & Pathak, 2016). King and Workman (in Dickson, 2000) found that someone more knowledgeable about environmental issues related to textiles and clothing (sustainable clothing knowledge) feels more affected by these problems. Kim and Damhorst (1998) examined the effect of US consumers' understanding of sustainable clothing on their purchasing behaviour and showed that although the general knowledge of the sample was inadequate, the relationship between intended knowledge and buying behaviour was significant. The analysis results of the survey by Chan and Lau (2000) on consumers in the People's Republic of China also found similar results. Apart from having a direct effect, other researchers have also discovered the significant impact of environmental knowledge on consumer attitudes towards sustainable products (Barber et al., 2009; Chan, 2001; Flamm, 2009) and found that

knowledge is one of the essential variables that can moderate the relationship between their attitudes and buying interest in sustainable products (Chan, 2001; Mostafa, 2007, 2009). Conversely, Amar et al. (2020) found that Indonesians' buying intentions for sustainable products are not affected by their environmental knowledge.

H7: SCK positively affects a consumer's PI towards sustainable clothing.

H8: SCK positively moderates the relationship between a consumer's ATT and PI towards sustainable clothing.

1.7. Perceived consumer effectiveness (PCE)

Purchase intentions are influenced by whether or not a person believes their behaviour will lead to the outcome they want (Ellen et al., 1991). Environmental concern does not always lead to the desired behaviour, which is the purchase of sustainable products (Vermeir & Verbeke, 2008). Perceived consumer effectiveness (PCE) differs from environmental concern and contributes uniquely to predicting certain pro-environmental behaviours (Ellen et al., 1991, p. 102). Differences between environmental concern and purchasing behaviour have also been found in similar studies (Butler & Francis, 1997; Roberts, 1996; Vermeir & Verbeke, 2008). To fill the gap between environmental awareness and the purchase of eco-friendly products, PCE is one of the prominent factors in explaining the intended behaviour (Roberts, 1996). High levels of PCE motivate consumers to demonstrate their positive attitudes towards sustainable goods through their actual consumption behaviour (Kim & Choi, 2005; Vermeir & Verbeke, 2008). Consumers buy sustainable products because they assume their purchases are beneficial for environmental protection (Zheng & Chi, 2015). The availability of research examining this construct in Indonesia is still rare, and this research may provide an overview of how this construct affects the purchase intention of sustainable clothing in Indonesia.

H9: PCE positively affects a consumer's PI towards sustainable clothing.

1.8. Past behaviour (PB)

In addition to the discussed variables, past behaviour has also been used by several studies (De Cannière et al., 2009; Han & Kim, 2010; Smith et al., 2007; Sparks & Shepherd, 1992) to increase the explo-

ration power of the TPB in the context of purchase intentions and similar behaviours. According to Sparks & Shepherd (1992), past behaviour is the second strongest predictor of consumer intention to purchase organic vegetables after PBC. However, a study conducted by Zheng and Chi (2015) showed that past behaviour does not significantly affect a person's intention to buy sustainable clothing. No study has been found to discuss how past behaviour affects the purchase intention of sustainable clothing for Indonesian consumers. The following hypothesis is set on these matters.

H10: PB positively affects consumer's PI towards sustainable clothing.

2. RESEARCH METHODS

The data in this study was gathered using questionnaires distributed to Indonesian sustainable products customers.

Each latent variable in Fig. 1 has a manifest variable used to measure the value of these variables, which refers to previous research. It can be seen that hypotheses 4, 6, and 7 have a moderating relationship. These hypotheses were then tested to see how perceived behavioural control, concern for the environment, and knowledge of sustainable clothing affect the relationship between attitudes towards purchasing and the main predictors of purchase intention of environmentally sustainable products in Indonesia. The value of the moderating variable is determined by performing moderated regression analysis on the moderating and moderated variables.

