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Editorial

Transitioning to the green circular economy: The age of VUCA

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Transitioning to the green circular economy: The age of VUCA

In a world defined by environmental degradation, economic volatility, and technological disruption, the circular economy (CE) has moved from a theoretical concept to a practical imperative. This monothematic issue brings together diverse global perspectives and empirical research that demonstrate how CE serves as a strategic response to today's volatile, uncertain, complex, and ambiguous (VUCA) conditions. The research featured here confirms that circularity is no longer an optional pursuit. From hydroponic farming on Czech rooftops to green innovation in Vietnamese SMEs, CE practices are now integral to sustainable development. Jakubelskas and Skvarciany, for instance, highlight how key CE indicators, such as recycling rates and material use, positively impact the EU's Sustainable Development Goals. At the same time, Khan et al. show that leadership plays a crucial moderating role in managing climate change impacts on economies and the environment, making leadership a strategic asset in CE transitions.

Technology and behavior also emerge as critical drivers. Studies by Ali et al. and Nguyen et al. demonstrate how big data analytics and green innovation improve both environmental performance and financial outcomes. These findings point to the importance of digital infrastructure and stakeholder alignment. Behavioural studies, like those by Ubaidillah and Zulkarnain on Malaysian youth, and Hes et al. on re-use points in the Czech Republic, show how generational shifts in values and digital fluency are reshaping consumption patterns, accelerating demand for sustainable products and services.

This issue also reveals the sectoral breadth and systemic nature of CE. In fashion, Novo-Corti et al. show that ethical consumption is deeply tied to consumer identity. In the seafood industry, Fernandez-Gonzalez and team map out CE adoption using SWOT and PESTLE analyses, revealing regulatory support and innovation as key enablers. Mekic et al. explore the adoption of electric vehicles in the United Arab Emirates, finding consumer innovativeness to be a crucial predictor of sustainable mobility behaviors. Several papers further extend the CE discussion into broader socio-economic dimensions. Picatoste-Novo et al. examine how taxation and labor informality influence CE effectiveness, presenting a model where fiscal policy and formality matter. In post-Soviet economies, Khan et al. link tourism, emissions, and remittances to financial well-being and sustainability. These studies show how CE intersects with labor markets, public finance, and regional development strategies.

A few common themes stand out. Effective leadership and governance are essential across sectors. Digital transformation and robust data ecosystems are non-negotiable for scaling CE. Consumer behavior, especially among youth, is becoming a powerful force for change. And VUCA challenges require adaptive, interdisciplinary approaches that blend policy, finance, technology, and culture. Rather than prescribing a single CE model, this issue offers a dynamic roadmap grounded in evidence and relevance. It equips scholars, practitioners, and policymakers with insights for navigating sustainability transitions.

To all readers: whether you work in academia, policy, or industry, we hope this collection deepens your understanding and helps catalyze the collaborations needed to build a more circular, resilient, and inclusive future.

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Circular economy practices, green innovation and financial performance: The moderating role of big data analytics

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Abstract: *Environmental pollution and resource degradation have prompted researchers and policymakers to seek solutions. Circular economy practices (CEP) can help enterprises reduce emissions into the environment and move towards sustainable development. CEP has been studied widely in developed countries but less studied in developing countries due to the limited application of CEP in enterprises and the limitation of data. This paper aims to analyse the effect of CEP on financial performance, including revenue, profit and ROA. We also analyse the mediating role of green innovation and the moderating role of big data analytics in the relationship between CEP and financial performance. The natural resource based view (NRBV) theory is used to explain the relationship between variables and establish research hypotheses. We collected data from 413 Vietnamese manufacturing enterprises and used the regression method to test the research hypotheses. The results show that CEP positively impacts financial performance through the mediating role of green innovation. Besides, big data analytics also positively impacts the relationship between CEP and green innovation. In addition to the main results above, digital transformation positively impacts financial performance, but quality management practices do not affect financial performance. The research results are empirical evidence for enterprises considering implementing CEP to move towards sustainable development.*

Keywords: *Circular economy practices, green innovation, big data analytics, digital transformation, quality management practices, financial performance, ROA.*

JEL Classification: *O14, L15, L25, D22.*

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Introduction

The world economy is growing, and the environment is being polluted and degraded. Plastic has emerged as one of the most widely utilised materials because of its cost-effectiveness, especially in packaging. Therefore, it has become a crucial element of municipal garbage management. Annually, an estimated 19–23 million metric tonnes of improperly handled plastic garbage are dumped from terrestrial sources into aquatic bodies worldwide (Bergmann et al., 2022). In addition, air pollution caused by CO_2 emissions from industrial plants is also at an alarming level through annual statistical indicators. According to the Energy Information Administration, China, the world's largest energy consumer, emitted 9,899 megatonnes of CO_2 from fossil fuels in 2020. This figure represents 30.7% of the global CO_2 emissions for that year (Cai et al., 2023). Consequently, mitigating CO_2 emissions is crucial for advancing global objectives of low-carbon development (Shen & Zhang, 2024; Zhou et al., 2024). In short, the consequences of environmental pollution are enormous; it inhibits the development of countries. Therefore, it requires efforts to research methods to help reduce environmental pollution from researchers worldwide.

Circular economy practices (CEP) are enterprise activities aimed at recycling products at the end of their life cycle (Le et al., 2023). In addition, CEP also includes activities to reduce input resources and reuse defective materials or products (Khan & Haleem, 2021). CEP can help reduce the environmental impact of production activities and help enterprises develop sustainably (Singh & Singh, 2019). Mazzucchelli et al. (2022) investigated the impact of CEP, including waste treatment, reduction and recycling, on financial performance. The findings showed that CEP enhanced financial performance through the mediating role of brand reputation. Yu et al. (2022) found that CEP positively impacted financial performance through the mediating role of environmental and innovation performance. Besides, CEP also enhances economic and sustainable performance (Chowdhury et al., 2022).

Vietnam has established itself as the most rapidly expanding economy among emerging nations, with an average growth rate of 7% in recent years (Chowdhury et al., 2022). More and more domestic and foreign companies are investing in manufacturing goods and providing services in Vietnam to optimise their supply chains because Vietnam has cheaper labour than neighbouring China (Deshmukh, 2021). The production of goods negatively impacts the environment due to industrial waste such as plastic, liquid, and carbon emissions (Shen & Zhang, 2024). In that context, scholars and policymakers have recognised the CEP metric as a means to address the constraints of the conventional linear economic model (Chowdhury et al., 2022). During COP26, prime minister Pham Minh Chinh of Vietnam committed to achieving net zero emissions by 2050. Vietnam joined over 140 nations that have vowed net zero emissions by the middle of the century (Bui & Wang, 2024). Therefore, CEP is essential for policymakers and companies in Vietnam to help Vietnam achieve its net zero commitment by 2050. Environmental degradation is a global problem. Promoting the application of CEP in economic activities will help Vietnam reduce environmental pollution, thereby reducing pollution worldwide.

Various studies analyse the impact of CEP on financial performance to provide empirical evidence for researchers and policymakers. The results of these studies are still inconsistent. Some studies find that CEP has a positive impact on financial performance (Chen & Dagestani, 2023; Mazzucchelli et al., 2022; Yu et al., 2022), while others suggest that CEP has no impact or a nonlinear impact on financial performance (D'Angelo et al., 2023). Previous studies on the impact of CEP on financial performance have been mainly conducted in developed countries (Halog & Anieke, 2021; Sarfraz et al., 2023). There are very few studies on the impact of CEP on financial performance in developing countries because developing countries face technical barriers to applying CEP (Gedam et al., 2021). This study is one of the first attempts to analyse the impact of CEP on financial performance in a developing country. More studies in different contexts and countries help researchers and policymakers better understand the impact of CEP on financial performance.

This study has three main objectives to answer three research questions (*RQ*). The first question is (*RQ1*): *What is the impact of CEP on financial performance through the mediating role of green innovation?* The second question is (*RQ2*): *What is the moderating effect of big data analytics variables on the relationship* *between CEP and green innovation?* The third question is (*RQ3*): *How do digital transformation (DT) and quality management practices (QMP) impact financial performance?* The data are collected from Vietnamese enterprises in the manufacturing sector. We use the natural resource based view (NRBV) theory founded by Hart (1995) to propose hypotheses and explain the relationship between variables. Based on the NRBV theory, this study proposes that CEP is an organisational resource that can create a competitive advantage through green innovation. From this perspective, enterprises can enhance CEP, creating green innovation and advantages that competitors cannot imitate. From these advantages, enterprises can improve their financial performance.

From a theoretical aspect, the study contributes to explaining the impact of CEP on financial performance through the NRBV theory. This contribution once again affirms the role of CEP in creating enterprise competitive advantages, improving business operations and changing towards sustainable development. From a practical aspect, the study contributes to providing empirical evidence of the impact of CEP on financial performance in the context of a developing country. The research results will encourage Vietnamese enterprises to apply CEP in their operations and help Vietnam achieve net zero by 2050. Achieving net zero by countries will promote sustainable development worldwide. This study is structured into five parts. After introduction, part one presents main concepts such as the natural resource-based view theory, circular economy practices, green innovation, and research hypotheses. Part two presents the research methodology. Part three presents the research results, and discussion and the last part is conclusion.

1 Theoretical background

1.1 Natural resource based view theory

Hart (1995) developed the natural resource based view (NRBV) theory based on resource-based theory (RBT) by considering the environmental impacts of manufacturing enterprises and directing enterprises towards sustainable development. NRBV theory suggests that a company may implement three strategies to establish a competitive advantage by emphasising its natural resources, including pollution prevention, product stewardship, and sustainable development (Hart, 1995). Specifically, pollution prevention can be achieved through control, which involves trapping, storing, and treating emissions and effluents, and prevention. In the early stages of pollution prevention, simple changes can lead to significant emission reductions. However, as a firm improves its environmental performance, further reductions become more challenging, often requiring significant process changes or new production technology (Hart, 1995). In this stage, enterprises can apply product stewardship strategies, including stakeholder integration, to minimise product life-cycle costs and preempt competitors. Overcoming obstacles in the product stewardship stage, enterprises will move towards sustainable development.

NRBV theory is applied in many different fields, such as quality management (Nguyen et al., 2024), human resource management (Yahya et al., 2021), marketing management (Rahman et al., 2021) and circular economy practices (Coppola et al., 2023). In this study, we use NRBV theory to explain the impact of circular economy practices on green innovation. Green innovation will help businesses save costs and meet customer requirements, thereby helping businesses have better financial performance.

1.2 Definition of key concepts

Circular economy practices (CEP) are activities in which environmental concerns are integrated into enterprise operations (Khan & Haleem, 2021). CEP is a method to promote the development of economy and sustainable performance (Chau et al., 2023; Singh & Singh, 2019). In a circular economy, products and materials are reduced and reused as much as possible. Besides, waste and chemicals that pollute the environment are minimised, and products are recycled at the end of their life cycle (Kristoffersen et al., 2021). The aforementioned actions mitigate the negative environmental effects of manufacturing operations (Khan & Haleem, 2021). The integration and synchronisation of the organisational activities of marketing, sales, manufacturing, logistics, IT, finance, and customer service inside and between enterprises contribute to the improvement of corporate performance. This result is achieved by terminating material and energy loops, minimising input resources and waste, and emission leakage out of the system (Del Giudice et al., 2021). For the given situation, CEP allows business actions that are good for the economy, society, and the environment in many ways (Farrukh & Sajjad, 2024; Le et al., 2023; Noja et al., 2024).

Green innovation includes all kinds of new ideas that help make important goods, services, or processes that hurt the environment less and use natural resources more efficiently (Leal-Millán et al., 2017; Takalo & Tooranloo, 2021). Today, this form of innovation plays a critical role by focusing on effectively utilising natural resources to enhance the enterprise's operation. Furthermore, green innovation may facilitate sustainable development (Leal-Millán et al., 2017; Takalo & Tooranloo, 2021).

Green innovation combines innovations that reduce the environmental impact of operations by utilising enhanced technologies, systems, and management practices (Singh et al., 2020). Green innovation is distinguished from conventional technological innovation by its emphasis on facilitating the reduction of environmental effects (Singh et al., 2020). Green innovation also focuses on creating environmentally friendly products and processes by adopting eco-design principles, using fewer materials, and reducing emissions and water, electricity, and other raw material consumption (Leal-Millán et al., 2017; Singh et al., 2020). In this study, green innovation is employed by constructing green technology, processes, and products.

According to Dang and Hieu (2024), performance is measured by three indicators. The first is financial performance measured by profit, return on assets (ROS), or return on investment (ROI). The second indicator is market performance, measured by market share and revenue. The third indicator is shareholder returns, measured by shareholder returns or the enterprise's added value. Various factors influence an enterprise's financial performance. Dang and Hieu (2024) analysed the factors that influence financial performance. The results showed that government support, innovation, quality management practices, and enterprise characteristics impact financial performance. Yu et al. (2022) found that CEP positively impacted financial performance through the mediating role of environmental and innovation performance. Zhai et al. (2022) investigated the effect of digital transformation on firm performance using data from Chinese enterprises. They found that digital transformation positively impacts enterprise performance. When enterprises implement digital transformation, they have lower costs, better efficiency in operation, and better innovation. These results lead to better performance. In addition, quality management is also a factor that affects financial performance. Parvadavardini et al. (2016) collected data from 152 Indian manufacturing enterprises to investigate the impact of QMP and quality performance on financial performance. The result shows that QMP and quality performance positively impact financial performance.

1.3 Research model and hypotheses

According to NRBV, companies can implement CEPs as a strategy to gain a competitive advantage, either by preventing pollution through the use of recycled materials or by establishing policies and practices for the timely disposal of machinery and equipment. However, in the long run, this will lead to significant changes in processes or new production technology (Hart, 1995). Moreover, firms can engage in product stewardship by discontinuing environmentally harmful operations, revamping current product systems to minimise liability, and creating new products with reduced life-cycle costs (Hart, 1995). Consequently, NRBV supposes that when companies implement CEPs, they will generate new products with reduced life-cycle costs by considering the potential for product reuse after they have fulfilled their initial purpose during the design phase. This approach fosters green innovation. The relationship between CEP and green innovation is emphasised in the previous studies (Le et al., 2023; Schultz & Reinhardt, 2022). As a result, the authors propose that the implementation of CEPs has an impact on green innovation, including green process, technology, and product innovation.

H1: Circular economy practices positively impact on green innovation.

BDA is crucial in promoting circular economy strategies and improving CEP through green practices (Gupta & George, 2016; Jeble et al., 2018; Kumar & Chakraborty, 2022). The study by Kamble et al. (2021) emphasised that BDA practices improve CEP and green practices. Implementing BDA within the organisation will enable managers to promptly and accurately determine the implementation of CEPs, thereby enhancing GI within the organisation. Khan et al. (2024) concluded that BDA moderates the effect of green practices on green innovation. Thus, the research proposes the hypothesis that BDA moderates the relationship between CEP and GI in manufacturing enterprises.

H2: Big data analytics moderately impact the relationship between CEP and GI.

According to NRBV theory, product stewardship strategy suggests focusing on Environment-friendly materials and designing more optimal production cycles. These activities can reduce production costs and increase firm performance (Pan et al., 2024). Green innovation is the process of creating environmentally friendly products and processes by implementing organisational practices, such as using fewer materials when designing products, using eco-design principles and reducing emissions. This approach also aims to reduce the consumption of water, electricity, and other raw materials, increasing financial performance, including revenue, profit, and ROA. Numerous previous researches have indicated that organisations prioritise green innovation exhibit superior overall performance compared to their competitors. This result is because they utilise their green resources and capabilities to promptly and effectively address consumer requirements (Albort-Morant et al., 2016; Leal-Millán et al., 2017). Green innovation enhances corporate image, identifying new market opportunities and boosting success. Key outcomes include environmental performance, financial performance, competitive advantages, green image, and customer loyalty. Practical green innovations increase efficiency, core competencies, and superior performance (Afum et al., 2021; Asadi et al., 2020; Leal-Millán et al., 2017; Rezende et al., 2019). Therefore, the authors suggested that green innovation drives financial performance in manufacturing enterprises.

H3: Green innovation positively impact on financial performance.

The sustainable development strategy in NRBV theory focuses on the combination of stakeholders, especially technological cooperation, to simultaneously meet economic development and environmental protection requirements (Hart, 1995). According to Chen et al. (2015), digital transformation may boost the company's potential internal resources, acquire new external resources, and coordinate and integrate all internal and external resources to promote dynamic capabilities. With the expansion of digital transformation, enterprises can respond to the rising needs of consumers and the market, gaining competitive advantages and achieving excellent economic performance (Li, 2022). Digital transformation helps enterprises to increase process efficiency and better manage resources. Hence, digital transformation can improve economic performance (Masoud & Basahel, 2023). Recently, Li (2022) also demonstrated that digital transformation enhances economic performance by analysing survey data from 223 Chinese businesses. However, the majority of investigations were conducted in industrialised nations. Consequently, investigating the link between DT and financial performance in emerging economies is still being explored. In this study, the author proposes that digital transformation positively affects financial performance.

H4: Digital transformation positively impact on financial performance.

Quality management practices (QMP) are a widely used management approach in numerous countries that assists enterprises in achieving effective performance (Nguyen et al., 2024; Sila, 2020). Companies applying QMP must standardise their processes and continuously improve quality. Quality improvement can incorporate pollution prevention, product stewardship, and sustainable development strategies from NRBV theory to reduce product defects, reduce costs, and increase performance (Nguyen et al., 2024). Some studies indicated that QMP positively affected performance (Nguyen et al., 2021; Sila, 2020). In addition, some papers, including (Ochieng et al., 2015) and Liu et al. (2021), have reported conflicting results. These papers suggest that QM has a positive impact on ROA, but it does not have an impact on profit and revenue. In contrast, a few researchers concluded that non-certified companies showed higher financial performance (Nair & Prajogo, 2009). Some authors discovered no correlation between financial performance and QMP (Kafel & Sikora, 2014). Conversely, few researchers concluded that non-certified companies exhibited superior financial performance (Nair & Prajogo, 2009). In this study, the author continues exploring the correlation between QMPs and financial performance in the context of companies undergoing digital transformation and CEPs.

H5: Quality management practices positively impact on financial performance.

Enterprise characteristics are also one of the factors that affect financial performance. Previous studies confirmed that enterprise characteristics impact performance (Lin et al., 2019; Xia & Walker, 2015). Xia and Walker (2015) concluded that firm types positively impacted enterprise performance. Lin et al. (2019) confirmed that firm size significantly impacted financial performance. In this study, we propose firm type and firm size as control variables that affect financial performance. We propose the research model from the above hypotheses and arguments, as shown in Fig. 1.

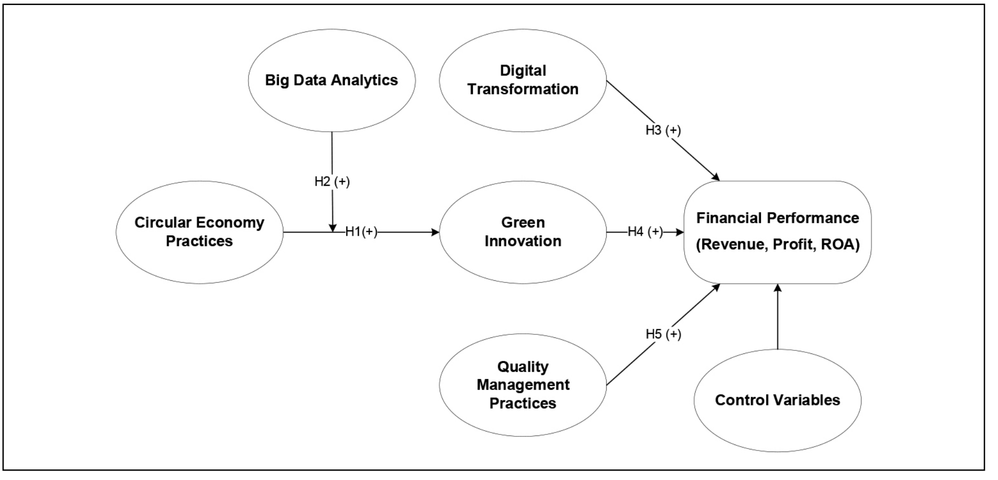

Fig. 1: Research model

Source: own

2 Research methodology and scales

This study uses quantitative methods to analyse data, such as descriptive statistics, correlation analysis and regression analysis. We use the ordinary least square (OLS) method to test the research hypotheses. According to Tabachnick and Fidell (2013), OLS regression provides the best estimates when seven OLS assumptions are met. These assumptions are linearity in its error term and coefficients, the mean of the error term is zero, no correlations between the error term and the independent variables, no serial correlation, constant error term's variance, no multicollinearity and normal distribution of residual. First, we test hypotheses *H1* and *H2* through Equation (1). In Equation (1), green innovation (GI) is the dependent variable, circular economy practice (CEP) is the independent variable, and big data analytics (BDA) is the moderate variable. The results of the hypothesis testing will be evaluated through the significance level of the coefficients β_1 and β_2. The coefficient of *CEP * BDA* evaluates the moderate effect of *BDA* on the relationship between *CEP* and innovation. The letter *i* represents observations with values from 1 to *n*, and α is a constant in the regression equation. Finally, ε represents the error term of the regression result.

$$INNO_i = \alpha + \beta_1 * CEP_i + \beta_2 * CEP * * BDA_i + \varepsilon_i \quad (1)$$

Next, we test hypotheses *H3*, *H4*, and *H5* through regression Equations (2–3). In Equations (2–3), Y_i is the dependent variable measured through three parameters: revenue, profit, and ROA. The independent variables include digital transformation (*DT*), green innovation (*GI*), and quality management practice (*QMP*). *CONTROL* represents the control variables, including firm size and firm type. The coefficients λ, θ, γ, and δ are the regression coefficients. The letters μ and ν represent the residuals of the regression equation. Equations (2–3) are presented in detail as follows.

$$Y_i = \lambda + \theta_1 * DT_i + \theta_2 * INNO_i + \\ + \theta_3 * QMP_i + \mu_i \qquad (2)$$

$$Y_i = \gamma + \delta_1 * DT_i + \delta_2 * INNO_i + \\ + \delta_3 * QMP_i + \delta_4 * CONTROL_i + \nu_i \qquad (3)$$

In Equations (2–3), CEP and DT are measured by the Likert scale. The CEP construct is inherited from the study of Chowdhury et al. (2022) and includes four indicators as follows: "i) we work with clients/suppliers for ecological design of products/services; ii) during the design stage, we consider the possibility to reuse products after they have served their initial purpose; iii) we are using recycled materials as inputs in our processes; and iv) we have policies and practices in place to dispose of machinery and equipment on time." The DT construct is inherited from the study of Kuo et al. (2022) includes three indicators as following: "i) our company invests in digital infrastructure and facilities for digital operation; ii) our company adopts digital technology applications for digital operations; and iii) our company empowers talented personnel and organisations to achieve digital operation." Details on the definitions of variables and their measurement are presented in Tab. 1.