In this study, a 7-point Likert scale was used, where 1 meant strongly disagree/very probably not/very unimportant and 7 meant strongly agree/definitely/very important. The value for the attitude variable was obtained by multiplying the individual's beliefs about the outcomes of their behaviour by the evaluation of the consequences of following these beliefs. Simultaneously, the Subjective Norm is the result of normative beliefs about what other people think about how the individual should perform the desired behaviour multiplied by the individual's motivation to comply with that belief (Kang et al., 2013). The variable of sustainable clothing knowledge has eight statements adapted from the questionnaire used by Kim and Damhorst (1998) related to fibre processing, fibre recycling, and the contribution of textile products to waste disposal. They were developed from various literature sources to assess the
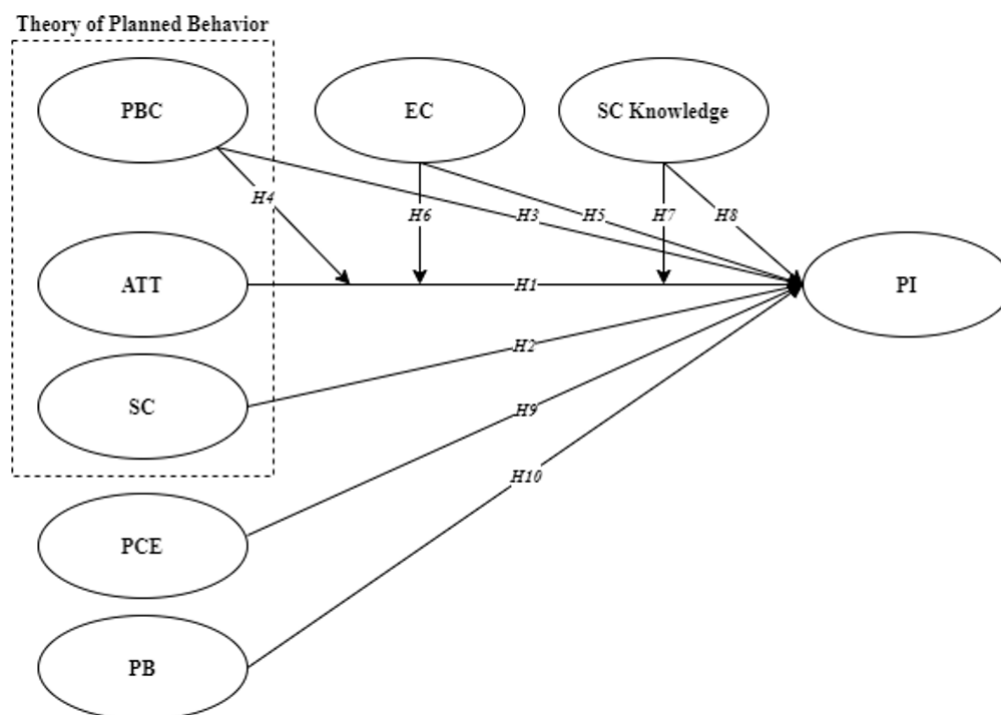
Fig. 1. Conceptual diagram

level of respondents' knowledge about the product. Clothing and its environmental implications, where four experts reviewed all items in the textile science, social psychology, and consumer behaviour. Modifications to the questionnaire were made to items 3, 4, and 7, which were excluded because they were unrelated to the research topic and left eight out of eleven statements, as well as the use of a reverse scale on items with incorrect statements. According to Kim and Damhorst, agreement on five correct items (1, 3, 4, 6, and 7) and disagreement on three incorrect items (2, 5, and 8) indicates that respondents know facts and information related to the environment from clothing products. Another scale used in this study is the ordinal scale on past behaviour. In the past behaviour variable, respondents were asked to write down how many clothes they bought in a predetermined period.

A pilot study was conducted, and items with insignificant product-moment correlations, i.e., PBC3, SCK8, PB1, and PB2, were declared invalid and eliminated from the final research questionnaire. Data from the final questionnaire will then be analysed using SEM. Not only does it assess the structural model, but it also evaluates the measurement model in the same analysis. As cited by Gefen et al. (2000, p. 5), "the combined analysis of the measurement and the structural model enables measurement errors of the observed variables to be analysed as an integral part of the model and factor analysis to be combined in one operation with the hypotheses testing".

Based on the formulated model, 79 parameters were obtained, so at least 395 respondents were needed to process it (Bentler & Chou, 1987). Respondents were selected from several regions in Indonesia using a simple random sampling technique, and 502 responses were obtained from the survey.