Tab. 1: Definition of variables in the research model

Variables	Labels	Definition
Revenue	*REV*	Revenue at the end of 2023 (billion VNDs)
Profit	*PRF*	After-tax earning in 2023 (billion VNDs)
Return on asset	*ROA*	EBIT/total asset in 2023 (%)
Digital transformation	*DT*	Likert scale from Kuo et al. (2022)
Green innovation	*GI*	Dummy variable, equals 1 if the enterprise had one of the following activities in 2023 (using cleaner technology to prevent pollution, using eco-labelling, using new technology to minimise energy consumption, reducing, reusing and recycling material); otherwise it equals 0
Quality management practice	*QMP*	Dummy variable, equals 1 if the enterprise used advanced quality management systems or obtained quality management system certificates (ISO 9001, 14001, HACCP); otherwise it equals 0
Circular economy practice	*CEP*	Likert scale from Chowdhury (2022)
Big data analytic	*BDA*	Dummy variable, equals 1 if the enterprise applies big data analytics in operations; otherwise it equals 0
Firm size	*SIZE*	Number of staff at the end of 2023
Firm Type 1	*TYPE1*	Equals 1 if the enterprise is in the food and beverage industry; otherwise it equals 0.
Firm Type 2	*TYPE2*	Equals 1 if the enterprise is in the rubber and plastic industry; otherwise it equals 0
Firm Type 3	*TYPE3*	Equals 1 if the enterprise is in the mechanical engineering and automation industry; otherwise it equals 0
Firm Type 4	*TYPE4*	Equals 1 if the enterprise is in the information technology, electronics, and telecommunications industry; otherwise it equals 0

Source: own

After proposing the research hypotheses, we designed a preliminary questionnaire based on previous studies on circular economy practice and on factors affecting financial performance of enterprises. The preliminary questionnaire will be revised by group discussions with experts, including circular economy practice researchers (three members) and company leaders (three members, including managers and supervisor) involved in quality management, innovation and digital transformation activities. After receiving comments from the experts, we revised the questionnaire and proposed the final questionnaire for the survey.

We collected data by interviewing the leaders of enterprises in the manufacturing sector based on the final questionnaire. We used the snowball sampling technique. First, we contacted our friends and alumni working in manufacturing enterprises to schedule an interview. After completing the survey by interviewing, we ask the respondents to introduce us to other companies in the manufacturing sector that they know so that we can continue to conduct the survey. After we have more information about other enterprises, we will contact them and schedule the subsequent interviews. After five months of data collection, we collected data from 413 enterprises, including 55 enterprises in the food and beverage industry, 102 enterprises in the rubber and plastic industry, 154 enterprises in the mechanical engineering and automation industry, 18 enterprises in the information technology, electronics, and telecommunications industry, and 84 enterprises in other manufacturing sectors.

3 Results and discussion

3.1 Descriptive statistics

First, we analysed descriptive statistics to see the distribution of the variables. Tab. 2 presents details of the results. Among the 413 surveyed enterprises, the average revenue is VND 804 billion (equivalent to USD 32.3 million), the maximum revenue is VND 91.536 billion, and the minimum revenue is VND 0.1 billion. Enterprises have an average profit of VND 73.7 billion (equivalent to USD 2.96 million) and an average ROA of 6.2%. Current enterprises have low ROA because enterprises are still affected by the post-COVID-19 and the negative impact of wars in Europe and the Middle East.

For the independent variables, digital transformation (DT) and circular economic practice (CEP) were measured by a Likert scale with mean values of 3.572 and 3.630, respectively. This result shows that manufacturing enterprises have invested in digital transformation

Tab. 2: Descriptive statistics

Variables	Mean	Maximum	Minimum	Std. dev.	Observations
REV	804.899	91,536.000	0.100	7,112.004	413
PRF	73.672	10,426.790	−6.811	715.006	413
ROA	0.062	11.332	−1.036	0.562	413
DT	3.572	5.000	1.000	0.955	413
GI	0.240	1.000	0.000	0.427	413
QMP	0.453	1.000	0.000	0.498	413
CEP	3.630	5.000	1.250	0.908	413
BDA	0.206	1.000	0.000	0.405	413
SIZE	66.533	880.000	3.000	73.839	413
TYPE1	0.133	1.000	0.000	0.340	413
TYPE2	0.247	1.000	0.000	0.432	413
TYPE3	0.373	1.000	0.000	0.484	413
TYPE4	0.044	1.000	0.000	0.204	413

Source: own

and circular economic practice. Cronbach's alpha analysis was used to assess the reliability of these two variables. The analysis results in Tab. 3 show that Cronbach's alpha of CEP and DT are 0.839 and 0.825, respectively. These values are all greater than 0.7, so the scale meets the reliability requirement (Hair et al., 2019).

With green innovation activities, 24% of enterprises invested in these activities in 2023, such as using cleaner technology to prevent pollution, using eco-labelling, using new technology to minimise energy consumption, and reducing, reusing and recycling material. This rate is low because green innovation activities always require a significant financial investment. Currently, enterprises in the manufacturing sector in Vietnam still face difficulties due to a lack of orders, so there is not much financial investment in innovation activities.

Tab. 3: Reliability analysis of CEP and DT variables

Variables	Indicator	Mean	*N*	Item (total correlation)	Cronbach's alpha (if item deleted)	Cronbach's alpha
Circular economy practice	*CEP1*	3.683	413	0.687	0.790	0.839
	CEP2	3.588	413	0.639	0.811	
	CEP3	3.661	413	0.689	0.789	
	CEP4	3.588	413	0.675	0.795	
Digital transformation	*DT1*	3.598	413	0.667	0.774	0.825
	DT2	3.569	413	0.663	0.777	
	DT3	3.550	413	0.715	0.725	

Source: own

For the quality management practice (QMP) variable, 45.3% of enterprises applied advanced quality management systems or obtained quality management system certificates (ISO 9001, 14001, HACCP). This rate is relatively high because manufacturing enterprises are always concerned about quality management, which contributes to the enterprises' competitiveness. The certificates will help the enterprises meet the customers' requirements. 20.6% of enterprises apply big data analytics in their operations. This rate is still relatively low because big data analytics is a new technology. In Vietnam, manufacturing enterprises lack expertise in big data analytics. Besides, enterprises have not seen the benefits of big data analytics, so they have not applied it to their operations.

For the firm size, each firm had an average of 67 employees. The largest firm had 880 employees, and the smallest had three employees. Finally, for firm types, enterprises in the food and beverage industry accounted for 13.3%, in the rubber and plastic industry accounted for 24.7%, in the mechanical engineering and automation industry accounted for 37.3%, in the information technology, electronics, and telecommunications industry accounted for 4.4%, and in other manufacturing sectors accounted for 20.3%.

3.2 Correlation and regression results

Before regression analysis, we analysed the correlation between variables in the research model to see the relationship between variables (Tab. 4). Correlation analysis helps avoid the phenomenon of multicollinearity when highly correlated variables are entered into the model at the same time (Nguyen & Nguyen, 2020). In regression Equation (1), the correlation coefficient of CEP and BDA is 0.3066. In Equations (2–3), the correlation coefficient between the three independent variables DT, GI, and QMP has values from 0.2071 to 0.3671. The correlation coefficients between independent variables are all less than 50%, so there is a weak correlation between independent variables. In other words, the possibility of a multicollinearity phenomenon in the regression equation is not high.

Tab. 4: Correlation analysis

Variables	*REV*	*PRF*	*ROA*	*DT*	*GI*	*QMP*	*CEP*	*BDA*
REV	1.0000							
PRF	0.8826	1.0000						
ROA	0.0325	0.0239	1.0000					
DT	0.1391	0.1389	0.0866	1.0000				
GI	0.1793	0.1775	0.1200	0.2459	1.0000			
QMP	0.0755	0.0354	0.0702	0.3671	0.2071	1.0000		
CEP	0.0921	0.0783	0.0755	0.6611	0.3743	0.4875	1.0000	
BDA	0.1953	0.1951	0.1240	0.1970	0.9066	0.2107	0.3066	1.0000

Source: own

We test the first and second hypotheses using regression Equation (1) with the dependent variable green Innovation (GI). The results in Tab. 5 show that the variable circular economy practice (CEP) positively impacts GI at a significance level of 5%. The regression coefficient corresponding to the variable BDA * CEP shows the moderate effect of the variable big data analysis (BDA) on the relationship between CEP and GI. The results show that BDA positively impacts the relationship between CEP and GI at a significance level of 1%. In addition, the VIF coefficients of a regression Equation (1) are all less than 2, and the White (1980) test for heteroscedasticity has a significance level greater than 5%. This result proves that regression Equation (1) does not have multicollinearity and heteroscedasticity.

Next, we conduct regression analysis using Equations (2–3), with the dependent variable being financial performance represented by three variables: revenue, profit and ROA. Equation (2) analyses the impact of independent variables on the dependent variable, while Equation (3) adds control variables (firm size, firm type). The results in Tab. 6 show that GI positively impacts financial performance in all regression equations, with a significance level of 1% to 5%. The variable digital transformation (DT) only positively impacts revenue and profit but does not affect ROA. The variable QMP does not affect the dependent variable in all regression equations. For the control variables, firm size impacts revenue and profit but does not affect ROA. The variable TYPE4 has an impact on revenue and costs, while the variables TYPE1, TYPE2 and TYPE3 have an impact on ROA.

To ensure the reliability of the regression equations, we estimated the variance inflation factor (VIF). The results showed that all VIF coefficients in Equations (2–3) were less than 2.

Tab. 5: Regression analysis with green innovation as dependent variable

Variable	Coefficient	Std. error	*T*-stat.	Prob.	VIF
Constant	−0.0309	0.0409	–0.7547	0.4509	
CEP	0.0234	0.0114	2.0533	0.0407	1.1614
BDA * CEP	0.2159	0.0060	35.9441	0.0000	1.1614
***R*-squared**	0.7929				
***F*-statistic**	784.6578				
Prob. (*F*)	0.0000				

Source: own

This result proves that the regression equations do not have multicollinearity. In addition, we also performed the White (1980) test for the regression equations. The analysis results showed that the significance level of the heteroskedasticity tests was all greater than 5%. This result proves that the regression Equations (2–3) do not have heteroskedasticity.

Tab. 6: Regression analysis with revenue, profit and ROA as dependent variable

Independent variables	Revenue		Profit		ROA	
	Equation (2)	Equation (3)	Equation (2)	Equation (3)	Equation (2)	Equation (3)
Constant	−2,479.8090	−3,452.5540	−270.3950	−334.1150	−0.0920	0.0121
DT	734.6030*	677.8280*	85.7970**	78.3770**	0.0297	0.0376
GI	2,553.7300***	2,290.9900***	263.3300***	236.6820***	0.1330**	0.1406**
QMP	107.2160	−140.5900	−56.3740	−85.5730	0.0346	0.0533
SIZE		15.3680***		0.9990**		−0.0003
TYPE1		517.4290		160.1300		−0.2148**
TYPE2		−149.0000		16.3800		−0.1627*
TYPE3		−47.6400		−1.1810		−0.1311*
TYPE4		7,202.2100***		422.4870**		−0.1649
Observations	413	413	413	413	413	413
R^2	0.0420	0.1200	0.0430	0.0750	0.0280	0.0440
***F*-statistics**	5.9490	6.8940	6.0450	4.0650	2.7930	2.8150
Prob. (*F*-stat)	0.0000	0.0000	0.0000	0.0000	0.0450	0.0410

Note: *** 1% significance; ** 5% significance; * 10% significance.

Source: own

3.3 Discussions

The regression results in Tab. 5 show that the circular economy practices (CEP) positively impact green innovation (GI). This evidence supports hypothesis *H1*. This result is consistent with the NRBV theory of Hart (1995). Adopting CEP drives GI by directing the enterprise resources, management systems, and the involvement of stakeholders toward CEP. This finding corroborates the earlier authors' contention that CEP supplies an essential environmentally friendly basis for fostering green innovations by converting the conventional linear paradigm into a sustainable development paradigm (Le et al., 2023). Furthermore, this finding supports the assertion by Schultz and Reinhardt (2022) that resources, management systems, and knowledge play a crucial role in promoting GI. Next, the regression results show that BDA positively impacts the relationship between CEP and GI. The current outcomes indicate that for enterprises applying BDA, the impact of CEP on GI will be greater than when enterprises do not apply BDA. This result supports the hypothesis *H2*. Prior studies have also identified a positive effect of BDA on green innovation (Khan et al., 2024; Le et al., 2023; Schultz & Reinhardt, 2022).

The results in Tab. 6 show that GI positively impacts financial performance, including revenue, profit and ROA, with a significance of 1% to 5%. This result supports hypothesis *H3*. The impact of green innovation on financial performance has been confirmed by previous researches (Afum et al., 2021; Asadi et al., 2020; Leal-Millán et al., 2017). Therefore, enterprises with green innovation can improve their financial performance by managing operational costs and satisfying customers and suppliers (Rezende et al., 2019). People saw the benefits of green innovation in the form of better financial performance. This result included lower costs for materials and energy use, lower costs for getting rid of trash, and lower fines for environmental problems.

The variable digital transformation (DT) positively impacts financial performance, including revenue and profit. This finding is consistent with previous studies examining the effect of digital transformation on financial performance (Masoud & Basahel, 2023). In contrast to the above results, DT does not affect ROA. This result can be explained by the fact that enterprises spend much money to invest in assets when implementing digital transformation. Therefore, the ROA results of enterprises implementing digital transformation are not high. Besides, Li (2022) argued that the digital transformation process should be comprehensive, as organisations must assess their level of digital maturity and consider various influencing elements, including organisational culture, management team and employee preparedness, business quality processes, and IT department preparedness. In this context, it is important to note that digital transformation does not provide immediate growth in a company's profits. Specifically, during the early phase of digital transformation, enhancing a company's economic performance is expected to be limited.

Quality management practices (QMP) do not affect financial performance. This result is in contrast to the research results of Sila (2020) and Nguyen et al. (2021) but similar to the research results of Ochieng et al. (2015). Liu et al. (2021) suggested that QMP only affects financial performance in the short term. In the long term, the positive impact of QMP on financial performance will disappear one to two years after achieving quality awards or quality certification. For the control variables, firm size impacts revenue and profit but does not affect ROA. This result is explained by the fact that the larger the company and the more employees, the more revenue and profit the enterprise has. In addition, firm type has a positive effect on ROA. Enterprises in the information technology, electronics, and telecommunications industry (Type 4) have higher revenue and profit results than other enterprises. Enterprises in the food and beverage industry (Type 1), rubber and plastic industry (Type 2), mechanical engineering and automation industry (Type 3) have higher ROA results than other enterprises. This result is similar to the research results of Xia and Walker (2014) and Lin et al. (2019). Different types of enterprises have different competitive advantages and produce different products, so different types of enterprises will have different financial performance.

Conclusions

This study aims to examine the influence of circular economy practices (CEP) on financial performance, specifically on attaining sustainable development goals. Specifically, it focuses on the responsible use of resources and mitigating environmental and societal consequences of enterprise manufacturing. These efforts align with the Vietnamese government's objectives to achieve net zero carbon emissions by 2050. Using surveyed data from 413 enterprises in the manufacturing sector, we empirically tested the impact of CEP on financial performance, including revenue, profit, and ROA and obtained the following findings. First, CEP positively impacts green Innovation (GI). Second, big data analytics (BDA) moderately impacts the relationship between CEP and GI. Third, GI positively enhances financial performance including revenue, profit and ROA. Fourth, digital transformation (DT) positively enhances financial performance, including revenue and profit. In summary, this study uncovers how CEP, BDA, and DT improve financial performance in the manufacturing sector.

Based on the study results, enterprises should have business strategies in adopting circular economy practices to achieve the Vietnamese government's sustainability goals, especially in promoting digital transformation activities. Enterprises should invest in BDA to promote green innovation. Besides, policymakers should enforce waste management laws and strengthen existing policies, with stricter enforcement of recycling and waste segregation. The state should impose high taxes on materials that are difficult to recycle or cannot be recycled. In addition, the state should also provide low-interest loans or grants for startups and companies investing in circular technologies. In addition, the state can also invest in education and conduct public education campaigns to increase awareness about the benefits of recycling and sustainable consumption.

Nevertheless, this study is subject to its limitations. Firstly, this study uses the snowball sampling method, which may have potential biases, such as the presentation of certain firm types or industries. Future research can try another sampling method to minimise the biases in the data collection. Secondly, the suggested model was first assessed using cross-sectional data, and future examinations may include longitudinal data. Primary data sources such as company annual reports, the General Statistics Office database, the Vietnam Stock Market database, and other relevant sources may be utilised to analyse the causal connection between corporate environmental success and financial success. Thirdly, this study only examined the role of CEP in the Vietnamese manufacturing industry, thereby lacking a certain degree of generality. Further enquiries can be conducted in comparable economies such as Germany, China, Japan, the United States, and others. Finally, contextual factors may alter the impact of CEP on financial performance. Prospective future research should concentrate on analysing the impact of moderating variables, such as corporate strategy, institutional environment, market risk, and atypical occurrences, on the adoption of circular economy practices.

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Evaluation of circular economy indicators seeking sustainable development goals

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Abstract: *To tackle climate change, resource scarcity, and environmental degradation, the circular economy (CE) is gaining popularity as a key tool for promoting sustainability by harmonising societal, economic, and environmental needs and contributing to global sustainable development goals. This research aims at determining which circular economy indicators most significantly impact the sustainable development goals (SDGs) in European Union (EU) countries. Panel regression analysis was used to determine which circular economy indicators most significantly impact the Sustainable development goals index across the EU countries. In this study, five separate panel regression models were developed, each representing a pillar of the European Union's CE framework: production and consumption, waste management, secondary raw materials, competitiveness and innovation, global sustainability and resilience. Based on the results, CE indicators have varying effects: material and consumption footprint, generation of municipal and packaging waste per capita, the recycling rate of municipal waste, circular material use rate, trade in recyclable raw materials as well as persons employed in the circular economy sector and material import dependency are associated with the improvement of the SDG index, while recycling rate of WEEE (waste of electrical and electronic equipment) and greenhouse gas emissions are associated with the decrease of the SDG index. These outcomes are often linked to economic growth and the expansion of green technologies, which are essential for a more sustainable future. This research explains the linkage between the circular economy and its contribution to achieving the SDGs in EU countries. It enables policymakers, businesses, and other stakeholders to recognise the significance of CE practices in attaining sustainable development. The research outcomes can guide the development of CE policies, prioritising impactful areas for countries dedicated to achieving sustainable development through CE practices.*

Keywords: *Climate change mitigation, resource productivity, recycling, circular material use, sustainable development policies.*

JEL Classification: *Q00, Q01, Q56.*

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Introduction

To address climate change, environmental degradation, and the scarcity of natural resources while guaranteeing a high quality of life for current and future generations, individuals, companies, and nations must seek alternative production and consumption methods to balance society, the economy, and the environment (Kristensen & Mosgaard, 2020). For that reason, the circular economy is presented as an alternative to an unsustainable linear economy. As stated by Fořt and Černý (2020), a circular economy could help solve sustainability issues and minimise resource intake (Alhawari et al., 2021). Although some criticism regarding the linkage between circular economy and sustainable development exists, according to Merli et al. (2018), De Oliveira and Oliveira (2023), and Korhonen et al. (2018), circular economy contributes to SDG. Although circular economy and sustainable development are gaining popularity among researchers, the role of circular economy practices in achieving sustainable development is fragmented. The gap in research highlights the need for a more comprehensive analysis to understand how circular economy practices can be effectively integrated and what specific benefits they bring to sustainable development. As specified by Rosa et al. (2023), the circular economy fosters a symbiosis of sustainable practices, innovation, and economic capabilities, essential for cleaner production and waste reduction.