The normality test was employed to explain the distribution of the data so that an appropriate estimation model could be used. It was found that the data were not normally distributed, so the Robust Maximum Likelihood (RML) estimation method was used to correct the bias caused by the normality violation (Boomsma & Hoogland, 2001). Furthermore, the measurement model fit test was performed to determine whether the hypothesised model could represent the actual situation by performing Confirmatory Factor Analysis (CFA) and calculating reliability using Construct Reliability (CR) and Average Variance Extracted (AVE), and all met the criteria.

Finally, the structural model fit test results were examined using the fit index value. The model was found to be fit, which means that the proposed theoretical model did not differ from the empirical data.

Tab. 1. Respondent demographic

Demographic Variable	Percentage
Gender	
Male	51.99 %
Female	48.01 %
Age	
17 − 21	22.31 %
22 − 26	25.90 %
27 − 31	8.57 %
32 − 36	10.96 %
37 − 41	8.37 %
> 41	23.90 %
Current Residency	
Makassar	59.96 %
Jakarta	8.57 %
Yogyakarta	3.39 %
Parepare	2.19 %
Surabaya	1.99 %
Bekasi	1.79 %
Malang	1.79 %
Other cities	20.33 %
Educational qualifications	
High School	32.87 %
Diploma	14.54 %
Bachelor's degree	41.63 %
Masters's degree	9.16 %
Doctoral degree	1.79 %
Profession/employment	
University student	31.67 %
Civil servant/government employees	31.27 %
Professional employee	20.92 %
Entrepreneur	7.37 %
Not Working	2.99 %
Housewife	2.39 %
Others	3.39 %
Average discretionary money per quarter	
Less than IDR 3,000,000	39.64 %
IDR 3,000,000 to IDR 4,999,999	14.34 %
IDR 5,000,000 to IDR 9,999,999	23.31 %
IDR 10,000,000 to IDR 14,999,999	10.16 %
IDR 15,000,000 or more	12.55 %
Average apparel expenditure per quarter	
Less than IDR 200.000	24.70 %
IDR 200,000 to IDR 499,999	35.26 %
IDR 500,000 to IDR 799,999	18.13 %
IDR 800,000 to IDR 999,999	6.57 %
IDR 1,000,000 or more	15.34 %

Tab. 2. Confirmatory factor analysis (CFA)

Latent Variable	Manifest Variable	Factor Loading	Validity	CR	AVE	Reliability
ATT	ATT1	0.83	Valid	0.9031	0.7008	Reliable
	ATT2	0.74	Valid			
	ATT3	0.88	Valid			
	ATT4	0.89	Valid			
SN	SN1	0.91	Valid	0.9481	0.8589	Reliable
	SN2	0.94	Valid			
	SN3	0.93	Valid			
PBC	PBC1	0.83	Valid	0.9069	0.6618	Reliable
	PBC2	0.77	Valid			
	PBC4	0.74	Valid			
	PBC5	0.85	Valid			
	PBC6	0.87	Valid			
EC	EC1	0.87	Valid	0.9267	0.7169	Reliable
	EC2	0.84	Valid			
	EC3	0.78	Valid			
	EC4	0.87	Valid			
	EC5	0.87	Valid			
SCK	SCK1	0.72	Valid	0.9271	0.6505	Reliable
	SCK2	0.67	Valid			
	SCK3	0.78	Valid			
	SCK4	0.98	Valid			
	SCK5	0.73	Valid			
	SCK6	0.71	Valid			
	SCK7	0.99	Valid			
PCE	PCE1	0.87	Valid	0.8996	0.6925	Reliable
	PCE2	0.73	Valid			
	PCE3	0.84	Valid			
	PCE4	0.88	Valid			
PI	PI1	0.84	Valid	0.8951	0.7399	Reliable
	PI2	0.86	Valid			
	PI3	0.88	Valid			

Tab. 3. Goodness of fit

Goodness of Fit Indicators	Cut-off Value	Result	Model Fit
Chi-Square (χ^2)	P-value ≤ 0,05	0,00	Good Fit
Degree of Freedom (df)	≥ 0	485	Good Fit
CFI	≥ 0.95	0.99	Good Fit
TLI	≥ 0.95	0.99	Good Fit
RMSEA	< 0.07 (with fit CFI)	0.054	Good Fit

3. RESULTS AND DISCUSSION

The loadings of the fit model that SEM analysed are as follows. The relationship between the variables is portrayed by the t-value of the hypothesis test and the value of the completely standardised solution.