Despite its importance, the integration and impact of circular economy practices in sustainable development, as mentioned above, are still not thoroughly examined, as most research focuses on the relationship between circular economy practices and specific SDGs. Schroeder et al. (2019) state that circular economy practices directly contribute to achieving several sustainable development goals, including SDG 6 (clean water and sanitation), SDG 7 (affordable and clean energy), SDG 8 (decent work and economic growth), SDG 12 (responsible consumption and production), and SDG 15 (life on land). Dantas et al. (2021) research showed that circular economy and Industry 4.0 directly benefit SDG 7 (affordable and clean energy), SDG 8 (decent work and economic growth), SDG 9 (industry, innovation and infrastructure), SDG 11 (sustainable cities and communities), SDG 12 (responsible consumption and production), and SDG 13 (climate action). However, there is a lack of studies focusing on the relationship and impact between a circular economy and the entire set of SDGs. Hence, the present research aims to determine which circular economy indicators most significantly impact sustainable development goals in European Union countries, emphasising the importance of circular economy practices as tools for achieving sustainable development goals. This research explores the relationship between the circular economy and its contribution to achieving sustainable development goals in European Union countries, the current research gap in understanding how circular economy practices contribute to the overall sustainability of a country, as well as fostering a deeper understanding of the circular economy concept and its relation to sustainable development. This research covers the entire set of 17 sustainable development goals, while most other studies typically explore the link between the circular economy and specific individual goals. The research also covers an extensive list of countries, providing an opportunity to gain a comprehensive view of the European Union's transformation towards a circular economy and sustainable development. The European Union is particularly significant in this context, as the EU introduced its Green deal with the ambition to become the first climate-neutral continent. This initiative aims to ensure no net emissions of greenhouse gases, attain economic growth independent of resource consumption, and guarantee that no person and no place is left behind, aligning with the vision of a sustainable future. The results of this study enable policymakers, businesses, and other stakeholders to recognise the significance of circular economy practices in attaining sustainable development, guiding the development of policies that prioritise impactful areas for countries dedicated to achieving sustainable development.

1 Theoretical background

A linear economy model, or the take-make-dispose model based on unsustainable production and consumption, is being changed to an alternative circular economy model aiming to mitigate environmental degradation, enhance social equity, and foster sustainable economic growth (Millar et al., 2019). Circular economy strives to maximise the value and utility of products, materials, and resources through distinct cycles, thereby aiming to dissociate economic growth from the consumption of finite resources (Grzymala, 2023). By promoting green innovations and applying closed production cycles, the circular economy reduces greenhouse gas emissions, slows temperature rise, and preserves the environment (Avramchikova et al., 2021). On the other hand, sustainable development encompasses the pursuit of improved quality of life for current and future generations, promoting economic growth, social stability, and environmental preservation.

There are ongoing discussions among researchers about the circular economy and its role in sustainable development. Merli et al. (2018) state that while the circular economy primarily addresses environmental and economic issues, it also supports sustainable development and contributes to achieving sustainable development goals. Korhonen et al. (2018) acknowledge that implementing circular economy principles effectively supports all dimensions of sustainable development, including social factors. According to De Oliveira and Oliveira (2023), the circular economy serves as a tool to achieve sustainable development. Khajuria et al. (2022) agree that the circular economy is vital for sustainable development, and its advantages are broadly recognised by societies, governments, and various stakeholders.

As stated by Mehta (2023), the circular economy is a significant instrument for accelerating progress toward achieving SDGs. Additionally, de Oliveira and Oliveira (2023) confirm that a relationship exists between the circular economy and sustainable development. In order to validate this, it is necessary to conduct an empirical study and select suitable indicators.

Since this study focuses on a whole set of sustainable development goals, one of the ways to evaluate progress regarding achieving these goals is the SDG index, which was selected as a dependent variable in the current research, while circular economy indicators (independent variables) were selected based on the European Union circular economy monitoring framework, which is part of the EU's strategy for sustainable development. In other words, in this research, the effect of selected circular economy indicators on sustainable development goals was evaluated.

The European Union's circular economy framework includes production and consumption, which consist of material consumption and waste generation sub-pillars. The circular economy aims to redefine the traditional linear economy by minimising waste and increasing resource efficiency. As stated by Ottelin et al. (2020), the circular economy seeks to minimise the use of raw materials by extending the lifecycle of materials in use. It is crucial to promote sustainable manufacturing. According to Nokele and Sebola-Samanyanga (2022), sustainable manufacturing can be achieved through a closed-loop 6R-based concept, which includes reducing, reusing, recovering, redesigning, remanufacturing, and recycling, representing core circular economy practices. This concept focuses on the environmental impacts of manufacturing, including energy consumption, waste generation, natural resource use, and costs. In the context of material footprint and waste generation reduction, redesign and remanufacture are the main focus of the concept. Reduce emphasises minimising resource and energy use and waste. Redesign involves creating more sustainable products, while remanufacturing restores used products to a fully functional state. For waste prevention, reuse in the 6R-based concept emphasises extending a product's life cycle by repurposing it after its initial use and using the same product or its components for subsequent lifecycles, thus reducing the demand for new raw materials (Jawahir & Bradley, 2016). If reuse and remanufacturing are no longer available, recycling comes into place. Effective waste management aims to reduce, recycle, and treat waste, transforming it into valuable resources. This approach aligns with circular economy principles by viewing waste as a resource rather than a problem. The European Union's circular economy framework includes waste management that consists of overall recycling rates as well as recycling rates for specific waste streams. As stated by Provin et al. (2021), incorporating waste from one industry into another, such as using food industry waste to produce biotextiles, promotes sustainability and supports a circular economic system. This also leads towards achieving the sustainable development goals. This could be applied to various sectors. As proposed by Schützenhofer et al. (2022), efficient construction waste management is critical for sustainable development as it helps conserve natural resources, reduce landfill usage, and lower carbon emissions, thereby contributing significantly to the goals of a circular economy.

Secondary raw materials consist of the impact of recycled materials on the demand for raw materials and the trade of recyclable raw materials. As stated by Martins and Castro (2019), the use of secondary raw materials plays a crucial role in stabilising prices, reducing market volatility, and mitigating supply chain risks. This is particularly important for economies such as the European Union, which confront challenges related to resource depletion and environmental impacts. Secondary raw materials also reduce dependency on imports, which is vital for countries with limited natural resources, ensuring resource security and leading to sustainable economic growth (Lee & Cha, 2020). Promoting secondary raw materials also contributes to achieving sustainable development.

Competitiveness and innovation encompass private investment, employment, and gross value added associated with circular economy sectors and innovative activities. The relationship between competitiveness and innovation is a two-way relationship. The linkage between competitiveness, innovation, and the circular economy involves the integration of sustainable practices to enhance business performance and societal benefits. As stated by Bucea-Manea-Țoniş et al. (2021), green R&D, clean production and innovations within a circular economy framework help boost enterprise competitiveness. Saari et al. (2022) agree that manufacturing companies that incorporate circular economy practices into their operations notice improved product or service innovativeness and competitiveness. The circular economy maximises resource value, minimises environmental impact and promotes competitive and sustainable business practices (Konietzko et al., 2020).

Global sustainability and resilience consist of global sustainability and resilience derived from the circular economy. Circular economy principles improve sustainability and ensure resilience in many ways, which were already discussed in this section. As stated by Bag et al. (2019), integrating circular economy principles into supply chains can strengthen resilience by encouraging sustainable manufacturing practices and minimising vulnerability to disruptions. By reducing dependency on raw materials, increasing efficiency, and generating new revenue streams, a circular economy enhances economic resilience, affecting global value chains and the economic system (Di Stefano et al., 2023). Global sustainability and resilience are vital to ensuring long-term environmental, social, and economic stability and achieving a sustainable and resilient future.

The literature indicates a strong connection between circular economy principles and the attainment of sustainable development goals. Based on the literature review, the following research hypothesis was developed: the implementation of circular economy principles positively contributes to achieving sustainable development goals. In order to accept or reject this hypothesis, the current research was conducted.

2 Research methodology

In order to assess the impact of selected circular economy indicators on sustainable development, which is expressed via the Sustainable development goals index (SDGI), panel regression modelling was selected. The data

Tab. 1: Selected independent variables – Part 1

Pillar	Indicator	Definition
Production and consumption	Material footprint (X_1)	Measures the total amount of raw materials extracted globally to meet the consumption demands of a country's residents
	Resource productivity (X_2)	Measures the ratio of gross domestic product (GDP) to domestic material consumption (DMC)
	Generation of municipal waste per capita (X_3)	Measures the amount of municipal waste generated annually by each person in a given population
	Generation of packaging waste per capita (X_4)	Measures the amount of packaging waste generated annually by each person in a given population
	Generation of plastic packaging waste per capita (X_5)	Measures the amount of plastic packaging waste generated annually by each person in a given population

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Tab. 1: Selected independent variables – Part 2

Pillar	Indicator	Definition
Waste management	Recycling rate of municipal waste (X_6)	Measures the percentage of municipal waste that is recycled out of the total municipal waste generated
	Recycling rate of packaging waste by type of packaging (X_7)	Measures the percentage of packaging waste recycled, categorised by different types of packaging materials such as plastic, paper, glass, and metal
	Recycling rate of waste of electrical and electronic equipment (WEEE) separately collected (X_8)	Measures the percentage of collected WEEE that is recycled out of the total amount of WEEE collected separately
Secondary raw materials	Circular material use rate (X_9)	Measures the share of material recovered and fed back into the economy, reducing the need for new material extraction
	Trade in recyclable raw materials (X_{10})	Measures the import and export flows of raw materials that can be recycled and reintroduced into the production process
Competitiveness and innovation	Private investment and gross added value related to circular economy sectors (X_{11})	Measures the financial investments and the economic value generated by sectors involved in circular economy activities, such as recycling, repair, and reuse
	Persons employed in circular economy sectors (X_{12})	Measures the number of people working in industries related to the circular economy, including recycling, repair, reuse, and other sustainable practices
Global sustainability and resilience	Consumption footprint (X_{13})	Measures the environmental impact of the consumption of goods and services by a country's residents, encompassing various factors such as resource use, emissions, and waste generated throughout the lifecycle of consumed products
	Greenhouse gases emissions from production activities (X_{14})	Measures the total amount of greenhouse gases emitted as a result of production processes within a country
	Material import dependency (X_{15})	Measures the extent to which a country's economy relies on imported raw materials to meet its material needs

Source: own (based on Eurostat (2023))

used in the research were received from the Eurostat open database. Selected independent variables are presented in Tab. 1. The dependent variable should be mentioned as SDGI.

The regression model is used on ten years' worth of panel data from 2012 to 2021 (the latest available data) for a sample of 27 EU countries. The focus on the EU countries has been selected for several reasons. The EU has established clear policies, such as the Circular economy action plan, providing a clear framework for member states, which they should follow in order to transition to the circular economy. Additionally, data from EU countries is more consistent and accessible, making it easier to compare their progress. However, the results of the research could be considered for non-EU members in order to reach progress in the circular economy context. The 10-year period was selected mainly due to the available data. However, it should be mentioned that during this time, many countries began systematically reporting circular economy indicators following the implementation of EU policies like the Circular economy package and the global adoption of the SDGs.

In order to find out the impact of the circular economy on sustainable development, five models have been developed. Before developing the models, they were tested for being fixed or random-effect. For that purpose, the Hausman test was employed. According to the results, Model 1 appeared to be random-effects, Model 2 – fixed-effects, Model 3 – random-effects, Model 4 – fixed-effects and Model 5 – fixed-effects. The developed models are presented in Tab. 2. It is worth mentioning that the data used for Model 3, Model 4 and

Tab. 2: Research models

Pillar	Definition
Production and consumption	Model 1: $SDGI_{it} = \alpha + \beta_1 X_{1it} + \beta_2 X_{2it} + \beta_3 X_{3it} + \beta_4 X_{4it} + \beta_5 X_{5it} + u_{it} + \epsilon_i$, where: α – intercept; β_1, β_2, β_3, β_4, β_5 – coefficients to be estimated for the independent variables; u_{it} – idiosyncratic error term for entity *i* at time *t*; ϵ_i – random error term
Waste management	Model 2: $SDGI_{it} = \alpha_i + \beta_6 X_{6it} + \beta_7 X_{7it} + \beta_8 X_{8it} + u_{it}$, where: α – intercept for entity *i*; β_6, β_7, β_8 – coefficients to be estimated for the independent variables; u_{it} – idiosyncratic error term for entity *i* at time *t*
Secondary raw materials	Model 3: $SDGI_{it} = \alpha + \beta_9 X_{9it} + \beta_{10} X_{10it} + u_{it} + \epsilon_i$, where: α – intercept; β_9, β_{10} – coefficients to be estimated for the independent variables; u_{it} – idiosyncratic error term for entity *i* at time *t*; ϵ_i – random error term
Competitiveness and innovation	Model 4: $SDGI_{it} = \alpha_i + \beta_{11} X_{11it} + \beta_{12} X_{12it} + u_{it}$, where: α – intercept for entity *i*; β_{11}, β_{12} – coefficients to be estimated for the independent variables; u_{it} – idiosyncratic error term for entity *i* at time *t*
Global sustainability and resilience	Model 5: $SDGI_{it} = \alpha_i + \beta_{13} X_{13it} + \beta_{14} X_{14it} + \beta_{15} X_{15it} + u_{it}$, where: α – intercept for entity *i*; β_{13}, β_{14}, β_{15} – coefficients to be estimated for the independent variables; u_{it} – idiosyncratic error term for entity *i* at time *t*

Source: own

Tab. 3: Pedroni cointegration test results

		Modified Phillips-Perron	Phillips-Perron	Augmented Dickey-Fuller
Model 1	**Statistics**	7.4832	−13.1879	−15.5561
	***p*-value**	0.0000	0.0000	0.0000
Model 2	**Statistics**	4.9491	−4.9582	−2.1897
	***p*-value**	0.0000	0.0000	0.0143
Model 3	**Statistics**	4.9415	−3.5869	−1.3442
	***p*-value**	0.0000	0.0002	0.0894
Model 4	**Statistics**	3.6603	−3.0644	−2.7263
	***p*-value**	0.0001	0.0011	0.0032
Model 5	**Statistics**	4.8159	−8.6632	−6.9737
	***p*-value**	0.0000	0.0000	0.0000

Source: own

Model 5, while the data used for Model 1 and Model 2, was unbalanced, i.e., some data was missing. However, this problem was resolved, and the calculations were done with STATA, which could handle unbalanced panel data directly in most regression commands.

In order to proceed with the panel regression analysis, it is essential to consider the cointegration of the panels. Two series are considered cointegrated if they share common trends, meaning they exhibit some level of similarity. The null hypothesis posits that the series are not cointegrated. In order to test for cointegration, the Pedroni cointegration test was utilised, which is considered to be one of the most commonly used tests. The results are displayed in Tab. 3.

The results provided in Tab. 3 indicate that all the panels are cointegrated, so the research results are provided below.

3 Results and discussion

In this study, five panel regression models have been developed. Each group represents one of the key circular economy areas based on EU circular economy policy: production and consumption, waste management, secondary raw materials, competitiveness and innovation, global sustainability and resilience.

First group: production and consumption. The European Union's circular economy framework consists of 8 indicators within the production and consumption area. However, three indicators were excluded from this research due to a lack of statistical data. The used indicators include waste generation per capita, waste generation excluding major mineral wastes per GDP unit, and food waste. The results of the panel regression modelling are presented in Tab. 4.

As summarised in Tab. 4, three out of five indicators are considered to be statistically significant, and all three indicators have a positive effect on the Sustainable development goals index. Based on the given coefficient values, the material footprint (X_1) has the most considerable comparable effect, while the generation of municipal waste per capita (X_3) has the least. The result of material consumption confirms the need for well-developed, circular production. Although increased material footprint refers to a higher need for raw materials required to ensure the needs of society and might seem as opposite as the ultimate goal of sustainable development, in the long run, increased demand for raw materials is directed towards green innovation, or sustainable alternatives can help to achieve sustainable development goals. The positive effect of the material footprint for achieving sustainable development goals might seem contradictory; however, short-term and long-term effects should be taken into account. In the short term, investing in sustainable projects could lead

Tab. 4: Production and consumption pillar's panel regression results

Y	Coefficient	Std. error	*z*	*P* > |*z*|	[95 conf. interval]	
Material footprint (X_1)	0.118	0.032	3.670	0.000	0.055	0.182
Resource productivity (X_2)	0.668	0.354	1.880	0.060	−0.027	1.363
Generation of municipal waste per capita (X_3)	0.006	0.001	5.760	0.000	0.004	0.008
Generation of packaging waste per capita (X_4)	0.036	0.008	4.450	0.000	0.020	0.052
Generation of plastic packaging waste per capita (X_5)	0.024	0.025	−0.990	0.323	−0.072	0.024
Cons	68.017	1.079	63.050	0.000	65.903	71.132

Source: own

to an increase in material footprint. Such projects are usually related to sustainable infrastructure or green technologies (for example, renewable energy projects, electric vehicles, and batteries) and require various materials, which can be hard to extract. In the long term, these infrastructures or green technologies provide environmental benefits, such as reduced greenhouse gas emissions and support sustainable development goals (Celik et al., 2024; Razzaq et al., 2021). Since economies are in a transition period and most countries have not entirely switched to a circular economy and are still highly dependent on the take-make-dispose model, and since the circular economy is in its initial phase, we can state that we are in the short-term phase. The short-term phase ends when circular economy principles become widely integrated, resulting in more efficient resource use and a reduced material footprint.

From another point of view, a higher material footprint is associated with economic growth. In some cases, as countries develop and their economy grows, material footprints could also increase. This is associated with higher household incomes, leading to higher expenditures as well. Countries could also invest more in green technologies and reduce their environmental footprint in the long run. Such investments usually include advanced waste management systems, as well as recycling facilities or technologies that help to improve the efficiency of resource use, which in the long term reduce material footprint (Sharma et al., 2021).

The generation of municipal waste and generation of packaging waste also has a positive effect on the Sustainable development goals index.

From an environmental perspective of sustainability, waste has a negative effect on the environment. However, from an economic perspective, higher income levels are associated with higher waste generation per capita (Ari & Şentürk, 2020; Lagman-Bautista, 2020). Since achieving sustainable development goals is also related to economic growth and increased household income, especially for those who are in need, in the short run, it can lead to increased waste generation per capita. However, countries should implement policies and invest in infrastructure to ensure that additional waste is well managed, since effective waste management is one of the most important things when it comes to sustainability.

From the perspective of the research hypothesis, this part of the results rejects the hypothesis that circular economy principles positively impact the achievement of sustainable development goals. However, the fact that we are still in the short-term and developmental stage may explain the effect of increased material footprint and the generation of municipal and packaging waste.

Waste management is also one pillar of the European Union's circular economy framework. This part consists of 4 indicators; however, the recycling rate of all waste, excluding major mineral waste, was not included in this research due to a lack of statistical data.

Tab. 5: Waste management pillar's panel regression results

Y	Coefficient	Std. error	*t*	*P* > |*t*|	[95 conf. interval]	
Recycling rate of municipal waste (X_6)	0.111	0.011	10.30	0.000	0.090	0.133
Recycling rate of packaging waste by type of packaging (X_7)	0.006	0.014	0.39	0.694	−0.022	0.033
Recycling rate of waste of electrical and electronic equipment (WEEE) separately collected (X_8)	−0.042	0.009	−4.50	0.000	−0.061	−0.024
Cons	77.908	1.140	68.33	0.000	75.661	80.155

Source: own

The model consists of three indicators, and panel regression results for this model are presented in Tab. 5.

As provided in Tab. 3, two out of three indicators are considered statistically significant. The recycling rate of municipal waste has a positive effect on the Sustainable development goals index, while the recycling rate of waste of electrical and electronic equipment (WEEE) separately collected has a negative effect. Based on the given coefficient values, the recycling rate of municipal waste (X_6) has the most considerable comparable effect. Given that the value is higher than the coefficient value of generation of municipal waste per capita (X_3), confirming the importance of recycling facilities ensures that materials are returned to the production cycle.