Based on the research hypothesis test, the t-value was 0.64, indicating no significant effect between ATT and PI. Furthermore, the completely standardised loading obtained shows that ATT affects the PI positively but not significantly, with a p-value of 0.067. With an insignificant effect, the difference with previous studies is that these studies found that ATT is one of the variables with the greatest influence and a significant influence on the buying of environmentally friendly goods generally and sustainable clothes in particular (e.g., Yadav & Pathak, 2016). According to this research finding, Indonesians are more willing to purchase sustainable clothing because of the feeling they will get from wearing it rather than the environmental issues it may solve from using it.

SN was another variable used in this research. According to hypothesis testing, the t-value was 2.54, so SN affected the PI positively and significantly or more precisely, by 0.12 based on completely standardised loading. With a significant value, SN is one of the second-largest independent variables among the nine other independent variables. That way, it can be seen that the Indonesian people are very considerate of input or suggestions from those closest to them when purchasing sustainable clothing. Indonesians deeply consider and follow the suggestions of their relatives, significant others, and close friends consecutively. Findings from this research confirmed previous works by Sparks and Shepherd (1992), Harland et al. (1999), and Kaiser and Gutscher (2003), who also found that SN was the main predictor of purchase intention in general and purchase intention of environmentally sustainable products in particular.

In this study, the statement items for the PBC variable include a variety of factors, such as product availability, price, location, and other considerations that may deter someone from purchasing sustainable clothing. Based on the hypothesis test, the t-value was 0.48, which means that PBC affected the PI positively but not significantly, or rather, only 0.034 based on completely standardised loading. This variable has the smallest effect when compared to other non-moderating variables. Additionally, Zheng and Chi (2015) reported a non-significant positive impact, indicating that PBC did not significantly affect a per-

son's intention to buy sustainable clothing in the United States. According to this survey, Indonesians have a challenge distinguishing between sustainable and fast-fashion clothing. Moreover, the variability of available designs remains limited. This product is quite easy to find, considering that most clothes are sold online. However, the results reveal that the Indonesian people also have unfavourable perceptions of product availability, price, location, and other concerns that can reduce the PI for sustainable clothing, but they are not the primary reason for this failure. In addition, the measurement error shows a value that is slightly larger than the measurement error for the other latent variables. This suggests that the observed variables did not adequately describe the latent variable. Besides, there are other obstacles apart from the constraints specified in the manifest variables that result in relatively larger measurement errors despite the fact that the loading value of each manifest variable on the latent variable has the same numerical range as the loading value of each manifest variable on other latent variables.

The t-value of the relationship between EC and PI is 0.97, indicating a positive but not significant effect between the two variables. More precisely, changes in EC affect the PI value of 0.088 based on the completely standardised solution. This value shows that Indonesians pay enough attention to their environment and feel encouraged to buy sustainable clothing. Indonesian concern for the environment is shown in more verbal-collective participation than actual-individual participation. This finding is also confirmed by the prior works of Caruana (2007), Hartmann and Apaolaza-Ibáñez (2012), Lee et al. (2014), Pagiaslis and Krontalis (2014), Paul et al. (2016), Sang and Bekhet (2015), and van Doorn and Verhoef (2011). This result is thought to occur because although some consumers believe that the environment should be considered when buying clothes, it is not considered during the actual purchase, as found by Butler and Francis (1997), so the PCE variable should be included in measuring purchase intention.