While recycling typically supports sustainability, waste electrical and electronic equipment (WEEE) present specific challenges. Waste electrical and electronic equipment contains scarce and valuable materials, meaning that WEEE needs to be effectively managed. If the recycling processes are not optimised or if secondary raw materials are not effectively reintegrated into the production cycle, it could lead to inefficiencies that negatively impact the sustainable development goals (Shittu et al., 2021). At the current state, recycling of waste electrical and electronic equipment is intensive and complex process that include high energy consumptions and the use of chemicals to recover valuable materials, potentially increasing greenhouse gas emissions and causing other environmental issues (Ardolino et al., 2021). Inefficiency of WEEE recycling can be related to weak regulation in some countries. In the context of WEEE recycling, the focus towards increased product durability and product life extension is underestimated (Cole et al., 2017). Extending the lifespan of electronic devices has more significant environmental benefits than recycling them once they turn into waste. It is crucial to develop strategies for reuse and repair to minimise the environmental impact. This method preserves the embedded energy and materials in the devices and supports the higher levels of the waste hierarchy, which emphasises prevention and reuse rather than recycling (Anandh et al., 2021).

From the perspective of the research hypothesis, this part of the results partly confirms the hypothesis. It is also important to highlight that the effect of the recycling rate of municipal waste is significantly higher than the generation of municipal waste, emphasising the importance of investing in advanced recycling technologies to achieve sustainable development.

The third group: secondary raw materials. The European Union's circular economy framework consists of 3 indicators within the secondary raw materials area. However, one indicator was excluded from this research due to a lack of statistical data. The final model consists of 2 indicators, and the results are presented in Tab. 6.

As shown in Tab. 6, both indicators are considered statistically significant. Both of these indicators have a positive effect on the Sustainable development goals index. Circular material use rate (X_9) has the most considerable comparable effect among the secondary raw materials pillar's variables. The circular material use rate directly represents how effectively an economy maintains materials within the economic system and implements circular economy practices while minimising waste and input of raw material through closed loops. As stated by Walker et al. (2018), material circularity as well as efficiency are essential elements of the circular economy and can lead to reduced impacts on

Tab. 6: Secondary raw materials pillar's panel regression results

Y	Coefficient	Std. error	*z*	*P* > |*z*|	[95 conf. interval]	
Circular material use rate (X_9)	0.125	0.036	3.480	0.001	0.054	0.195
Trade in recyclable raw materials (X_{10})	4.37e−07	2.20e−07	1.990	0.047	5.67e−09	8.68e−0.7
Cons	77.097	0.782	98.610	0.000	75.565	78.630

Source: own

the environment. Circularity also prevents resource scarcity and is aligned with sustainable practices (Moraga et al., 2021).

Trade in recyclable raw materials also reduces the intake of natural resources and enhances cross-country collaboration. In this case, countries can ensure the needed demand for resources and have a sustainable alternative for extracting natural resources. Trade in recyclable raw materials is especially crucial for less common materials like lithium, cobalt or others (de Sa & Korinek, 2021). Trade in recyclable raw materials also promotes sustainable development and can help to achieve various sustainable development goals. This includes international recycling systems that could help manage waste more efficiently and reduce environmental impact, as well as create new job opportunities. Greenhouse gas emissions can also be reduced by incorporating recycled materials into production processes, which reduces reliance on virgin raw materials. From the perspective of the research hypothesis, this part of the results confirms the hypothesis.

The fourth analysed group is competitiveness and innovation. The European Union's circular economy framework consists of 3 indicators within the competitiveness and innovation area. However, patents related to recycling and secondary raw materials were not included in this research due to a lack of statistical information. The developed model consists of two indicators, and panel regression results are presented in Tab. 7.

Tab. 7: Competitiveness and innovation pillar's panel regression results

Y	Coefficient	Std. error	*t*	*P* > |*t*|	[95 conf. interval]	
Private investment and gross added value related to circular economy sectors (X_{11})	−2.24e−05	4.78e−05	−0.470	0.639	−1.17e−04	7.17e−05
Persons employed in circular economy sectors (X_{12})	2.87e−05	5.60e−06	5.130	0.000	1.77e−05	3.97e−05
Cons	74.942	0.666	112.560	0.000	73.631	76.254

Source: own

As summarised in Tab. 7, only persons employed in circular economy sectors are considered statistically significant and have a positive effect on the Sustainable development goals index, while private investment and gross added value related to circular economy sectors are not considered statistically significant based on the given results (X_{11}).

Generally, demand for circular economy or green jobs is increasing each year. In some cases, circular economy sector jobs, especially in enabling circular economy sectors, require higher skills or experienced employees (Burger et al., 2019). Promoting circular economy practices creates new job opportunities, enhances skills and innovation, and contributes to sustainable and inclusive economic growth (Kurnia et al., 2023). In this case, emerging circular economy jobs foster innovations and ensure decent work, promoting sustainable development and contributing towards achieving sustainable development goals. From the perspective of the research hypothesis, this part of the results confirms the hypothesis.

Finally, the fifth investigated group is global sustainability and resilience. The European Union's circular economy framework consists of 3 indicators within the global sustainability and resilience area; all these indicators were included in the panel regression analysis. The obtained results are provided in Tab. 8.

As can be seen from Tab. 8, all three indicators are considered statistically significant. Consumption footprint and material import dependency positively affect the Sustainable development goals index, while greenhouse gas emissions from production activities have a negative effect. Taking into account

Tab. 8: Global sustainability and resilience pillar's panel regression results

Y	Coefficient	Std. error	*t*	*P* > |*t*|	[95 conf. interval]	
Consumption footprint (X_{13})	0.069	0.011	6.160	0.000	0.047	0.091
Greenhouse gas emissions from production activities (X_{14})	−4.30e−04	6.24e−05	−6.870	0.000	−5.5e−04	−3.1e−04
Material import dependency (X_{15})	0.110	0.026	4.190	0.000	0.058	0.162
Cons	70.737	1.558	45.400	0.000	67.668	73.081

Source: own

comparable effects, among all statistically significant variables, material import dependency (X_{15}) has the most significant comparable effect. Greenhouse gas emissions from production activities (X_{14}) have the smallest comparable effect. From the perspective of the research hypothesis, this part of the results partly confirms the hypothesis. The effect of consumption footprint is related to the impact of material footprint, which was explained in this research previously. Rising efforts to reduce poverty and boost economic growth can lead to increased footprints among different sectors, which is associated with increasing income and expenditure among the most disadvantaged groups of people. It is essential to mention that footprint increases more than income or expenditure; however, it is clear that inequality of people should be reduced even in compromises with environmental aspects, but it is necessary to look for ways to create a human operating environment that is both eco-friendly and fair (Scherer et al., 2018).

The effect of greenhouse gas emissions from production activities is straightforward. In the circular economy, all products are designed and made to reduce waste and maximise long-term value while also minimising greenhouse gas emissions and ensuring efficient use of resources. It is aligned with sustainable development, especially in the context of the environmental pillar.

Although high material import dependency can lead to vulnerability of economies, supply chain disruptions or price volatility, as well as high transportation costs and additional greenhouse gas emissions, it could also provide access to specific resources that are not available domestically and are crucial for green innovations, such as renewable energy technologies. The import of materials can also foster international cooperation and partnerships, drive innovation, and enhance the technological capabilities of a country.

Overall, the research partly confirms the hypothesis that circular economy principles positively impact the achievement of sustainable development goals. Some results were not as expected, including those related to the production and consumption pillar, as well as the consumption footprint from the global sustainability and resilience pillar. Additionally, particular results, such as the effect of material import dependency or trade-in recyclable raw materials, may vary depending on the context. However, it is undeniable that the circular economy and its practices are a crucial part of sustainable development.

The comparison of the results of this study with the findings of previous research indicates that a circular economy can significantly benefit the achievement of all sustainable development goals. Unfortunately, the individual examples of prior research on the relation between circular economy and sustainable development goals do not allow for a broad discussion of the results presented in this study, since the majority of previous research is focused on specific sustainable development goals or targets. As presented by Valverde and Avilés-Palacios (2021), the circular economy can help to achieve SDG 6 (clean water), SDG 8 (decent work), SDG 12 (responsible consumption and production), and SDG 15 (life on land). Schroeder et al. (2019) study revealed that the circular economy directly contributes to SDG 7 (affordable and clean energy). Dantas et al. (2021) research showed contribution to the mentioned sustainable development goals as well as SDG 8 (decent work and economic growth), SDG 9 (industry, innovation and infrastructure), SDG 11 (sustainable cities and communities), and SDG 13 (climate action). Garcia-Saravia Ortiz-de-Montellano et al. (2023) state that while circular economy practices most effectively contribute to SDG 8 (decent work and economic growth), SDG 12 (responsible consumption and production), and SDG 13 (climate action), circular economy strategies can contribute to all sustainable development goals. Ferraz and Pyka (2023) emphasise that the circular economy primarily focuses on SDG 12 (responsible consumption and production), as well as SDG 9 (industry, innovation, and infrastructure), SDG 7 (affordable and clean energy), and SDG 6 (clean water and sanitation). However, when combined with the bioeconomy, which is closely related to the circular economy in terms of overall goals, it can contribute to all sustainable development goals. This aligns with the outcomes of this research.

Other, more specific research shows that individual sustainable development goals can also benefit from the circular economy. For instance, Schröder et al. (2020) state that by creating inclusive employment opportunities and empowering women in sustainable industries, circular economy initiatives can promote gender equality (SDG 5). This research shows how the circular economy can contribute to a set of sustainable development goals, which is crucial for the EU's ambitious goal to become the first climate-neutral continent and ensure that no person or place is left behind.

Conclusions

The aim of this research was to determine which circular economy indicators most significantly impact the Sustainable development index in European Union countries. It emphasises the importance of circular economy practices as essential tools for achieving sustainable development goals. Panel regression analysis was used to empirically explore the impact of the EU Circular economy monitoring framework indicators on sustainable development, as represented by the Sustainable development goals index.

The results of the analysis are in line with the prior studies and confirm the linkage between circular economy and sustainable development, as presented in the literature review.

Although different circular economy indicators can have varying impacts on achieving sustainable development goals, considering both the possible short- and long-term effects, the circular economy is one of the solutions for a sustainable future. For instance, the circular material use rate and trade in recyclable materials showed significant positive effects on the Sustainable development goals index. This can not only accelerate progress towards sustainability but also ensure cross-country collaboration and improve competitiveness in the sustainable product market. The negative effect of the generation of municipal or packaging waste per capita highlights the need for effective recycling and waste management solutions. Together with the positive impact of the recycling rate of municipal or packaging waste, these factors contribute to achieving the sustainable development goals. This research has several practical contributions. It serves as a guide for understanding the relationship between the circular economy and sustainable development. This includes an extensive study of different circular economy pillars and their impact on achieving sustainable development goals. By highlighting specific areas of the EU Circular economy monitoring framework that have the most significant impact on achieving sustainable development goals, countries can refine their national policies to promote sustainable practices. Utilising the circular economy as a tool can accelerate the achievement of sustainable development goals.

Additionally, this research contributes to the academic field by filling gaps in the current understanding of how circular economy initiatives can directly influence sustainable development goals. This research confirms that using circular economy practices can accelerate the achievement of the entire set of sustainable development goals. Furthermore, the circular economy, as a modern alternative to the linear economy, contributes to a sustainable future.

This research proposes opportunities for future research. Future research opportunities can build on this study by incorporating a broader set of indicators from the EU Circular economy framework. Due to data limitations, some indicators were not included in the current analysis. Additionally, the analysis was constrained to a specific timeframe, which may not capture long-term trends. Moreover, future research could explore the potential of clustering countries based on regional or economic backgrounds. By grouping countries with similar characteristics, research can provide insights into region-specific or economy-specific strategies and challenges. This approach could enable more tailored policy recommendations, ultimately supporting more effective implementation of circular economy principles. Another direction for future research would be to target specific sustainable development goals that, according to other researchers, are most closely related to the circular economy.

It should be noted that the current study has several limitations. The indicators and data have been collected from the Eurostat database; however, the selection of the used indicators might not capture all the dimensions of the circular economy, potentially omitting some qualitative aspects, such as social inclusion, cultural attitudes and behavioural changes. Moreover, the current study focuses on the EU, which limits the generalisation of the research findings, and their application in other regions is limited due to differences in the economic and cultural context. In spite of the mentioned limitations, the present research offers a solid basis for understanding the role of the circular economy in achieving sustainable development in countries.

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Central European sustainable economy: The role of green finance, technological innovation, and circular economy

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Abstract: *The European Green Deal has clarified the need to evaluate the factors affecting the ecological footprint and find strategies to reduce their impact. The study evaluates the correlation between green finance, technological innovation, circular economy, urbanization, energy consumption, economic progress, and ecological footprint. It analyzes data from Central European communities from 1990 to 2022, using robust econometric evaluations, including common correlated effect mean group (CCEMG) and augmented mean group (AMG) models, along with an initial examination of cross-sectional dependence, unit roots, cointegration, and slope heterogeneity. The findings highlight that a reduction in ecological footprints can be achieved through technological innovation, green finance, and a circular economy. In contrast, energy consumption, urbanization, and economic development tend to increase the ecological footprint. Advanced models such as fully modified ordinary least square (FMOLS) and Driscoll and Kraay (DSK) support these findings. The causality analysis revealed the unidirectional and bidirectional relationship between variables. Based on these outcomes, the study recommends that Central European countries implement suitable policies to push the transition toward a sustainable economy.*

Keywords: *Green finance, technological innovation, circular economy, urbanization, economic progress, Central Europe.*

JEL: *Q01, Q30, Q40, Q55.*

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Introduction

With demand exceeding supply and increased environmental depletion, novel strategies are needed to meet the ever-appreciated population demand of individuals and enterprises (Mukherjee et al., 2023). Institutions, governments, and individuals have called for prudent measures to mitigate the ecological footprint due to the increasing population and limited resources (Cheng et al., 2024; Rodríguez-Reb'es et al., 2024). Ecological footprint (EFP) is triggered by different factors, including energy consumption (ENE), urban pollution, deforestation, and sea level depletion. According to the global footprint network, Central European communities require four times the land size needed to meet their ecological footprint (Fig. 1). Germany contributes 4.4986, Czechia 5.0830, Hungary 3.7886, Slovakia 4.1589, Slovenia 4.7899, Poland 4.6867, and Austria 0.25933 to global pollution (Network G.F., 2019). As a result, reducing the footprint caused by anthropogenic activities and global crises has led to the development of various policies, such as the EU Green Deal and the EU circular principle in 2015. The circular economy is a limited model for addressing global waste, energy, and pollution (Almulhim, 2024). In 2015, the EU presented to its member communities its circular economy strategy of eliminating waste and pollution, circular products and materials, and regenerating nature (EU, 2019). Establishing indicates that circularity complements the EU Green Deal by limiting the principle of make-use-disposed linearity.

Numerous academics have demonstrated that a circular economy will help to meet the sustainability progress set by many nations (Yu et al., 2023). Waste-energy is one of the alternative ways to reduce the huge landfill sites around Europe (Halkos & Aslanidis, 2024). They specifically demonstrated waste conversion into energy for production or household consumption. Additionally, waste separation and trade in the EU countries accounted for 50%, part of which is shipped to Vietnam for recycling (Thapa et al., 2024). On the IPAT equation model, Figge and Thorpe (2023) examined different principles to a sustainable level. These include circular economy, operational eco-efficiency, and sufficiency. Central Europe advocates a circular economy and green deals to reduce landfill waste. Exploring the interconnection between circularity and ecological footprint within Central European communities is important. Furthermore, these regions are experiencing rapid economic progress, and there is no doubt that they are investing in innovative procedures. Research and development in technologically innovative ways is an efficient way to depreciate the ecological footprint within the Central European communities (Alina-Petronela et al., 2023; Hao et al., 2023). In Italy, Javed et al. (2023) conducted an empirical evaluation on green technology and ecological footprint to enhance the quality of the ecosystem. Their findings identify renewable energy and technological innovation (TNI) as the keys to reducing industry footprints. Similarly, Appiah et al. (2023) found that implementing innovation principles in 29 OECD communities between 1990 and 2020 reduced their EFP and improved the quality of the ecosystem. Therefore, evaluating the influence of technological innovation in Central Europe will help improve biocapacity and depreciate the ecosystem footprint.

Nevertheless, the financial strength of a nation determines its development. Green finance (GNF) includes green credit, bonds, and loans, which are tailing towards a sustainable economy (Qing et al., 2024; Yu, 2024). Mohsin et al. (2023) evaluation in Europe demonstrated that communities such as Poland could decrease their emissions footprint by reducing their coal funding. The EU taxonomy has recently addressed the question of what sustainably qualifies for green finance. The European Union’s 1 trillion-euro investment to achieve climate neutrality by 2050 is a way to inform governments and investors to invest in sustainable financial assets. Tiwari et al. (2025) conducted a study on the progress of the green economy in the USA between 1990 and 2021. The results showed that financial development had a lower emissions footprint. Similarly, Sampene et al. (2023) investigated the ecological footprint and green finance of South Asian communities. The econometric findings demonstrated that green finance was effective in depreciating ecological footprints. Similar work has confirmed that green finance is important in reducing the ecological footprint (Chen et al., 2024; Sapp, 2024). The Central European communities are no different from other economies in terms of green finance principles.

The increased urban population and resource utilization are causing pollution in Central Europe. According to the EU Report 2022, urban pollution in the European Zone has increased due to industrial and transportation consumption of non-renewable energy sources (Clora & Yu, 2022; Kirat et al., 2024). Addai et al. (2022) evaluated ecological footprint and urbanization in Eastern Europe using various econometric approaches. The findings indicated that urbanization had a bidirectional relationship with ecological footprint. Additionally, Cheng et al. (2024) empirically examined China’s provincial dual carbon goals from

2010 to 2019. The findings indicated that the link between renewable energy innovation was appreciated when urbanization was added as a control variable. By employing the cross-sectional autoregressive distributed lag (CS-ARDL) model on G11 nations. Mehmood (2024) analyzed the influence of urbanization and ecological footing between 1990 and 2020. The results show that urbanization increases environmental depletion in regions. With more industries and individuals moving into urban communities in Central Europe, the demand for natural resources and pollution has increased.

The literature has shown unclear relations between energy consumption (ENE), circular economy (CRE), urbanization (UBZ), green finance (GNF), technological innovation (TNI), and economic progress (ECP), with Central Europe not being unique. The following questions are presented: (1) What is the nexus between the EFP and its factors? (2) What, if any, explanations are available for this relationship? This investigation aims to evaluate the impact of various factors on reducing ecological footprints in Central European economies from 1990 to 2022. These factors include energy consumption, circular economy practices, technological innovation, urbanization, and green finance. The Central European economies were chosen due to their under-representation in environmental climate studies, significant progress in the past two decades, and their role as emerging economies with substantial energy consumption. The V-4 group, including Poland, the Czech Republic, Hungary, Slovakia, and Slovenia, has an expected growth rate of 5% per year, while Central Europe is 6.4% over the next 40 years, narrowing the gap with the V-4 group. Notably, Central European economies account for more than 15.7% of the Eurozone's energy consumption on solid fuels and rank among the top twenty in ecological footprint (Mohsin et al., 2023). These regions have embraced the EU's green deal, circular economy principles, and increased investments in environmental technologies, green finance, and renewable energy. The study employs robust techniques such as the CCEMG and AMG approaches, which address the dearth of empirical studies in this area. In addition, the study investigates the role of CRE, GNF, and innovations in reducing the ecological footprint in the economies of Central Europe. Fig. 1 illustrates the EFP levels in Central European communities.

The study commences with a summary of the previous literature, then proceeds with data and an econometric model, and concludes with empirical findings and policy recommendations.

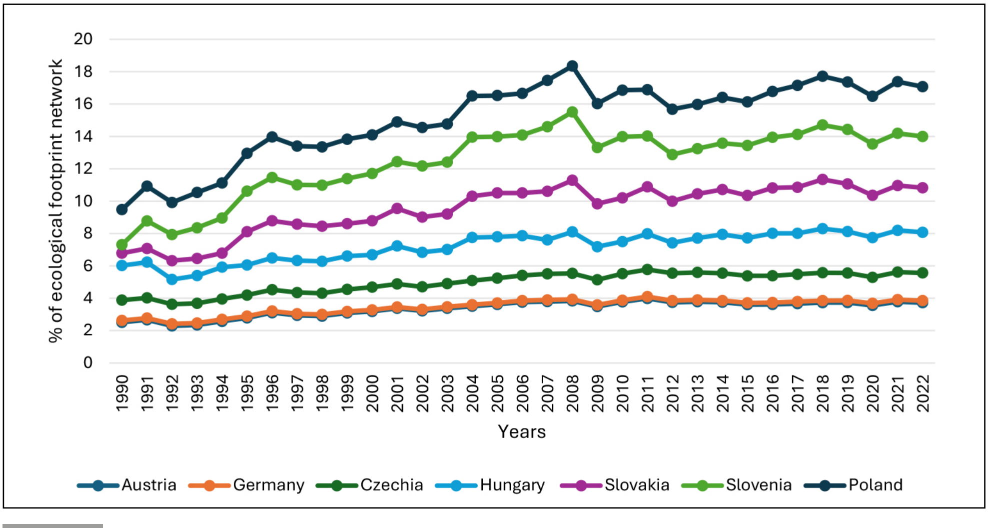

Fig. 1: EFP levels in Central European regions

Source: Global footprint network report (2023)

1 Theoretical background

1.1 Circular economy and ecological footprint

Given the volume of waste associated with a linear economy and the depreciation in nations' biocapacity, the desire to employ a more sustainable approach is necessary to reduce industrial and residential waste (Mukherjee et al., 2023). Yu et al. (2023) evaluated China's green growth policy using the ARDL model. Their findings show a correlation between the adoption of the circular economy and waste trade at 0.15% and 0.07%. Allevi et al. (2021) examine the various approaches to reusing waste within the communities of Lombardy in Italy. The evaluation developed a model to reuse waste to generate electricity and goods. Tauseef et al. (2023) stated that the EFP of the BRICS economies is their high dependency on linear economy principles regarding emissions abatement. However, their carbon footprint has improved following the Paris emission targets policies and the development of innovative approaches. Sauvé et al. (2021) explored blue, grey, and green water sustainability to reduce water contamination in the context of water footprint. Despite the impact of climate change and linear waste from enterprises on the quality and quantity of water exploration, Sauvé et al. (2021) proposed using eco-efficiency, circular economy, and eco-innovation policies to mitigate the water footprint. Meanwhile, Halkos and Aslanidis (2024) studied municipal waste in European communities, examining how enterprises can harness this waste to generate energy. While waste can negatively impact the ecosystem, it can also serve as a valuable resource for producing fertilizer and energy. Solid waste from industrial poultry can be converted into fish feed and other forms of fertilizer. Thapa et al. (2024) suggest that the industrial level can achieve a circular economy through waste trade and management. Yang et al. (2023) have established the principles of industrial ecology.

1.2 Green finance and ecological footprint

Research on GNF has recently emerged in academia due to its impact in alleviating ecological depletion (Mohsin et al., 2023). In emerging economics, Vardar et al. (2023) selected 47 nations to identify the long-run effects of green finance. Their investigation asserts that GNF and renewable energy utilization are the paths to sustainable ecology. From the point of resource scarcity, Zhang and Chen (2023) asserted in China that green finance and renewable electricity depreciate ecological impact with a bidirectional relationship between the variables. Employing the EKC model, Yu (2024) explored the road to carbon neutrality through natural resource utilization, highlighting natural resources' role in increasing emissions. The results change when green finance is connected to natural resources to mitigate the EFP. In the more polluting economics of South Asia, the principal effect of green finance and biocapacity was evaluated from 1990–2017 on panel analysis. Employing various econometric models and the EKC approach, the results demonstrated that biocapacity appreciates ecological footprint with green finance depreciation factor for EFP (Sampene et al., 2023). Likewise, in the context of Europe, Sun and Rasool (2023) confirm a material effect of green financing in reducing ecological footprint. Khan et al. (2022) indicated that green finance is the answer to the challenge for a nation to trigger economic progress. Furthermore, Qing et al. (2024) established that the Paris climate target can be achieved through green finance. Therefore, we expect that GNF will have an effect on the mitigation of the EFP.

1.3 Technological innovation and ecological footprint

Governments and policy communities have been concerned with adopting and investing in technological innovation to improve environmental quality (Rodríguez-Reb'es et al., 2024). Literature has established the effect of TNI on EFP reduction and increasing the biocapacity of nations. In China, Sun et al. (2024) evaluated the petrochemical enterprises and their investments in technology structures. Their study concludes that technological innovation is a catalyst causing an increase in environmental depletion. This happens when environmental governance moderates it. Hassan (2023) examined South Africa due to its status as a prominent coal mining country. From 1981 to 2017, the econometric findings of the FMOLS indicated that the environmental impact significantly diminished as coal exploitation was integrated with technological advancements. This finding is corroborated by the investigation of Bekun (2024) on net zero carbon and technological innovation between 1975 and 2020 in South Africa. Particularly with

UNSDG13, the empirical results demonstrated that technological innovation mitigates short-term and long-term carbon emissions. Furthermore, Kirat et al. (2024) expounds the effect of climate changes and environmental externalities on data curation of 111 regions. The outcome of the investigation established that the European community's energy consumption was affiliated with temperature diseases. Employing the ARDL model in the US, Tiwari et al. (2025) explored technological innovation and ecological footprint. The estimates indicated that, in the long run, environmental pollution influenced the deprivation of ecosystems. Affirming this research, twenty-seven European communities, plus the UK and Switzerland, were analyzed by Clora and Yu (2024). They indicated that to mitigate carbon emissions and carbon leakage, these regions should adopt technological innovation approaches and techniques.

1.4 Urbanization and ecological footprint

The rapid pace of urban development has put pressure on the biocapacity within Central European communities (Quito et al., 2023). Chen et al. (2022) delves into 110 economics on the effects of UBZ on EFP. The empirical results pointed out that urbanization is a catalyst for ecological footprint. They recommended that nations with high human capital manage their environmental depletion better. According to Sahoo and Sethi's (2022) investigation of new industrial communities, technological innovation in urban areas appreciates the quality of the environment. This is possible when economic progress hinges on innovation, research, and development policies. Additionally, the environmental Kuznets curve (EKC) model of economic progress is tired to urban pollution. This was affirmed in the investigation of Mehmood (2024) in G11 states. The econometric test demonstrated that urbanization and economic progress impact the ecosystem partners. In the context of MENA regions, Satari Yuzbashkandi et al. (2023) evaluation of panel data from 1990–2019 on urbanization and ecological footprint highlighted that urbanization is not the cause of depreciation in biocapacity leading ecological footprint. Meanwhile, Toth and Sebova (2024) employed the SLR technique to investigate the influence of environmental externalities in Kosice population bias. This finding is corroborated by the results from Africa by Ekeocha (2021) on the connection between urbanization, economic progress, and ecological footprint. They identify an N-shaped distribution within low-income regions. This phenomenon was attributed to the disparity in income levels. Furthermore, Khan et al. (2023) established that urbanization did not affect the ecological footprint in India. Diversified studies have identified an effect of urbanization on the EFP. Addai et al. (2022) Eastern Europe, and Arif et al. (2023) Pakistan. According to the investigations above, urbanization adversely contributes to ecological footprints, and smart urbanization is the next novelty.

Tab. 1: Variables definition – Part 1

Variables	Proxy	Definition	Reference
Ecological footprint	*EFP*	Ecological footprint in global hectares (gha) per person	https://data.footprintnetwork.org/
Green finance	*GNF*	GRF measures environmental product protection by residents	OECD
Circular economy	*CRE*	Waste recycling technologies, industry value addition	https://databank.worldbank.org/reports.aspx?sou rewords-development-indicators
Technological innovation	*TNI*	Measured with % of all technologies	OECD
Energy consumption	*ENE*	Percentage of oil, gas, fossil fuel (non-renewables)	https://databank.worldbank.org/reports.aspx?sourceworld-development-indicators

Tab. 1: Variables definition – Part 2

Variables	Proxy	Definition	Reference
Urbanization	*UBZ*	Percentage of urban total population	https://databank.worldbank.org/reports.aspx?sou rewords-development-indicators
Economic progress	*ECP*	GDP (constant USD – 2015)	https://databank.worldbank.org/reports.aspx?sou rewords-development-indicators

Source: own

2 Methodology

The evaluation employed panel data from various verified databases, including the World Bank, Global Footprint Network, and OECD, for the period 1990–2022. The research has established that ecological footprint is associated with increased economic progress in the early stages but declined in the long run with development and changes from non-renewable to adopting renewable energy. However, these are not the only factors contributing to ecological footprint appreciation within the Central European communities. Urbanization signs have been confirmed by Ekeocha et al. (2021). Technological innovation and circular economy assessment by Yang et al. (2023) demonstrated a negative nexus with ecological footprint. Previous articles have recommended green finance to help mitigate ecological footprint and appreciation of biocapacity. Central Europe was selected as it forms about 35.5% of the European region of 27 communities. The ecological footprint within these regions accounted for four times the biocapacity available. Tab. 1 presents the variables definition, measurement, and sources employed for the research.

2.1 Econometric model

The evaluation employed various econometric models that have been verified previously (Ekeocha et al., 2021). We developed our model to present the link between *CRE*, *GNF*, *TNI*, *ENE*, *UBZ*, and *ECP* on *EFP*.

The initial model was developed as:

$$EFP = f(TNI, GNF, CRE, UBZ, ENE, ECP) \quad (1)$$

The variables were changed to the logarithm form to have a favorable econometric approach suitable for the analysis. According to Sampene et al. (2023). Equation (2) presents the technique.

$$\begin{aligned} \text{In}ECF_{i,t} &= \lambda_0 + \lambda_1 \text{In}TNI_{i,t} + \lambda_2 \text{In}ENE_{i,t} + \\ &+ \lambda_3 \text{In}GNF_{i,t} + \lambda_4 \text{In}UBZ_{i,t} + \lambda_5 \text{In}CRE_{i,t} + \\ &+ \lambda_6 \text{In}ECP_{i,t} + \varepsilon_{i,t} \end{aligned} \quad (2)$$

where: In – log form; *EFP* – ecological footprint; *TNI* – technological innovation; *GNF* – green finance; *CRE* – circular economy; *UBZ* – urbanization; *ENE* – energy utilization; *ECP* – economic progress; coefficients of $\lambda_1 - \lambda_1$. The slope is coined as λ_0 with the error assessment given by ε_{it}; *t* – the period 1990–2022; and *i* – Central European communities.

Cross-sectional dependence and slope heterogeneity test

Panel data analysis is susceptible to biased interpretations and inaccurate statistical results when cross-sectional dependence (CSD) is overlooked or neglected. In panel data analysis, obtaining reliable and unbiased estimates necessitates identifying and correcting CSD. Research findings and policy recommendations may be compromised if this dependency is overlooked, perhaps leading to inaccurate conclusions about the relationships between the variables (Adebayo et al., 2023; Sampene et al., 2024).

$$CSD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \sigma_{ij}^{t} \right) \quad (3)$$

Next, the slope homogeneity was evaluated to identify the independent variables across time and groups. When investigating whether or not slopes are homogeneous, this evaluation is crucial since it sheds light on how stable the nexus is under different circumstances. When using panel data studies to make predictions or propose policies, it is essential to understand if the slopes are consistent. This is particularly true when the connections between variables may alter over time or between dimensions. Equations (4–5) present the function of the slope homogeneity test (SHT).

$$\tilde{\Delta}SHT = (N)^{\frac{1}{2}}(2K)^{\frac{-1}{2}}\left(\frac{1}{N}\tilde{S} - K)\right) \quad (4)$$

$$\tilde{\Delta}ASHT = (N)^{\frac{1}{2}}\left(\left(\frac{2k(T-k-1}{T+1}\right)^{\frac{-1}{2}}\right)\left(\frac{1}{N}\tilde{S} - K)\right) \quad (5)$$

where: $\tilde{\Delta}SHT$ denotes the delta of the slope and $\tilde{\Delta}ASHT$ presents the adjusted SHT.

Unit root test

Panel root evaluation is fundamental in panel data analysis to ensure the order and the stationarity of the construct. In the econometric approach common augmented dickey-fuller (CADF) and cross-sectional augmented impesaran-shin (CIPS) tests are considered to check for issues of cross-sectional in the data. The utilization of the test expounds to the next appropriate evaluation.

$$CADF = \gamma x_{it} = \alpha_{it} + \beta_{it-1} + \delta_I T + + \sum_{j=1}^{N} \gamma_{ij}\, \gamma x_{it-j} + \varepsilon_{it} \quad (6)$$

where: γ – the disparities among the indicators; X_{it} – the variables assessed in this research.

$$CIPS = \frac{1}{N}\sum_{i=1}^{N} \varphi_i \ (N,T) \quad (7)$$

where: *N* – the research period; *T* – the cross-sections among the indicators.

Cointegration test

The Westerlund (2007) cointegration test, formulated for panel data, facilitates the examination of long-term connections between variables. Cointegration is essential in time series evaluation, signifying a shared stochastic tendency among variables. The Westerlund (2007) test for panel data includes cross-sectional dependence, which lets you examine whether a set of variables has a cointegrating connection. This is especially useful for analyzing economic phenomena with long-term equilibrium dynamics, as it helps identify persistent comovements across variables spanning time and various entities. Equations (8–11) demonstrated the cointegration test.

$$G_\tau = \frac{1}{N}\sum_{i=1}^{N} \frac{\eta_i}{S.E(\widehat{\eta_\iota})} \quad (8)$$

$$G_a = \frac{1}{N}\sum_{i=1}^{N} \frac{T\eta_i}{1 - \sum_{j=1}^{k}\widehat{\eta_{\iota J}}} \quad (9)$$

$$P_\tau = \frac{\widehat{\eta_\iota}}{S.E(\widehat{\eta_\iota})} \quad (10)$$

$$P_a = T\eta_{\mathrm{i}} \quad (11)$$

where: the means for the group statistics is depicted by ($G_a - G_t$) and the cointegration is donated by ($P_t - P_a$).

Long-term estimation models

In panel data analysis, the common correlated effects mean group (CCEMG) estimator is a good way to deal with possible CSD. The CCEMG estimator enhances the mean group (MG) estimator by accommodating common correlated effects (Pesaran, 2006). The CCEMG estimator provides superior coefficient estimates compared to conventional MG estimators due to its utilization of data from the entire panel. This renders it particularly advantageous for analyzing economic processes that exhibit interdependence across temporal and spatial dimensions. This strategy enhances our understanding of how prevalent factors influence various units over time. It improves the model's accuracy and mitigates the bias risks associated with neglecting cross-sectional dependence. Designed to address the differences between cross-sectional observations, the augmented mean group (AMG) estimator is a valuable tool for evaluating panel data. The AMG estimator enhances the conventional MG estimator by incorporating individual-specific fixed effects. This addresses unobserved heterogeneity among units, offering a more adaptable and realistic framework for studying panel data. The AMG estimator is particularly useful when analyzing economic phenomena that differ between entities, such as industries or regions. The AMG estimator makes parameter estimates more accurate in panel data analysis by considering effects specific to time and units. This makes econometric studies stronger and more reliable. Equations (12–13), which express the AMG technique computationally, are based on a two-stage methodology:

Phase I AMG technique:

$$\Delta Y_{it} = \varphi_i + \delta_i \delta X_{it} + \gamma_i \vartheta_t + \sum_{t=2}^{T} \theta_i \, \Delta D_t + \mu_i \quad (12)$$

Phase II of the AMG technique:

$$AMG_{Estimator} = N^{-1} \sum_{i=1}^{N} \widehat{\beta_\iota} \quad (13)$$

where: φ_i – the intercept, Y_{it} and X_{it} – the evaluated element; ϑ_t – heterogeneous terms having common causes that are not evaluated, Δ – the initial operator of the indicators; time dimension *t*; and μ_{it} – the model's stochastic error term.

The CCE-MG technique is the next archetypal estimator we employed since it is a reliable and consistent estimator. The robustness of no affiliation structural weakness, the serial connection between the series, and unexplained common elements are all considered by the CC-MG (Kapetanios et al., 2011). Equation (14) provides an algebraic expression for the CCE-MG:

$$Y_{it} = \alpha_{1i} + \beta_i X_{it} + \theta_i n_{it} + \mu_{it} \quad (14)$$

where: Y_{it} and X_{it} are shown as observed variables; α_{1i} – the definite group effect; β_i – the steep of cross-sectional estimators, indicates the unidentified common component that loads with θ_i heterogeneous and μ_{it} depicts the model's probabilistic error term.

Equation (15) represents the enhanced approach with a mean CSD of the described and unknown parameters:

$$Y_{it} = \alpha_{1i} + \beta_i Z_{it} + \varphi_i \bar{y}_{it} + \bar{z}_{it} + \theta_i n_{it} + \mu_{it} \quad (15)$$

This regression was computed using the ordinary least squares approach for each cross-section. Equation (16) provides a rigorous solution for estimating the country-wise co-efficient used by linear models:

$$CCEMG = N^{-1} \sum_{i=1}^{N} \widehat{\theta_\iota} \quad (16)$$

Robustness analysis

Driscoll and Kraay (1998) proposed the standard error estimating method in panel data analysis, which offers a robustness test, particularly when using the CCEMG and AMG estimators. However, the accuracy of their parameter estimates depends on the validity of the assumed covariance structure. The DSK evaluation provides a diagnostic tool to demonstrate the sensitivity of results to potential misspecifications in the covariance structure. By incorporating these standard errors into the evaluation, researchers can gain insights into their estimates' robustness and improve their findings' reliability. As a way to make panel data analyses more rigorous, the DSK approach tests how stable the results are under different assumptions about the covariance structure. This makes sure that the econometric conclusions are more solid and reliable.

As a result of the earlier discussion, the analysis utilized the ordinary least squares method to estimate the DSK equations, as designated in Equation (17).

$$y_{it} = x'_{it-1} \beta + z_{it} y + \mu_{it}, \quad i = 1, \ldots, N, t = 1, \ldots, T \quad (17)$$

where: y_{it} – the explanatory variable (*EFP*); x'_{it} – the regressors (*TNI*, *GNF*, *CRE*, *ENE*, *UBZ*, *ECP*). In addition, μ – the error term of the function; *i* – the Central European communities; *t* – the period for the research.

Panel causality test

The investigation employs the panel Granger causality test Dumitrescu and Hurlin (2012) to evaluate the link. The DH test becomes even more important when error terms are cross-sectionally dependent. Furthermore, in heterogeneous and balanced panels, the DH is applicable when the duration is longer than the cross-section units. In contrast to the alternative hypothesis, which supports the existence of a causal nexus in the archetype, the null hypothesis of the DH Granger causality test is based on the premise that there is no causal interaction between the variables.

$$Y_{it} = \alpha_i + \sum_{m=1}^{M} \psi_i^m \, , \, Y_{i(m-t)} + \sum_{m=1}^{M} \lambda_i^m \, , \, Z_{i(m-t)} \quad (18)$$

where: m – the segment of the lag; ψ_i^m – the model's autoregressive parameters.

3 Results

3.1 Descriptive and correlation evaluation

The descriptive evaluation is explored to assess the variables' initial match for the econometric analysis (Tab. 2). The results demonstrated that economic progress had the highest average mean (26.078). Urbanization mean value is 15.812. The results implied that 15.8% of Central European communities live in urban areas. The other variables had the following mean values: technological innovation (5.977), circular economy (8.496), energy consumption (0.864), and ecological footprint (0.417). The variables had negative and positive skewness with their kurtosis and Jarque bera distributed.

Tab. 2: Descriptive evaluation

	EFP	*TNI*	*GNF*	*UBZ*	*ENE*	*CRE*	*ECP*
Mean	0.417	5.977	2.662	15.812	0.864	8.496	26.078
Median	0.861	5.648	2.543	15.734	0.851	8.352	25.885
Maximum	1.438	10.062	4.605	17.990	1.261	10.896	28.921
Minimum	−2.553	0.100	−0.083	13.820	−0.377	6.329	23.997
Std. dev.	1.131	2.174	0.711	1.234	0.206	1.201	1.365
Skewness	−1.734	0.110	0.840	0.236	−1.176	0.602	0.706
Kurtosis	4.473	2.153	4.976	2.314	10.139	2.598	2.670
Jarque-Bera	136.769	7.373	64.816	6.671	543.942	15.512	20.248
Probability	0.000	0.025	0.000	0.035	0.000	0.000	0.000
Observations	231	231	231	231	231	231	231

Source: own

3.2 Cross-sectional evaluation and slope heterogeneity

We use cross-section and slope heterogeneity to check the independence of the indicators explored in this research. Tab. 3 presents the outcomes from Breusch-Pagan, bias-corrected scaled, and Pesaran, along with their significance. The distribution exhibits independence

Tab. 3: Cross-sectional evaluation and slope heterogeneity

	Breusch-Pagan $_{LM}$	Bias-corrected scaled $_{LM}$	Pesaran $_{LM}$
ln*EFP*	289.454***	41.423***	41.314***
ln*TNI*	385.529***	52.081***	51.972***
ln*GNF*	142.865***	33.738***	33.447**
ln*UBZ*	386.188***	56.349***	56.240***
ln*ENE*	297.732***	42.395***	42.281***
ln*CRE*	132.769***	16.166***	16.056***
ln*ECP*	307.953***	44.277***	44.168***
Slope homogeneity	**Test statistics**		
$\hat{\Delta}$	28.536***		
$\hat{\Delta}_{adjusted}$	32.704***		

Note: *** p = <0.01; ** p = <0.05; * p = <0.10 indicate the significance levels.

Source: own

due to its high significance. In addition, the sloping heterogeneity depicts the nexus between the indicators and their dependent variables. The $\hat{\Delta}$ and $\hat{\Delta}$ adjusted highlights the favorable levels of independent and dependent affiliation across the variables.

3.3 Unit root assessment

Examining the variables of technological innovation, circular economy, urbanization, economic progress, energy utilization, and ecological footprint holds significant importance due to their sloping heterogeneity and cross-section dependence. We used the CIPS and CADF approach, as shown in Tab. 4, to determine the stationarity of the indixcators. We calculated the estimates at the first level, ensuring a 1% significance level. The results of literary works by Bekun (2024) for South Africa confirmed a unit root at the first level.