This study modified the measurements used by Kim and Damhorst (1998) to measure respondents' objective knowledge of sustainable clothing and its relationship to their intention to purchase clothing in Indonesia. No significant effect was found between SCK and PI. Based on the results of the loading value using SEM, an effect of 0.059 on completely standardised loading was obtained. Several previous studies suggest that consumers who understand environ-
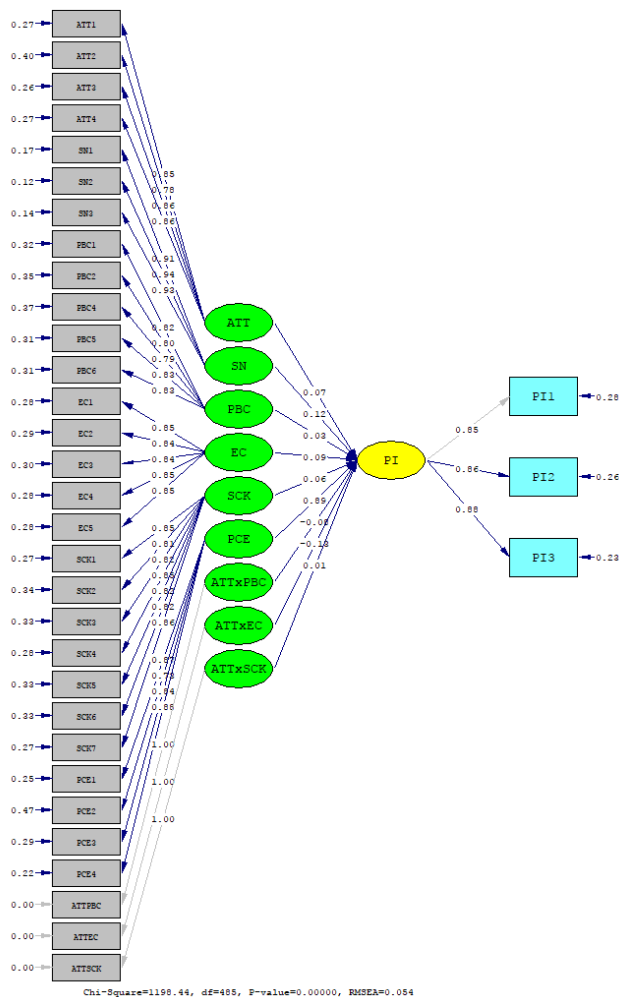
Fig. 2. Completely standardised loadings of the fit model

Tab. 4. Result

	Exogen Var (X)	Endogen Var (Y)	Moderator (Z)	X → Y		Z → Y		X*Z → Y		Result
				Effect	T-value	Effect	T-value	Effect	T-value	
H₁	ATT	PI	-	**0.067**	**0.64**	-	-	-	-	ATT does not affect PI
H₂	SN	PI	-	**0.120**	**2.54**	-	-	-	-	SN positively affects PI
H₃	PBC	PI	-	**0.034**	**0.48**	-	-	-	-	PBC does not affect PI
H₄	ATT	PI	PBC	0.067	0.64	0.034	0.48	**-0.075**	**-0.69**	PBC does not moderate the relationship between ATT and PI
H₅	EC	PI	-	**0.088**	**0.97**	-	-	-	-	EC does not affect PI
H₆	ATT	PI	EC	0.067	0.64	0.088	0.97	**-0.130**	**-0.75**	EC does not moderate the relationship between ATT and PI
H₇	SCK	PI	-	**0.059**	**0.67**	-	-	-	-	SCK does not affect PI
H₈	ATT	PI	SCK	0.067	0.64	0.059	0.67	**0.008**	**0.048**	SCK does not moderate the relationship between ATT and PI
H₉	PCE	PI	-	**0.890**	**5.47**	-	-	-	-	PCE positively affects PI

mentally sustainable clothing are also environmentally aware and concerned (Barber et al., 2009; Chan, 2001; Flamm, 2009; Kim & Damhorst, 1998). The results of the questionnaire show that not all Indonesians are well-versed in the long-term environmental impact of the clothes they buy. The items used in this study had previously been tested for validity by several experts. An inverted scale was used to predict bias or the tendency of respondents to reply positively. Based on responses, the community's objective knowledge regarding sustainable clothing is still very limited and is based solely on common knowledge. However, this study finds the same results as Amar et al. (2020): knowledge has no relationship with the intention of buying green products in Indonesia. Zheng and Chi (2015) also found that environmental knowledge affected the intention to buy eco-friendly products in the United States, and it had the second smallest effect after PBC.

Hypothesis testing found that PCE is a variable that positively and significantly influences the PI of sustainable clothing in Indonesia, with a t-value of 5.47 and a completely standardised solution of 0.89. Based on these results, it can be stated that PCE has the greatest influence, even greater than the other variables. The research indicates that Indonesians do not consider the impacts of the clothing they purchase on the environment when they are offered fast-fashion clothing. When they are presented with a more sustainable option, buying becomes a significant contribution to the environment and the currently confronted societal issues. Similar findings were found in studies by Roberts (1996) and Chen and Chai (2010), which concluded that PCE is the best predictor of environmentally aware consumer behaviour. PCE significantly influences the purchasing behaviour of sustainable products. It was found that consumers buy environmentally sustainable products because they believe that their actions or efforts to purchase these products can help protect the environment.