Tab. 4: Unit root assessment

Series	CIPS		CADF	
	Level	First difference	Level	First difference
ln*EFP*	−1.120	−8.470***	−1.486	−5.070***
ln*TNI*	1.179	−10.776***	1.650	−10.498***
ln*GNF*	1.421	−7.458***	−1.786	−6.781***
ln*UBZ*	−0.897	−7.216***	1.558	−13.554***
ln*ENE*	−1.213	10.149***	1.127	11.216***
ln*CRE*	−1.326	−8.246***	1.489	9.109***
ln*ECP*	0.850	−14.277***	0.861	−12.742***

Source: own

3.4 Cointegration assessment

The investigation undergoes a cointegration evaluation of Westerlund's assessment to confine a long-term relation between technological innovation, circular economy, economic progress, green finance, urbanization, and ecological footprint between Central European countries (Tab. 5). The cointegration coefficient and *p*-values $G\tau$ and $P\tau$ established a cointegration relationship and long-term nexus within the variables for the research period. In Asia, Ahakwa et al. (2023) and Eastern Europe, Addai et al. (2022) align with these results.

Tab. 5: Cointegration assessment

Test	Statistics	*p*-value
G_t	−6.954***	0.001
G_a	−1.112	0.831
P_t	−9.946***	0.000
P_a	−1.472	0.654
Variance ratio	161.866***	0.000

Source: own

3.5 Long-term estimation

Tab. 6 presents an estimate of the CCEMG and AMG models to explore the nexus between technological innovation, economic progress, circular economy, urbanization, and green finance on the *EFP* in Central Europe. The findings revealed that technological innovation, circular economy, and green finance decelerate ecological footprint, with a percentage change in these variables econtributing to a reduction in ecological damage by 0.782, 0.303, and 0.355, respectively. However, *UBZ*, *ENE*, and economic progress accelerated environmental deterioration, with a 1% change contributing to values of 0.883, 0.601, and 0.652 under the CCEMG approach. Likewise, AMG results align with CCEMG estimates with minor changes in coefficient values. This indicates that an increase or decrease in these variables aligns more closely with the *EFP* over the long term. The diagnosis outcome of *R*-squares adjusted *R*-squares, and the *F*-statistics affirmed that the independent variable explained the dependent variable favorably under both models.

Tab. 6: Long-term evaluation

Variable	CCEMG		AMG	
	Coefficient	Std. error	Coefficient	Std. error
ln*TNI*	−0.782***	0.029	−0.407***	0.043
ln*GNF*	−0.355***	0.068	−0.116***	0.053
ln*UBZ*	0.883***	0.163	0.428***	0.104
ln*ENE*	0.601***	0.266	0.590***	0.697
ln*CRE*	−0.303***	0.204	−0.734***	0.255
ln*ECP*	0.652***	0.092	0.683***	0.235
Constant	8.796***	2.190	14.936***	3.283
Diagnostic test				
R-squared	0.869		0.854	
Adjusted *R*-squared	0.861		0.845	
SE of regression	0.658		0.715	
Sum squared resid	97.190		96.135	
Log-likelihood	−227.781		−235.090	
F-statistic	75.759		87.644	
Prob(*F*-statistic)	0.000		0.000	

Source: own

3.6 Robustness test

In Tab. 7, two econometric models were employed to test the robustness of the empirical outcome from Tab. 6. The FMOLS and DSK estimators were considered following Ahakwa et al. (2023) which served as a reliability check. The estimates and coefficients affirmed the previous results that technological innovation, green finance, and circular economy exhibited a positive effect on the ecological footprint within Central European communities. Likewise, energy consumption, economic progress, and urbanization negatively impacted the ecological footprint.

Tab. 7: FMOLS and DSK evaluation

Variable	FMOLS model		DSK model	
	Coefficient	*p*-value	Coefficient	*p*-value
ln*TNI*	−0.775***	0.000	−0.953***	0.004
ln*GNF*	−0.802***	0.000	−0.862***	0.000
ln*UBZ*	0.825***	0.003	0.785***	0.000
ln*ENE*	0.947***	0.000	0.931***	0.000
ln*CRE*	−0.702***	0.001	−0.597***	0.000
ln*ECP*	0.525***	0.000	0.783***	0.000

Note: *** depicts significant coefficient at 1%, ** 5% and * 10%, respectively.

Source: own

3.7 Causality test

We evaluated the causality approach of D&H to assess the impact of *TNI*, *CRE*, *ENE*, *GNF*, *UBZ*, and *ECP* on *EFP* in the Central European region. The D&H principle outlines the long-term bidirectional, unidirectional, or no-directional nexus between the indicators. As illustrated in Tab. 8 and Fig. 2, technological innovation had a unidirectional connection with *EFP* in the long term. The evaluation demonstrated that *TNI* depreciates the speed of ecological footprint within Central Europe. The outcome depicts that policy adoptions toward technological innovation by enterprises and governments will lead to a quality ecosystem. The work of Kirat et al. (2024) affirms these findings. Again, the investigation revealed that green finance had a two-way nexus with ecological damage. The underlying results explained that green finance upsurges or surges ecosystem quality in Central European communities.

Tab. 8: D&H evaluation

Null hypothesis	W-stat.	*Z*-stat.	Prob.	Decision
TNI ⇎ ***EFP***	2.171	0.004	0.996	
EFP ⇎ **TIN**	20.188***	20.243	0.000	Unidirectional
ENE ⇎ ***EFP***	12.5467***	7.426	0.000	
EFP ⇎ ***ENE***	10.058**	8.245	0.011	Bidirectional
GNF ⇎ ***EFP***	1.464	0.788	0.430	
EFP ⇎ **GFN**	8.172***	6.746	0.002	Unidirectional
CRE ⇎ ***EFP***	1.578	0.660	0.508	
EFP ⇎ ***CRE***	11.485***	3.270	0.756	Unidirectional
UBZ ⇎ **ECF**	7.439**	0.305	0.020	
EFP ⇎ ***UBZ***	10.311**	4.148	0.000	Bidirectional
ECP ⇎ ***EFP***	1.819	0.225	0.550	
EFP ⇎ ***ECP***	8.295***	0.744	0.4565	Bidirectional

Note: *EFP* – ecological footprint; *TNI* – technological innovation; *CRE* – circular economy; *UBZ* – urbanization; *ENE* – energy consumption; *ECP* – economic progress.

Source: own

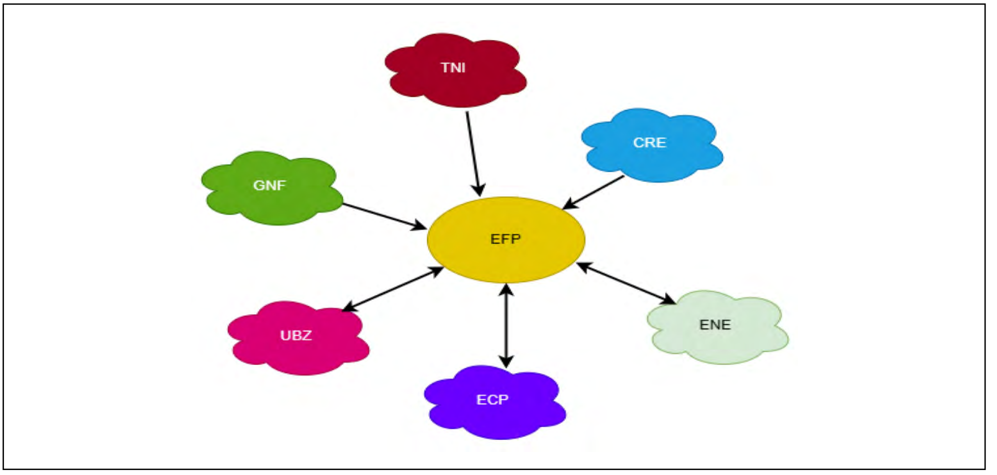

Fig. 2: **Causality evaluation**

Source: own

4 Discussions

The highlighted findings from the CCEMG and AMG models indicated that technological innovation had a negative link with ecological footprint, with −0.775 and 0.953, respectively, within the Central European communities. The results attested to the improvement of green technological innovation investments, such as electric automobiles. The European Union deals with principles to forge and transit to a more sustainable community. On the path to UNSDG-13, Bekun (2024) explored South African technological innovation methodologies to mitigate ecological deterioration. The investigation's findings confirm that technological advancement enhances ecosystem quality. Additionally, Saqib et al. (2024) examined ten most polluted and with high ecological footprint quota. The empirical findings demonstrated that innovation deployment in the communities had aligned with a depreciation in greenhouse gas. Conflicting with our estimates, Sun et al. (2024) established that China's recent investment in petrochemical enterprises and adoption of technological innovations had posed an increase in their ecological footprint.

According to empirical estimates, a 1% appreciation in green finance reduces ecological deterioration by −0.355 CCEMG and −0.116 AMG in the Central European regions. The recently adopted green monetary policies (green bonds, green credit, and green loans) initiatives by the EU central bank government are a signpost to mitigate ecosystem damage. The experiment conducted by Sampene et al. (2023) in South Asian communities, the assessment conducted by Khan et al. (2022) in 26 Asian regions, and the evaluation conducted by Mohsin et al. (2023) in European nations all support the notion that green portfolios can enhance environmental quality. Despite the positive findings, Sun and Rasool (2023) found that these policies in Europe's top 10 green finance regions negatively impact the environment. The article recommended that a proper green finance initiative will reduce environmental deterioration.

With the econometric empirical assessment of urbanization, all the dynamic approaches established an upsurge in ecological footprint with a percentage of 1% shift in urbanization, resulting in 0.833 and 0.428 favorable rises in environmental damage within Central European communities. This outcome is associated with the desire for the population to move from rural enclaves to urban communities in search of white-collar jobs, infrastructure, and a favorable lifestyle. This trend coincides with the rise in urban transport emissions, which are primarily attributed to fossil fuel emissions and road infrastructure. Zhang and Chen (2023) investigation in China illustrated the connection between carbon emissions and urbanization, affirming that urbanization appreciates China's urban carbon footprint. Similarly, Arif et al. (2023) confirmed in the context of Pakistan that the urban carbon footprint is associated with foreign investment and the establishment of industrial enterprises in urban areas. Contradictory to the estimates, Addai et al. (2022) investigation in Eastern Europe on the affiliation between ecological footprint and urbanization for a period 1998Q4 and 2017Q4. Employing the econometric technique of common correlated effect mean group and the Dumitrescu Hurlin causality, the findings indicated that urbanization appreciate ecological footprint. Also, a bidirectional causality was found between the nexus of urbanization and ecological footprint. Additionally, Tanveer et al. (2024) argued that urbanization improves the quality of ecosystems. An important element in reducing the damaging effect of urbanization could be linked to the awareness-action nexus of Toth and Sebova (2024) in the mitigation context.

Furthermore, *ENE* demonstrated a significant and positive correlation, with *EFP* accounting for 0.601 and 0.590 for every 1% increase in the use of coal, fossil fuels, and gases in Central Europe. This evaluation clarified that due to Central Europe's reliance on non-renewable energy, countries like Poland and Hungary consume a significant amount of coal and fossil fuels, increasing their carbon footprint indices. This empirical study shows that economic growth harmed the ecological footprint, as shown by the coefficients 0.635 and 0.683 for the CCEMG and AMG approaches, respectively. This suggests that a 1% appreciation in economic progress intensifies the *EFP* in Central European regions. The outcome from the investigation corroborates with Baz et al. (2020) employed the nonlinear model to examined ecological footprint in Pakistan between 1971–2014. The findings demonstrated that energy consumption is affiliated with economic growth resulting in carbon footprint rising. Likewise, Qing et al. (2024) confirm a material effect traditional energy consumption on ecological footprint in Pakistan. They established that both in the long and short run oil, coal, and gas had adverse effects on biocapacity.

A circular economy had a favorable affiliation with *EFP* in the long term, with a CCEMS value of −0.303 and an AMG value of −0.734. Circular economic principles are linked with waste and food security to diminish ecological footprints in the Central European community. The global food indices for 2019 bring household food waste to sixty-one percent. The findings demonstrated that methodologies like e-waste and recycling, reproduction, and reuse reduce ecological footprints. In line with the evaluations, Almulhim (2024) assessment in Kingdom of Saudi Arabia on the affiliation between circular economy and environmental sustainability. The outcome established that circular economy principles were able to improve the nation's food sector. Likewise, Thapa et al. (2024) corroborated the affirmation that the circular economy paradigm reduces environmental deterioration. The research is not consistent with the works of Figge and Thorpe (2023) and Halkos and Aslanidis (2024). Unsurprisingly, the circular economy had a major impact on ecological footprint depreciation, with these communities integrating the EU green deals and principles into their sustainability target.

Conclusions

The increase in anthropogenic activities on natural resources has motivated the government and researchers to evaluate these ecological damages. The influence of technological innovation, green finance, circular economy, urbanization, and economic progress on ecological footprint is assessed in the Central European communities. The data curation from 1990–2022 was adopted from verified sources to avoid bias. A robust econometric approach was employed to test the data normality and its nexus effect. The cross-sectional dependence and slope heterogeneity were evaluated to estimate the various collinearities. Likewise, the unit root and cointegration accounted for the approach stability and long-run connection between the variables. The study highlighted that *TNI*, *GNF*, and *CRE* positively impacted ecological footprints through CCEMG and AMG estimators, which were confirmed by the FMOLS and DSK approaches. This analysis demonstrates that when Central European communities adopt these measures, their ecological footprint will be reduced. Moreover, the affiliation with the *EFP* highlighted the negative impact of urbanization, economic progress, and energy consumption. In this sense, economic progress is needed to switch to more efficient and renewable energy while not affecting productivity.

Next, the D&H causality was employed to estimate the link between *TNI*, *CRE*, *ENE*, *GNF*, *UBZ*, and *ECP* on ecological footprint. Consistent with econometric approaches evaluations, technological innovation, green finance, and circular economy displayed a unidirectional nexus with ecological footprint within Central Europe regions. The results have induced suggestions to depreciate ecological damage without a reverse effect. On the other hand, urbanization, energy utilization, and *ECP* had a bidirectional nexus with the ecological footprint in the Central European countries. The findings exhibited policy directions to combat environmental deterioration in the Central European communities. Central European countries should invest in research and support industrial enterprises in adopting necessary technologies to mitigate environmental damage. Additionally, tax incentives and policies that facilitate the inflow of technology from neighboring regions to utilize eco-friendly resources should be prioritized in future agendas. Again, green finance had a favorable and significant impact on the ecological footprint. Countries such as Germany, which lead in green finance policies like green credit, green bonds, and green loans play a crucial role in directing investments. Regions like Poland and Slovakia can adopt similar strategies to empower local manufacturers with the necessary capital to invest in energy projects, such as electric vehicles and household energy efficiency, thereby reducing their reliance on coal and fossil fuels. Additionally, circular economy is viewed as the future of resource conservation because it keeps products in circulation and allows them to be reused for various purposes before they eventually end up in landfills. With the EU Green Deal and the municipal waste separation policy set for 2030, Central European communities that implement stringent policies will lower their levels of municipal waste, contributing to a healthier ecosystem and potentially increasing life expectancy. Furthermore, governments could modernize small communities by improving basic facilities and infrastructure to reduce migration to urban areas. Encouraging the private sector to invest in rural development such as opening branches in these regions can help retain young people and prevent them from moving to cities in search of better jobs. Finally, as energy consumption and economic progress go hand in hand, it is recommended that governments invest in renewable energy sources which are more environmentally friendly. Additionally, policies should encourage households to minimize energy use during times.

Limitation. The study has some specific shortfalls, including the fact that it only includes data from Central Europe. As a result, the findings may not apply to Asian or African communities. Future research should explore regions such as Africa, BRICS nations, Asia, and Oceania. Moreover, various econometric principles and methodologies should be employed to analyze the affiliation between these factors and the ecological footprint.

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Taxation and informality in the labor market: Implications for the transition to a circular economy

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Abstract: *This paper explores the intricate relationships between the sustainable development goals (SDGs) with a specific focus on SDG8 (decent work and economic growth), and key circular economy (CE) indicators: recycling, resource efficiency, waste reduction, and CO_2 emissions reduction. This study introduces a log-linear model to analyze the synergies and trade-offs between SDG8 and CE indicators, emphasizing the critical role of fiscal policies and informality in shaping sustainable outcomes. Various scenarios are evaluated, integrating these contextual factors to assess their impact on the effectiveness of CE practices in advancing SDG8. The findings highlight that a combination of low informality and favorable fiscal policies produces the strongest synergies, enhancing job quality, resource efficiency, and environmental sustainability. Conversely, high informality paired with neutral fiscal policies leads to diminished impacts, underscoring the need for integrated approaches to formalize economies and strengthen fiscal incentives for sustainability. The results lead to a structured framework to understand how different policy environments affect the role of CE in sustainable development, presenting testable hypotheses for future empirical research. By examining the dynamic interplay between the informal economy, taxation, and sustainability, this work offers valuable insights for policymakers aiming to align economic, social, and environmental objectives. The conclusions contribute to developing effective strategies that support balanced, sustainable growth, enhancing the practical application of CE within the SDG framework.*

Keywords: *Circular economy, sustainable development goals (SDGS), decent work, economic informality, labor informality, taxation, economic transition.*

JEL Classification: *E26, H23, J46, K34.*

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Introduction

Sustainability is a complex goal encompassing intertwined environmental, social, and economic challenges. The UN's sustainable development goals (SDGs), adopted in 2015, outline a global development roadmap, but progress across these goals is interconnected. Synergies occur when advancement in one SDG benefits others, while trade-offs may limit progress on other goals (Bali & Ranganathan, 2021; Kuc-Czarnecka, 2020). This interconnectedness necessitates a systematic analysis of SDG relationships and potential tensions for effective sustainability policies.

The circular economy (CE) has emerged as a strategy to reduce environmental impact by closing production cycles through recycling, reuse, and material efficiency (Geissdoerfer et al., 2017). However, CE risks becoming an "empty concept" without a focus on inclusivity and equity, especially in sectors like recycling, where informal labor dominates in less developed countries, often under low social protection (Amato et al., 2024; Gittins & Letenyei, 2023; Steuer et al., 2018).

This paper focuses on SDG8 (decent work and economic growth) due to its dual emphasis on social and economic development, making it a key target for examining SDG and CE interactions. In many developing countries, informal employment represents a large share of the workforce, posing challenges for sustainable development, as informality reduces transparency and hampers sustainable policy implementation (ILO, 2018).

In addition to informality, this study considers the role of fiscal systems in promoting sustainability. Informality acts as a barrier, particularly in waste recycling, where lack of regulation is common (Fevrier, 2022; Steuer et al., 2018). A favorable tax system, however, can encourage sustainable practices, particularly in countries with high informality (OECD, 2022). This paper seeks to analyze synergies and trade-offs between SDG8 and CE indicators under varying informality and tax scenarios, proposing hypotheses for future empirical research.

For the purposes of this study, informality is defined as the proportion of economic activities and employment that operate outside of formal regulatory and taxation frameworks. This includes unregistered businesses and workers who do not benefit from formal labor protections (ILO, 2018).

Fiscality is defined as the array of fiscal policies, including taxation and fiscal incentives, that governments employ to regulate economic activities and promote sustainable practices. In this context, fiscality specifically refers to the policy measures that can either enhance or hinder the effectiveness of circular economy practices in achieving sustainable development goals (OECD, 2011).

This research is organized as follows: a theoretical review introduces key variables and relationships, the second section details the methodology, and the third presents results with a discussion. Conclusions and references follow.

1 Theoretical background

The notion of sustainability in the literature encompasses a systemic approach where economic, social, and environmental aspects must be balanced to ensure inclusive and long-term development (Brundtland, 1989). In the quest for a better world, the SDGs represent a comprehensive framework for achieving this purpose. They set specific goals, concrete targets, and indicators to assess progress. In this way, countries can focus their efforts in a coordinated manner. However, these goals are interrelated with each other (UN General Assembly, 2015); they interact through networks of interdependence that generate synergies or trade-offs. These relationships, documented in work such as that of Bali and Ranganathan (2021), are essential for understanding how progress in one area can spill over into others in order to maximize co-benefits and mitigate adverse effects.

In this context, the circular economy (CE) has positioned itself as a strategy to promote sustainability by reducing waste and maximizing resource efficiency (Stankeviciene et al., 2020). The main CE indicators, such as recycling, resource efficiency, waste reduction, and reduction of CO_2 emissions, are indicators that allow the progress and assessment of EC toward a more sustainable economic system (Ghisellini et al., 2016). However, CE presents challenges when applied in social justice and sustainable development contexts, especially in lower-income countries. For example, waste recycling, a core practice of CE, is highly linked to informality in developing countries, where workers without labour protection or social security are involved in materials recovery (Vázquez Silva & de Rivera Outomuro, 2024). This calls into question the EC's ability to promote sustainable development if there are not adopted specific strategies to include these sectors in decent conditions.