As already stated, this paper also studies the moderating effect of PBC, EC, and SCK on the relationship between ATT and PI. It was found that PBC did not moderate the relationship between ATT and PI sustainable clothing PI. The t-value and the obtained loading factor value were negative, -0.69 and -0.075, respectively, indicating that an increase in perceived behavioural control would reduce the urge to behave positively on sustainable clothing, which would lead to a rise in product purchase intentions, although not significantly. However, the conclusion is

based on testing with the SEM method and hypothesis testing. It was found that this variable did not strengthen or weaken the relationship between ATT and PI because the t-value was smaller than 1.96. These findings contradict the findings by Kim and Chung (2011), who discovered that an increase in PBC results in a stronger positive relationship between ATT and PI.

Although EC is one of the variables with a significant effect, EC is proven to weaken the relationship between ATT and PI. This is indicated by the t-value of -0.75 and the loading factor of -0.13. The results show that in Indonesia, the greater a person's concern for the environment, the more demotivated he/she is to buy sustainable clothing, even though the attitude shown is rather positive. However, based on the results of hypothesis testing, which is not significant, it can be concluded that EC does not moderate the relationship between ATT and PI. The results are not consistent with those of earlier studies. Based on the current literature survey on research with the intention to buy green or sustainable products, no studies with similar results were found. Although the influence of EC as a mediator of the relationship between ATT and PI has not been widely studied, several studies that have been conducted have found that EC was a positive and significant mediator (e.g., Laskova in Ali & Ahmad, 2016; Han et al., 2009; Hartmann & Apaolaza-Ibáñez, 2012).

The tests also show that SCK does not moderate the relationship between ATT and PI sustainable clothing. Although positive, in contrast to the effect of the other two moderating variables, the loading value is minimal, at only 0.0079, with a t-value of 0.048. This variable does not strengthen or weaken the relationship between ATT and PI. The results do not support the research by Barber et al. (2009), Chan (2001), and Flamm (2009). They reported a significant effect of environmental knowledge on consumer attitudes towards environmentally sustainable products. They found that knowledge is one of the important variables that can moderate the relationship between attitudes and buying interests towards sustainable goods (Chan, 2001; Mostafa, 2007, 2009).

4. RESEARCH IMPLICATIONS

Based on the analysis and discussion, some suggestions and inputs can be given to sustainable clothing producers to improve their customers' purchase intentions. The results indicate an uneven distribu-

tion of products. There is still limited information and knowledge about sustainable clothing among Indonesians, as indicated by the responses that tend to be neutral on items concerning these matters. Therefore, companies must either increase their familiarity or carry out a reasonably massive amplification of sustainable clothing by increasing marketing efforts. In addition, companies should anticipate the weakness of the community's PBC as potential consumers by increasing the availability of sustainable clothing both at outlets spread across several places (mainly in strategic locations) and online, which is now increasingly in demand by the public. Selling online is recommended more because it can target a broader market at a relatively lower cost. The company should also try to reduce the perception of the high price of sustainable clothing among consumers. Sustainable clothing as a product concept is not yet widely known due to its limited availability, and it is still considered a premium item, which causes a high price perception. Easy accessibility and perceived low prices (higher PBC) can increase the perceived ability of consumers to buy sustainable clothing.

In addition, companies need to increase public knowledge regarding the impact of sustainable clothing. Accurate information on how these products can help conserve the environment versus fast-fashion clothing should be stated on labels and commercials. Even though improved awareness of sustainable clothing has no significant effect on purchase intention, companies must educate potential consumers about the environmental benefits of sustainable clothing, as this gives the company a competitive advantage over its competitors. Companies can also work with other groups to spread the campaign on the importance of sustainable clothing for the environment.

Although not significant, EC showed a considerable influence on the PI of sustainable clothing in Indonesia. The high awareness of Indonesians towards the environment is not accompanied by an understanding of the impact of sustainable clothing. In addition, although this study did not find a significant effect between ATT and PI, other studies have shown that positive consumer attitudes increase purchase intentions. With this in mind, companies are encouraged to develop marketing strategies that promote positive attitudes, such as the physiological, psychological, and environmental impacts that can be felt when wearing sustainable clothing.