At this point, SDG8 is fundamental, as it addresses both economic development and social justice through the promotion of decent work; hence, it is a key element in this research. In developing countries, where informal

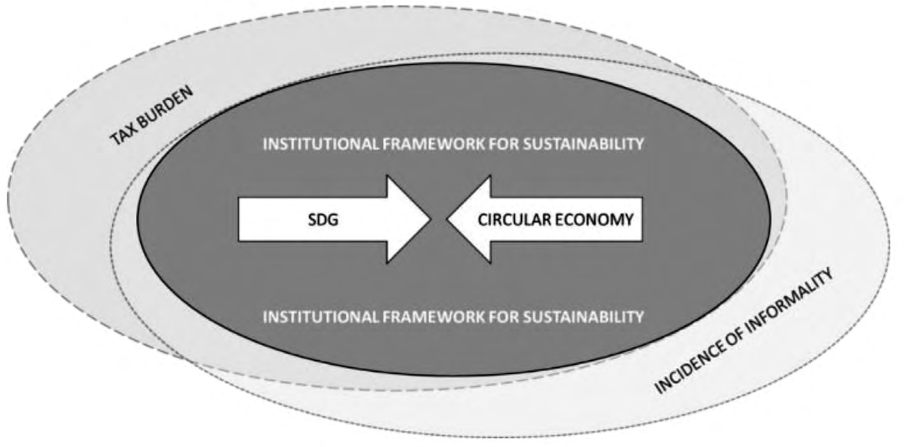

Fig. 1: Diagram of the interrelationships between SDGs and EC according to the institutional context, tax burden and incidence of informality

Source: own

employment reaches high rates in sectors such as agriculture and industry, barriers to sustainable growth are exacerbated, affecting the ability of countries to implement formal EC practices (International Labour Office, 2018).

Beyond income and development levels, institutional support for sustainability is key to advancing SDGs. Here, the fiscal system refers to government policies that shape economic and sustainability choices. A favorable tax system with incentives promotes sustainable practices like circular economy initiatives, resource efficiency, and emissions reduction, lowering costs and boosting benefits for aligned companies. A neutral tax system, lacking sustainability incentives, may limit positive impacts, especially in high-informality contexts where limited tax reach and capacity make tax design crucial, influencing connections between SDG8 and CE indicators (Barrie et al., 2022).

This model considers two interrelated variables (SDGs and CE) across multiple scenarios, accounting for varying outcomes based on context. Key factors include the government's commitment to sustainable development (assessed through the fiscal system) and the economic environment, particularly the influence of informal labor markets. This relationship and its contextual variations are shown schematically in Fig. 1. Fig. 1, provides a schematic representation of how institutional contexts, including tax burden and informality, influence the interactions between SDGs and CE indicators.

1.1 Variables in the model

While eco-design innovation and durability and product life cycle are recognized as important dimensions of the circular economy, this study intentionally excludes these indicators to maintain a focused empirical analysis. Our framework concentrates on recycling, resource efficiency, waste reduction, and CO_2 emissions reduction, which more directly capture the impacts of fiscal policies and labor informality on sustainable outcomes. This narrower focus is supported by the literature, which suggests that limiting the range of indicators can enhance empirical tractability and theoretical clarity (Kirchherr et al., 2017). By aligning our analysis with these dimensions, we ensure that the model robustly assesses the influence of institutional contexts on circular economy practices without diluting the central relationships under investigation.

We initially considered six CE indicators (Tab. 1), but opted for four key ones (recycling, resource efficiency, waste reduction, and CO_2 emissions) to simplify the analysis. The literature supports this selection (Fraser et al., 2023; Ghisellini et al., 2016; Lieder & Rashid, 2016) as it captures essential material management and direct environmental impact. Following Blomsma and Brennan (2017), the elimination of durability and product life cycle (DLLC) and eco-design innovation (EDI) is explained, without undermining their importance, by the fact that they present challenges in terms of precise quantification and their effects are often indirectly reflected in resource efficiency and waste reduction. Tab. 1 shows the CE summary of information captured for each indicator.

Tab. 1: Circular economy indicators

Initial indicator	Equivalent final indicator	Description of equivalence
1. Recycling (R)	Recycling (R)	The percentage of recycled materials is directly represented in the final recycling indicator
2. Resource use efficiency (ER)	Resource use efficiency (ER)	The proportion of reused products is directly reflected in this indicator, measuring resource optimization
3. Waste reduction (RW)	Waste reduction (RW)	The amount of waste avoided is a fundamental aspect that is retained in the waste reduction indicator
4. Product durability and lifecycle (DCLP)	Resource use efficiency (ER) and waste reduction (RW)	Extended product lifespan and durability reduce the need for new resources (ER) and decrease waste generation (RW)
5. Eco-design innovation (IED)	Waste reduction (RW) and resource use efficiency (ER)	Eco-friendly design minimizes waste production and optimizes resource use, indirectly contributing to these indicators
6. Carbon emissions (CO_2)	Carbon emissions (CO_2)	Circular economy practices that reduce carbon emissions are directly represented in this indicator

Source: own

1.2 The interrelationships of the different SDGs with each other

Each SDG is expressed as an equation that captures these interactions of synergies and trade-offs with respect to the other SDGs. The log-linear model represents the interrelationship among the SDGs in a suitable way, due to the characteristics of these variables. See Equation (1).

$$\log(SDG_i) = \beta_{i1} \cdot \log(SDG_2) + \beta_{13} \cdot \log(SDG_3) + \beta_{14} \cdot \log(SDG_4) + \cdots + \beta_{17} \cdot \log(SDG_{17}) + \epsilon_i \quad (1)$$

where: β_{ij} coefficients represent the nature of the interaction: if it is synergy ($\beta_{ij} > 0$ or trade-off $\beta_{ij} < 0$), and ϵ_i represents the error term, capturing any unexplained variation between SDGs. To represent these interrelationships in matrix form, let *SDG* be a vector containing the log-transformed values of progress levels for each SDG: Equation (2).

$$\log(SDG) = \begin{bmatrix} \log(SDG_1) \\ \log(SDG_2) \\ \vdots \\ \log(SDG_{17}) \end{bmatrix} \quad (2)$$

The interaction coefficient matrix *A* is a 17 × 17 matrix where each element; α_{ij} represents the influence of SDG_i in SDG_j shown in Equation (3), where $\alpha_{ij} > 0$, $\alpha_{ij} < 0$, $\alpha_{ij} = 0$ indicates a positive synergy, a potential trade-off and no direct interaction between SDG_i and SDG_i, respectively.

The baseline vector β is a 17 × 1 vector representing the baseline progress levels of each SDG without interactions. ϵ is a 17 × 1 vector representing external factors or random variations impacting each

SDG. The matrix equation is the one in Equation (3).

$$\log(SDG) = \beta + A \cdot \log(SDG) + \epsilon \qquad (3)$$

where: A log(SDG) is the matrix product that accounts for the influence of each SDG on the others; β is the baseline level of each SDG; ϵ is the error term vector.

Equation (4) gives the solution for solving the system for SDG progress.

$$\log\,(SDG) = (I - A)^{-1} \cdot (\beta + \epsilon) \qquad (4)$$

where: I is the identity matrix of size 17 × 17 and (I − A) represents the inverse matrix of I − A, which allows to capture the cumulative effects of interdependencies across SDGs. The invertibility of the matrix (I − A) is a key point and crucial for solving this model some key considerations and justifications for the likelihood of invertibility in this context must be attended. The first condition is that the determiant $|I - A| \neq 0$. If the diagonal elements of A are all 1, then (I − A) will have zeros on the diagonal, making it non-invertible and causing the system to have no unique solution.

As the main focus of this work is on SDG8 and the circular economy, taking into account the influence of the informal economy and taxation, this will not be an issue. Furthermore, this situation is analysed under different institutional scenarios. As a first step, a review of the academic literature is carried out to analyse the possible synergies and trade-offs between SDG8 and the other SDGs. So, we have selected for a more specific analysis the SDG8 (SDG8 decent work and economic growth), which is the one most appropriate for analysing the most direct effects of the informal economy and fiscality on the labour market (Tab. 2).

Tab. 2: Interactions of SDG8 with other SDGs and justification of coefficient signs – Part 1

SDG	Interaction sign (+/−)	Justification	Source
SDG1	+	Growth and jobs under SDG8 reduce poverty by increasing income and opportunity	Wei et al. (2023); Frey (2018); Banerjee and Duflo (2011)
SDG2	+	Decent work improves food security through higher income and better access	Salifu and Salifu (2024); Food and Agriculture Organization (2019); Larson and Larson (2019)
SDG3	+	Stable jobs contribute to better health by reducing insecurity and improving benefits	Picatoste et al. (2021); Benach et al. (2007)
SDG4	+	Education funding and job quality improve access and employability	Makarenko et al. (2021); Picatoste et al. (2018); Psacharopoulos and Patrinos (2018)
SDG5	+	Equal opportunities reduce gender gaps and enhance economic inclusion	International Labour Office (2019b); Picatoste et al. (2022); Rai et al. (2019)
SDG6	+/−	Jobs support water infrastructure, but growth can increase water strain	Mekonnen and Hoekstra (2016); UNESCO (2018)
SDG7	+/−	SDG8 can promote clean energy but may also raise energy demand if unmanaged	IEA (2024); McCollum et al. (2018)

Tab. 2: Interactions of SDG8 with other SDGs and justification of coefficient signs – Part 2

SDG	Interaction sign (+/−)	Justification	Source
SDG9	+	Economic growth drives investment in sustainable industry and infrastructure	Opoku et al. (2024); Mahmood et al. (2024)
SDG10	+	Decent work reduces inequalities by providing fair access and wages	Wilkinson and Pickett (2010); Piketty (2014).
SDG11	+/−	Urban resilience depends on sustainable planning; rapid growth can strain resources	Seto et al. (2012)
SDG12	+/−	Growth encourages sustainable production; high demand can strain resources	Suárez-Eiroa et al. (2019); Geissdoerfer et al. (2017); Jackson (2017)
SDG13	+/−	Sustainable jobs support climate goals, but traditional industries may raise emissions	Rueda Fiorentino and Coronell (2024); International Labour Office (2019a); Steffen et al. (2015)
SDG14	+/−	Responsible growth protects marine life; unregulated growth can harm ecosystems	Halpern et al. (2008); Mora and Sale (2011)
SDG15	+/−	Sustainable industry benefits biodiversity; unchecked expansion risks ecosystems	Barbier (2020); Dasgupta (2021)
SDG16	+	Decent work enhances governance by supporting economic stability and equality	Acemoglu and Robinson (2012); Rodrik (2007)
SDG17	+	Economic growth strengthens partnerships, increasing funding and collaboration	OECD (2018); Sachs (2015)

Source: own

SDG8 synergizes with SDGs1, 3, 4, and 10, as decent work and growth enhance stability, health, and equity. However, unsustainable growth risks environmental trade-offs with SDGs6, 12, 13, 14, and 15. Mixed effects in SDGs7 and 11 highlight the need for clean energy and thoughtful urban planning to sustain economic benefits.

Tab. 2 outlines SDG8's effects on other SDGs, highlighting growth and job creation's positive and negative impacts, contingent on sustainable policies. Each sign is backed by literature, providing a foundation for understanding interactions in the circular economy and SDG context.

To model the interactions of SDG8 with the other SDGs, the structure of the general equation is in Equation (5):

$$\log(SDG_8) = \sum_{j \neq 8} \beta_{8j} \log(SDG_j) + \epsilon_8 \quad (5)$$

where: SDG_8 represents the level of progress of SDG8; SDG_j represents each SDG that interacts with SDG8; β_{8j} is the interaction coefficient, positive for synergies (+) and negative for trade-offs (−); ϵ_8 is the error term, capturing other unexplained external factors.

To deepen the analysis of SDG8 (decent work and economic growth), we formalized a mathematical model using summations to capture synergies and trade-offs at the target level, with each SDG8 target interacting with other SDG targets, as shown in Equation (6):

$$\log(SDG_8) = \sum_k \log(M_{8k}) + \sum_k \sum_{i \neq 8} \sum_j \alpha_{8k,ij} \cdot \cdot \log(M_{8k}) \cdot \log(M_{ij}) + \epsilon_8 \quad (6)$$

where: SDG_8 represents overall progress on *SDG*8; M_{8k} are targets specific to SDG8; M_{ij} are the particular targets of other SDGs (with $i \neq 8$); $\alpha_{8k,ij}$ is the interaction coefficient between SDG_8 target M_{8k} and other SDG target: M_{ij}; $\alpha_{8k,ij} > 0$ indicates synergy (positive effect); $\alpha_{8k,ij} < 0$ indicates a trade-off (negative effect); ϵ_8 is the error term, which captures the unexplained variations.

This model captures all effects and interactions, providing a comprehensive view of economic growth and decent work policies within the SDG framework. We have examined SDG8's theoretical interactions with other SDGs using a matrix to visualize synergies and tensions. Then, we focused on SDG8's targets in relation to circular economy (CE) indicators: recycling (R), resource efficiency (RE), waste reduction (RW), and CO_2 emissions reduction (CO_2), clarifying SDG8's role in circular economy sustainability.

2 Research methodology

A log-linear model is the selected method to analyse the interactions between SDG8 and CE indicators. This structure allows interpreting each coefficient β_i as the elasticity of the corresponding indicator on SDG8, i.e., the percentage change in SDG8 resulting from a percentage change in each EC indicator (Greene, 2012). In addition, this approach is suitable for capturing the saturation effect in indicator performances, a feature observed in sustainability and environmental efficiency studies (Porter & van der Linde, 1995; Stern, 2004). Using a logarithmic approach, the linearized model simplifies analysis of diminishing returns, enabling clear interpretation of SDG8 and CE indicator interactions.

Through a relationship matrix capturing synergies and trade-offs, the model examines how taxation and economic informality levels impact these interactions. Simulation scenarios explore how these factors affect CE practices' progress on SDG8, identifying sustainable impact patterns and critical policy areas. Variables and log-linear relationships are detailed in Equations (5–6) for SDG interactions, and Equation (7) for CE. Taxation (favorable or neutral) and informality (adjusted by a γ coefficient for low/high informality) define the institutional context.

The theoretical model uses a log-linear function to connect SDG8 with essential CE indicators: recycling (R), resource efficiency (RE), waste reduction (RW), and CO_2 emissions (CO_2). This approach reflects diminishing returns, where each additional increase in CE indicators yields more minor marginal benefits as a saturation point approaches (Daly, 1996; Tietenberg and Lewis, 2018). The proposed functional form of the model is in Equation (7):

$$\log(SDG_8) = \beta_0 + \beta_1 \log(R) + + \beta_2 \log(ER) + \beta_3 \log(RW) + + \beta_4 (CO_2) + \varepsilon \quad (7)$$

where: $\log(SDG_8)$ represents the logarithm of SDG8 progress; β_0 is the constant of the model; β_i (for i = 1, 2, 3, 4) are the partial elasticity coefficients that measure the percentage effect of each EC indicator on SDG8; ϵ is the error term.

On the other hand, the relationship matrix effectively highlights possible synergies and trade-offs among multiple SDGs, offering a clear, structured view of how each CE indicator might impact various SDGs and vice versa. This is particularly valuable in theoretical analysis, as it facilitates examining multiple reciprocal relationships, especially when effects are non-linear or each SDG influences others both directly and indirectly. As pointed out by Le Blanc (2015), the synergies and trade-offs require a holistic approach like this, as it allows theorizing about the directions of interactions and initially categorizing the effects as positive (synergies) or negative (trade-offs), depending on the literature or the specific context (Nilsson et al., 2016).

3 Results and discussion

3.1 Results

Tabs. 3–6 are the four relationship tables, linking the targets of SDG8 with each circular economy (CE) indicator: recycling (R), resource efficiency (ER), waste reduction (RW), and CO_2 emissions reduction (CO_2).

Tab. 3: Relationship among SDG8 targets and recycling (R)

SDG8 target	Relationship with recycling indicator (R)	Justification	Academic source
Target 8.1: Economic growth	Enhances growth by improving resource efficiency	Reduces reliance on virgin resources, promoting sustainable growth	Porter and Linde (1995); Geissdoerfer et al. (2017)
Target 8.2: Labor productivity	Supports productivity in sustainable industries	Fosters innovation in materials, boosting green sector productivity	Stahel (2016); Kirchherr et al. (2017)
Target 8.3: Job creation in small and medium enterprises	Creates jobs and supports SMEs in waste management	SMEs are crucial in recycling, generating green jobs	Ellen MacArthur Foundation (2018); McCarthy et al. (2018)
Target 8.4: Resource efficiency	Directly improves resource efficiency	Minimizes virgin material waste, enhancing efficiency	Kirchherr et al. (2017); Korhonen et al. (2018)
Target 8.5: Inclusive and sustainable employment	Generates inclusive, sustainable jobs	Recycling supports formal, sustainable employment	ILO (2022); McCarthy et al. (2018)
Target 8.6: Youth employment	Provides entry-level opportunities	Offers accessible jobs for youth in sustainability	Ellen MacArthur Foundation (2018)
Target 8.7: Eradication of forced labor and child exploitation	Formalization reduces unregulated labor risks	Minimizes forced labor and exploitation in unregulated markets	Preston (2012); ILO (2022)
Target 8.8: Worker rights and safe environments	Formalization improves workplace safety	Enforces regulations that protect rights and safety	Stahel (2016); Geissdoerfer et al. (2017)
Target 8.9: Sustainable tourism	Not applicable	No direct link to tourism	N/A
Target 8.10: Financial access	Not applicable	No direct relation to financial inclusion	N/A
Target 8.a: Aid for trade	Aligns with sustainable trade aid	Supports sustainable recycling initiatives in developing countries	Preston (2012); Ellen MacArthur Foundation (2018)
Target 8.b: Job creation and economic development policies	Aligns with green job creation policies	Policy support for recycling promotes sustainable jobs	McCarthy et al. (2018); Kirchherr et al. (2017)

Source: own

Tab. 4: Relationship among SDG8 targets and resource efficiency (ER)

SDG8 target	Relationship with resource efficiency indicator (ER)	Justification	Academic source
Target 8.1: Economic growth	Enhances sustainable growth by reducing costs	Improved efficiency lowers costs, supporting sustainable growth	Geissdoerfer et al. (2017); Tietenberg and Lewis (2018)
Target 8.2: Labor productivity	Boosts productivity through optimized processes	Allows productivity gains without major cost increases	Stahel (2016); Korhonen et al. (2018)
Target 8.3: Job creation in small and medium enterprises	Strengthens SMEs via reduced material costs	Supports SMEs by lowering costs and enhancing efficiency	Kirchherr et al. (2017); Ellen MacArthur Foundation (2018)
Target 8.4: Resource efficiency	Fully aligned with improving efficiency	Resource-efficient production reduces waste and impact	McCarthy et al. (2018); Stahel (2016)
Target 8.5: Inclusive and sustainable employment	Generates green jobs in resource management	Efficiency in resources creates jobs in engineering, environmental fields	ILO (2023); Kirchherr et al. (2017)
Target 8.6: Youth employment	Opens sustainable job opportunities for youth	Provides roles in resource management and sustainability sectors	Ellen MacArthur Foundation (2018); McCarthy et al. (2018)
Target 8.7: Eradication of forced labor and child exploitation	Minimizes reliance on informal labor practices	Efficiency sectors support formal, safer jobs	Preston (2012); ILO (2023)
Target 8.8: Worker rights and safe environments	Reinforces safe, regulated workplaces	Regulated practices uphold safety and labor standards	Stahel, 2016; Tietenberg and Lewis (2018)
Target 8.9: Sustainable tourism	Not applicable	No direct impact on tourism	N/A
Target 8.10: Financial access	Not applicable	No direct impact on financial services	N/A
Target 8.a: Aid for trade	Supports sustainable practices in trade	Trade aid can promote efficiency in developing nations	Tietenberg and Lewis (2018); Ellen MacArthur Foundation (2018)
Target 8.b: Job creation and economic development policies	Aligns with job creation in sustainability sectors	Policies fostering efficiency create jobs in green sectors	Kirchherr et al. (2017); Stahel (2016)

Source: own

Tab. 5: Relationship among SDG8 targets and waste reduction (RW)