This study confirmed that PCE has an exceptionally significant effect on the purchase intention of sustainable clothing, which shows the importance of emphasising the positive impact that can be felt. Therefore, companies should put more effort into convincing consumers that switching to these products will support the preservation of the environment and benefit humanity. One strategy to increase consumer confidence is to offer transparent product details, including explaining how the product is made, the used materials, and how the manufacturing process has no negative impact on the natural environment (Zheng & Chi, 2015, p. 8).

Besides PCE, one variable that has a significant influence is the Subjective Norm (SN). Through this research, the purchase intention of sustainable clothing in Indonesia is influenced by the social pressure of potential consumers from individuals they consider essential (i.e., family, friends, and influential people) and their willingness to comply with these pressures. Suppose the group buys this product and refers it to their closest people. In that case, more social anxiety will be created, thereby increasing the purchase intention of the referred individual. Information through word of mouth or word-of-mouth communication (WOM), especially from the group in question, plays a vital role in attracting potential consumers in this era of mass communication. WOM is closely related to the consumer experience of a product or service. Consumers who have good experiences with products naturally tend to put the product (quality, brand, and value) on the conversation agenda. In addition, WOM from trusted sources has been proven to help shape the expectations of potential consumers before they purchase so that it can effectively attract new customers (Heskett et al. in Gremler & Brown, 1999). Improving quality, availability, the perception of value for money, the perception of the impact, and the promotion of these aspects will spur WOM communication, forming stronger subjective norms so that the purchase intention of sustainable clothing in Indonesia will increase.

It should be noted that this research only provides a reference for related parties in its development, both academically and managerially. In addition to the urgency of the transition from fast fashion to sustainable clothing, in recent years, issues related to the environment and social equality for the clothing industry, and sustainable clothing as a form of its manifestation, have received considerable attention with a significant increase. Research exploration on this topic can provide a better reference for developing sustainable clothing in Indonesia so that it does not lag behind other countries.

CONCLUSIONS

PCE and SN positively and significantly affect the PI of Indonesian consumers towards sustainable clothing. On the contrary, other variables used in this research (ATT, PBC, EC, and SCK) do not have a significant effect on PI. In addition, neither PBC, EC nor SCK moderate the relationship between ATT and PI sustainable clothing in Indonesia. The Past Behaviour (PB) variable was not included in the model because it failed to meet the validity test requirements of the preliminary study.

The study suggests that Indonesians' purchase intention for sustainable clothing is primarily driven by the influence of people who are considered essential and themselves. Hence, sustainable clothing retailers might consider carrying out efforts, such as collaborating with community organisations that have the same goal in campaigning for the importance of switching to eco-friendly clothing and intensifying campaigns that emphasise the role of environmentally friendly clothing in helping to preserve the environment and psychological impacts that can be felt. Additional efforts to improve quality, availability, perceptions of value-for-money and perceptions of the effects and promotion of these aspects will promote WOM communication, which will form stronger subjective norms so that purchase intentions for sustainable clothing in Indonesia will increase in the hope of increasing the actual product sales.

Future researchers may develop the research by performing the same study by targeting more specific samples and research objects or conducting research with larger samples using a cluster sampling technique in each region of Indonesia so that more representative results are obtained. Furthermore, this research is only limited to finding how much influence the variables have on the purchase intention for sustainable clothes and not the actual purchase. Future research can explore the effect of using other variables by implicating socio-demographic factors into the model and other factors that might affect the purchase intention of sustainable clothing or directly on the actual purchase.

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Appendix

Questionnaire constructs

LATENT VARIABLE	INDICATOR/MANIFEST VARIABLE		SOURCE
Attitude towards intention (ξ_1)	Likert scale (7-point): 1 = strongly disagree; 7 = strongly agree		Kang et al. (2013)
	Consumers' belief		
	ATT1a	I believe that sustainable clothing will be gentler and healthier for my skin	
	ATT2a	I believe that purchasing sustainable clothing will benefit the environment	
	ATT3a	I believe that purchasing sustainable clothing will provide me with pleasant feelings such as satisfaction and self-esteem for contributing to saving the environment	
	ATT4a	I believe that purchasing sustainable clothing makes me feel more comfortable because it can benefit my health	
	Likert scale (7-point): 1 = very unimportant; 7 = very important		
	Outcome evaluation		
	ATT1b	Wearing clothes that are gentler and healthier for the skin _____ to me	
	ATT2b	Preserving the environment _____ to me	
	ATT3b	Have positive feelings such as satisfaction and self-worth for contributing to environmental preservation _____ to me	
	ATT4b	Feel comfortable wearing clothes _____ to me	
Subjective norm (ξ_2)	Likert scale (7-point): 1 = very probably not; 7 = definitely		Kang et al. (2013)
	Normative belief		
	SN1a	My close friends may advise me to purchase sustainable clothing	
	SN2a	My relatives may advise me to purchase sustainable clothing	
	SN3a	My significant other may advise me to purchase sustainable clothing	
	Likert scale (7-point): 1 = very probably not; 7 = definitely		
	SN1b	If my close friends advise me to purchase sustainable clothing, I will do so	
	SN2b	If my relatives advise me to purchase sustainable clothing, I will do so	
	SN3b	If my significant other advises me to purchase sustainable clothing, I will do so	
Perceived behaviour control (ξ_3)	Likert scale (7-point): 1 = strongly disagree; 7 = strongly agree		Kang et al. (2013)
	PBC1	Sustainable clothing may be limited in design, style, and colour	
	PBC2	Sustainable clothing may be expensive	
	PBC3	Sustainable clothing may not be available in general stores	
	PBC4	Outlets selling sustainable clothing may be located a long distance away from where I live	
	PBC5	It might be difficult to determine whether an item of clothing is environmentally sustainable or not	
	PBC6	Perhaps I am unable to determine whether an item of clothing is truly sustainable, even if the label or company claims it is	

LATENT VARIABLE	INDICATOR/MANIFEST VARIABLE		SOURCE
Environmental concern (ξ_4)	Likert scale (7-point): 1 = strongly disagree; 7 = strongly agree		Paul et al. (2016)
	EC1	I am extremely concerned about the environment	
	EC2	I am willing to reduce my consumption in order to protect the environment	
	EC3	To protect the environment, major political reforms are required	
	EC4	To protect the environment, major social changes are required	
	EC5	Anti-pollution regulations must be strictly enforced	
Sustainable clothing knowledge (ξ_5)	Likert scale (7-point): 1 = strongly disagree; 7 = strongly agree		Kim & Damhorst (1998) modified on item number 3, 4 and 7
	SCK1	Chemical contaminants can be generated during the synthetic fibre manufacturing process (such as polyester and the like)	
	SCK2	Natural fibres, such as cotton, do not produce chemical contaminants during manufacturing *	
	SCK3	The staining process in textiles can contribute to air pollution	
	SCK4	Water is consumed extensively throughout the staining and finishing processes	
	SCK5	The use of large amounts of natural fibre will result in a significant reduction in energy usage*	
	SCK6	Fabrics with special characteristics can pose problems when recycled	
	SCK7	Natural fibres are typically biodegradable	
	SCK8	Fibers (such as wool and the like) cannot be recycled*	
Perceived consumer effectiveness (ξ_6)	Likert scale (7-point): 1 = strongly disagree; 7 = strongly agree		Kang et al. (2013)
	PCE1	It is worthwhile for a consumer to put forth efforts to protect the environment	
	PCE2	When I purchase a product, I tend to consider how its use will impact the environment	
	PCE3	Because every individual can have an impact on environmental issues, what I do has the potential to make a significant difference	
	PCE4	Every consumer can help the environment and society by purchasing environmentally products	
Past behaviour (ξ_7)	Ordinal (The average purchase score is then used to reflect past behaviour)		Zheng & Chi (2015)
	PB1	How much recycled clothing have you purchased in the last three months?	
	PB2	In the previous three months, how many items of natural fibre-based clothing have you purchased for yourself?	
Purchase intention (η)	Likert scale (7-point): 1 = very probably not; 7 = definitely		Kang et al. (2013)
	PI1	If I encounter a sustainable clothing product, I will buy or consider buying the product	
	PI2	If I come across a store that sells sustainable clothing, I will make a purchase	
	PI3	If I discover a sustainable clothing item that meets my needs, the probability that I will purchase it increases if the item is created from environmentally friendly materials	

*false statement