SDG8 target	Relationship with waste reduction indicator (RW)	Justification	Academic source
Target 8.1: Economic growth	Supports sustainable growth by lowering costs	Minimizing waste cuts production costs and resource dependency	Porter and van der Linde (1995); Geissdoerfer et al. (2017)
Target 8.2: Labor productivity	Boosts productivity by reducing inefficiencies	Waste reduction streamlines processes, increasing productivity	McCarthy et al. (2018); Kirchherr et al. (2017)
Target 8.3: Job creation in small and medium enterprises	Creates jobs in sustainable waste management	SMEs in waste management employ workers in recycling and sustainability	Ellen MacArthur Foundation (2018); Preston (2012)
Target 8.4: Resource efficiency	Directly enhances resource use efficiency	Minimizes material use, improving overall efficiency	Stahel (2016); Korhonen et al. (2018)
Target 8.5: Inclusive and sustainable employment	Fosters formal, sustainable jobs	Supports job creation in recycling, waste management, and environmental sectors	ILO (2023); McCarthy et al. (2018)
Target 8.6: Youth employment	Provides entry-level jobs for youth	Offers accessible jobs in waste management and sustainability	Ellen MacArthur Foundation (2018)
Target 8.7: Eradication of forced labor and child exploitation	Reduces informal labor risks	Formal waste management lowers forced labor risks	Preston (2012); ILO (2023)
Target 8.8: Worker rights and safe environments	Improves safety and worker rights	Formal waste practices ensure regulated, safer workplaces	Stahel (2016); Tietenberg and Lewis (2018)
Target 8.9: Sustainable tourism	Not applicable	No direct impact on tourism	N/A
Target 8.10: Financial access	Not applicable	No direct impact on financial inclusion	N/A
Target 8.a: Aid for trade	Aligns with sustainable trade practices	Trade aid can support waste reduction in developing countries	Preston (2012); Geissdoerfer et al. (2017)
Target 8.b: Job creation and economic development policies	Supports job creation in waste management	Waste reduction policies create jobs, fostering green growth	McCarthy et al. (2018); ILO (2023)

Source: own

Tab. 6: Relationship among SDG8 targets and WCO_2 emissions reduction (CO_2)

SDG8 target	Relationship with CO_2 emissions reduction indicator (CO_2)	Justification	Academic source
Target 8.1: Economic growth	CO_2 reduction supports sustainable growth	Reducing emissions lowers climate risks, building resilience	Stern (2004); Porter and Linde (1995)
Target 8.2: Labor productivity	Low CO_2 emissions enhance competitiveness in eco-markets	Complying with emission standards boosts market competitiveness	Geissdoerfer et al. (2017); Daly (1996)
Target 8.3: Job creation in small and medium enterprises	Low-carbon industries create jobs in SMEs	SMEs in low-carbon tech support eco-sector employment	Ellen MacArthur Foundation (2013); McCarthy et al. (2018)
Target 8.4: Resource efficiency	Emission cuts improve resource efficiency	Reducing emissions links to efficient resource use	Tietenberg and Lewis (2018); Stahel (2016)
Target 8.5: Inclusive and sustainable employment	Low-carbon transition creates green jobs	Supports job growth in renewables and sustainability sectors	ILO (2023); Ellen MacArthur Foundation (2013)
Target 8.6: Youth employment	Green sectors create jobs for youth	Low-carbon industries offer opportunities in renewables	ILO (2023); McCarthy et al. (2018)
Target 8.7: Eradication of forced labor and child exploitation	Regulated low-emission sectors reduce informal labor	Formalization reduces forced labor risks	ILO (2023); Stahel (2016)
Target 8.8: Worker rights and safe environments	Low-carbon sectors support safe work environments	Formal industries uphold safety and labor standards	Ellen MacArthur Foundation (2013); Tietenberg and Lewis (2018)
Target 8.9: Sustainable tourism	Low-carbon practices indirectly support tourism	Emission cuts align with sustainable tourism goals	Geissdoerfer et al. (2017)
Target 8.10: Financial access	Not applicable	No direct effect on financial inclusion	N/A
Target 8.a: Aid for trade	Aligns with sustainable trade aid	Trade aid for emission cuts supports sustainable growth	Stern (2004); Tietenberg and Lewis (2018)
Target 8.b: Job creation and economic development policies	Supports green job creation	Low-carbon policies drive job growth in renewables	ILO (2023); Ellen MacArthur Foundation (2013)

Source: own

3.2 Introducing the informal economy in the model

An adjustment coefficient (γ) that modulates the impact of each circular economy (CE) indicators on SDG8 ($0 \le \gamma \le 1$). A high informal economy may weaken the effectiveness of economic development policies, limiting the benefits of SDG8 in terms of formal employment, tax collection, and sustainability. This adjustment represents how the informal economy can reduce or amplify the effectiveness of economic development policies related to SDG8. Two levels for γ are considered: i) $\gamma_{low} = 1$, representing the low presence of the informal economy, resulting in no additional negative effect; and ii) $\gamma_{high} = 0.7$, indicating no additional negative effect and high presence of the informal economy, reducing the positive effect of policies by 30%, reflecting lower regulation and transparency. The adjustment for each SDG8 target related to the CE indicators are in Equation (8):

$$\log(SDG_{8i}) = \alpha_{i0} + \gamma[(\alpha_{i1}\log(R) + \alpha_{i2}\log(ER) + \alpha_{i3}\log(RW) + \alpha_{i4}\log(CO_2)] + \epsilon_i^{\gamma} \quad (8)$$

where: SDG_8 represents each specific SDG8 target; α_{i0}, α_{i1}, α_{i2}, α_{i3}, α_{i4} – elasticity coefficients for target *i* with respect to each CE indicator; γ – informal economy coefficient adjusting the intensity of the relationships; when $\gamma = 1$, the informal economy has no negative impact; when $\gamma = 0.7$, it reduces the positive effects by 30%; ϵ_i^{γ} – error term for target *i*.

Comparing results across scenarios shows that a low informal economy ($\gamma_{low} = 1$) maximizes the impact of CE indicators on SDG8, enabling effective SDG8 policies through higher formalization, tax revenue, and labor regulation, which support sustainable practices. Conversely, in a high informal economy ($\gamma_{high} = 0.7$) CE indicators' impact on SDG8 decreases by 30%, as limited regulation and transparency weaken policy effectiveness and reduce formalization and tax revenue, hindering the circular economy's full potential for SDG8.

3.3 Introducing the fiscality in the model

Fiscality, represented by the adjustment coefficient θ, modulates CE indicators' impact on SDG8 targets based on the fiscal environment. Fiscal incentives can enhance the effectiveness of circular economy practices in achieving SDGs. Two levels of θ: i) $\theta_f = 1.2$ represents a tax system that incentivizes circular economy practices with favorable policies, such as tax credits or reduced rates for sustainable sectors, boosting SDG8 impact by 20%; and ii) $\theta_n = 1$ represents a neutral tax system with no additional incentives for sustainability, keeping CE impact on SDG8 unchanged.

Similar to informality adjustments, this introduces a new model specification in Equation (9):

$$\log(SDG_{8i}) = \alpha_{i0} + \theta[(\alpha_{i1}\log(R) + \alpha_{i2}\log(ER) + \alpha_{i3}\log(RW) + \alpha_{i4}\log(CO_2)] + \epsilon_i^{\theta} \quad (9)$$

where: θ is the fiscal sensibility coefficient; $\theta_f = 1.2$ represents favorable taxation, amplifying the positive effect of CE indicators by 20%, and $\theta_f = 1$ shows neutral taxation, with no impact on the effect of CE indicators on SDG8; ϵ_i^{θ} – error term for target *i*.

To further enhance the practical relevance of our model, we have linked the coefficients to empirical evidence. As highlighted in the work of Kirchherr et al. (2017), high levels of economic informality can diminish the effectiveness of fiscal policies by approximately 30%, which supports our choice of setting $\gamma_{high} = 0.7$. Similarly, studies on sustainable fiscal incentives suggest that favorable tax regimes can enhance the positive impact of circular economy practices by roughly 20%, justifying our selection of $\theta_f = 1.2$. These observations substantiate our parameterization and demonstrate that the chosen coefficients reflect real-world policy impacts across diverse institutional contexts.

Results show that favorable taxation ($\theta_f = 1.2$) boosts CE indicators' impact on SDG8 by 20%, as fiscal incentives encourage sustainable practices and circular economy investments. In contrast, neutral taxation ($\theta_f = 1$) has no additional effect, lacking incentives to support circular economy practices.

3.4 Combined scenarios – Considering the impact of informality and taxation jointly

The simplified model in which we combine the interaction of these two variables would become the one shown in Equation (10) and in Tab. 7.

$$\log(SDG_{8i}) = \alpha_{i0} + \gamma\theta[\alpha_{i1}\log(R) + \alpha_{i2}\log(ER) + \alpha_{i3}\log(RW) + \alpha_{i4}\log(CO_2)] + \epsilon_i^{\gamma,\theta} \quad (10)$$

Tab. 7: Results for different scenarios related to informal economy

Scenario	Coefficient values	Equation	Result
1. Low informal economy, favorable taxation	γ = 1.0 θ = 1.2	(13)	Highest positive impact
2. Low informal economy, neutral taxation	γ = 1.0 θ = 1.0	(14)	Moderately positive impact
3. High informal economy, favorable taxation	γ = 0.7 θ = 1.2	(15)	Moderately reduced positive impact
4. High informal economy, neutral taxation	γ = 0.7 θ = 1.0	(16)	Lowest positive impact

Source: own

Considering these adjustments by introducing both fiscality and informality, the model in Equation (10) for each scenary becomes as explained in Equations (11–15):

$$\log(SDG_{8i}) = \alpha_{i0} + \gamma\theta[\alpha_{i1}\log(R) + \alpha_{i2}\log(ER) + \alpha_{i3}\log(RW) + \alpha_{i4}\log(CO_2)] + \epsilon_i^{\gamma\theta} \quad (11)$$

The corresponding equations for the four scenarios are:

Scenario 1 (S1):

$$\log(SDG_{8i}) = \alpha_{i0} + 1.2[\alpha_{i1}\log(R) + \alpha_{i2}\log(ER) + \alpha_{i3}\log(RW) + \alpha_{i4}\log(CO_2)] + \epsilon_i^{\gamma\theta} \quad (12)$$

Scenario 2 (S2):

$$\log(SDG_{8i}) = \alpha_{i0} + \alpha_{i1}\log(R) + \alpha_{i2}\log(ER) + \alpha_{i3}\log(RW) + \alpha_{i4}\log(CO_2) + \epsilon_i^{\gamma\theta} \quad (13)$$

Scenario 3 (S3):

$$\log(SDG_{8i}) = \alpha_{i0} + 0.7 \cdot 1.2[\alpha_{i1}\log(R) + \alpha_{i2}\log(ER) + \alpha_{i3}\log(RW) + \alpha_{i4}\log(CO_2)] + \epsilon_i^{\gamma\theta} \quad (14)$$

Scenario 4 (S4):

$$\log(SDG_{8i}) = \alpha_{i0} + 0.7[\alpha_{i1}\log(R) + \alpha_{i2}\log(ER) + \alpha_{i3}\log(RW) + \alpha_{i4}\log(CO_2)] + \epsilon_i^{\gamma\theta} \quad (15)$$

S1 represents the optimal scenario, with low informality and favorable taxation amplifying CE indicators' impact on SDG8 by 20%, maximizing sustainable practice effectiveness. S2 has a moderately positive impact, where low informality supports policy effectiveness, but without fiscal incentives, resulting in a standard impact on SDG8. In S3, high informality reduces fiscal incentives' effectiveness, leading to a net impact reduction of 16% on SDG8. The last scenario is the least favorable, where high informality and neutral taxation reduce the positive impact by 30%, making it the weakest option.

This model, shown in Equation (16), can be applied to each SDG8 target to evaluate the joint impact.

$$\log(SDG_8) = \beta_0 + \sum_{i=1}^{12}[\gamma\theta(\alpha_{i1}\log(R) + \alpha_{i2}\log(ER) + \alpha_{i3}\log(RW) + \alpha_{i4}\log(CO_2))] + \epsilon \quad (16)$$

Key takeaways from these results

Best-case scenario: the low informality, favorable taxation scenario offers the highest impact on SDG8, showing that a formal labor market with supportive fiscal policies is crucial for maximizing CE contributions to sustainable development.

Moderate impact with low informality: neutral taxation still yields a positive impact but lower than with fiscal incentives. Formal employment structures are necessary, but additional fiscal incentives are needed to fully leverage CE practices.

Diminished fiscal effectiveness with high informality: In the high informality, favorable taxation scenario, fiscal incentives' benefits are partially offset by high informality, indicating fiscal policies' effectiveness relies on lower informality levels.

Worst-case scenario: high informality, neutral taxation has the lowest impact, showing that high informality combined with a lack of fiscal incentives severely limits CE benefits for SDG8.

3.5 Discussion

The results of this theoretical model, particularly the differential impact of circular economy (CE) indicators on SDG8 under varying levels of informality and taxation, are consistent with findings in recent literature. For example, Barrie et al. (2022) explore the "circularity divide" and confirm that structural inequalities such as informality can weaken the benefits of CE initiatives. Similarly, Amato et al. (2024) highlight the importance of integrating informal workers into formal structures to enhance the environmental and social outcomes of recycling systems, an effect mirrored in our scenarios where high informality reduces the positive impact of CE on decent work.

From a fiscal perspective, the positive influence of favorable taxation policies is aligned with OECD (2022) findings, which underscore the need for targeted green fiscal policies to unlock CE investments. The model's result showing stronger impacts under favorable fiscal contexts echoes the empirical conclusions of Fraser et al. (2023), who show that circularity is more advanced in economies with structured policy incentives and low levels of informality.

Moreover, the logic of synergies and trade-offs, central to this paper's modeling approach, builds upon previous network-based analyses of SDG interlinkages (Bali Swain & Ranganathan, 2021; Le Blanc, 2015). The specific interaction between SDG8 and CE indicators reinforces earlier claims by Geissdoerfer et al. (2017) and Ghisellini et al. (2016), who emphasize that CE practices, when embedded in inclusive economic frameworks, are more likely to generate both environmental and social co-benefits.

In contrast, contexts with high informality and neutral fiscal policies mirror the limitations identified by Fevrier (2022), who critiques the effectiveness of CE policies when they overlook structural barriers such as informality or lack of fiscal capacity. This supports our worst-case scenario, where CE practices have diminished effects on sustainable employment.

Thus, this work adds to the growing body of literature that calls for integrated, context-sensitive policy frameworks. It emphasizes that the success of circular economy initiatives depends not only on technical or environmental efficiency but also on the institutional and economic environments in which they are deployed.

Conclusions

Maximizing the contribution of circular economy (CE) practices to SDG8 begins with a clear policy message: governments must tackle labor-market informality and fiscal design at the same time. When informal work is brought into the formal economy and tax systems are reshaped to reward circular investments, the institutional ground is prepared for CE initiatives to flourish, delivering not only environmental benefits but also higher-quality jobs, stronger worker protection and more resilient patterns of growth.

Against that backdrop, well-targeted fiscal instruments, tax credits for recycled inputs, accelerated depreciation for circular assets or reduced VAT rates for repair services, become powerful catalysts, especially in countries where informality is already contained. These incentives sharpen the financial case for firms to adopt resource-efficient technologies and business models, amplifying the positive effect of CE indicators on sustainable-development outcomes. By contrast, in highly informal economies the same measures struggle to gain traction: weak enforcement, limited transparency and widespread regulatory evasion dilute their reach, showing that taxation alone cannot compensate for deeper institutional shortcomings.

A more promising route, therefore, lies in advancing formalization and green-oriented fiscal measures hand in hand. Formal labor markets make it easier for authorities to monitor supply chains, collect revenue and police environmental standards, while supportive taxation sends a clear economic signal that circular practices are rewarded. In combination, these agendas reinforce one another, allowing CE initiatives to align more closely with national development priorities and to generate durable social and economic value.

When low informality and favorable taxation coincide, the model set out in this study reveals strong synergies: resource efficiency rises, waste and CO_2 emissions fall, and the stability and quality of employment improve, results that translate directly into faster progress on SDG8.

Conversely, a high level of informality coupled with weak or poorly designed fiscal support re-introduces trade-offs that limit the gains from CE and can even set environmental and economic objectives at odds. Recognizing these dynamics, and designing policy packages that minimize trade-offs while maximizing synergies, is therefore essential for unlocking the full transformative potential of the circular economy in pursuit of inclusive, sustainable growth.

Future research directions. This study highlights the need for empirical research to validate the scenarios analyzed here. Specifically, future studies could investigate the combined effects of low informality and favorable taxation on CE practices, testing hypotheses about how these factors synergize to advance SDG8 outcomes. Additionally, further research could explore potential trade-offs in other SDGs to understand better the broader implications of CE policies on sustainable development.

As a conclusion of this research, we got a set of hypotheses, each focused on a specific aspect, suitable for empirical testing in future research. This approach keeps each hypothesis targeted to a single variable or relationship for clarity and effectiveness in application.

Fiscal incentives and CE practices in low-informality economies: *H1: In economies with low informality, favorable taxation significantly enhances the positive impact of circular economy (CE) practices on SDG8.*

Fiscal incentives in high-informality economies: *H2: In economies with high informality, fiscal incentives alone do not significantly improve the impact of CE practices on SDG8.*

Impact of high informality on CE effectiveness: *H3: High levels of informality reduce the effectiveness of CE practices in achieving SDG8 targets.*

Impact of low informality on CE effectiveness: *H4: Low levels of informality enhance the effectiveness of CE practices in advancing SDG8.*

Combined effect of low informality and favorable fiscal policies: *H5: The combination of low informality and favorable taxation maximizes the positive impact of CE indicators on SDG8.*

High informality with neutral fiscal policy: *H6: High informality combined with neutral taxation minimizes the impact of CE practices on SDG8.*

Sectoral response to fiscal incentives in CE practices: *H7: Heavily regulated sectors respond more strongly to fiscal incentives for CE practices than less regulated sectors.*

Effectiveness of CE practices in highly informal sectors: *H8: In highly informal sectors, CE practices like recycling and emissions reduction show limited improvement, even when fiscal incentives are present.*

CE practices' impact in high-income regions: *H9: In high-income regions, CE practices have a stronger impact on SDG8 due to supportive fiscal policies and low informality.*

CE practices' impact in low- and middle-income regions with high informality: *H10: In low- and middle-income regions with high informality, CE practices have limited impact on SDG8 despite fiscal incentives, indicating a need for targeted interventions.*

Each hypothesis is derived from the empirical patterns observed in our analysis; for instance, the positive impact of fiscal incentives in low-informality contexts (*H1*) directly reflects the simulation results that show enhanced SDG8 outcomes under favorable tax regimes, while the reduced impact in high-informality scenarios (*H3* and *H6*) underscores the trade-offs identified in our model.

Finally, we want to point out that the main limitations of this study are its theoretical approach and simplifications in the log-linear model, which may not fully capture the complexity of real economic conditions; e.g., dynamic interactions and feedback effects within the economy are not modelled in detail. In addition, some interactions between SDGs and CE indicators are general. Despite these limitations, the study provides a structured framework for analyzing interactions between the SDGs and assessing the impact of taxation and informality on sustainability outcomes. It provides a solid basis for empirical research and policy design, facilitating strategic decisions towards sustainable and balanced economic growth.

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The intersection of ecological leadership and GHRM: A blueprint for a circular economy

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Abstract: *The circular economy now plays a crucial role in addressing ecological challenges. The exact function of green human management (GHRM) in transitioning to a circular economy has yet to be determined. Manufacturing firms are taking steps to enhance their sustainability practices to support the circular economy. The relationship between organizational green actions and GHRM in the transition to a circular economy remains uncertain. This study intends to discover the relationship among manufacturing firms' ecological leadership, green HR practices, green innovations, and circular economy models to enhance sustainable performance. 234 survey questionnaires from Pakistani small and medium-sized manufacturing industries were evaluated using structural equation modelling with partial least squares. GHRM had a positive and significant impact on circular economy and green innovation actions, as shown by the findings. This framework is specifically designed for manufacturing SMEs in Pakistan. The architecture can be adapted to different industries with minor modifications. The study may be biased due to its reliance on management and specialists. This study's findings will significantly contribute to human resources managers and SME owner-managers by clarifying the significance and interplay of essential green innovation components and GHRM. This will enlighten awareness of ecological leadership, circular economy, and GHRM practices for sustainable performance. The proposed framework simplifies the connection between ecological leadership, GHRM components, and circular economy for practitioners and decision-makers. Environmental leaders effectively encourage businesses to invest in proactive environmental strategies, lower pollution control, and enhance the performance of green innovation, all while promoting a green image and advancing environmental protection practices. This study determines the appropriate relationship between ecological leadership, circular economy, and GHRM components in the limited Pakistani manufacturing SME environment.*

Keywords: *Ecological leadership, green human resource management practices (GHRM), green innovation actions, circular economy, sustainable performance.*

JEL Classification: *D83, E22, L00.*

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Introduction

In Pakistan, SMEs make up to 40% of the country's GDP, 25% of its exports, 80% of its workforce, and 35% of its added value in the industrial sector (Khan et al., 2019; Kumar et al., 2013). However, because of their commercial operations, SMEs in the textile, metallurgy, and non-metallurgy sectors have a significant negative influence on the environment (Boiral et al., 2019). Research on ecological management has demonstrated that creating an innovative environment in businesses results in resource management (Awan et al., 2019). Particularly, consumers are putting more and more pressure on businesses to carry out ecological management initiatives to promote green development without negatively impacting the industry's ability to operate sustainably in Pakistan (Iqbal et al., 2023). Increased knowledge is therefore required on which ecological management practices, like resource reutilizing and leftover reduction (Awan et al., 2019), impact the circular economy. Circular economy, which focuses on recycling, repair, reuse, remanufacturing, altering consumption patterns, product sharing, new business systems, and modularization, is the optimal approach for sustainable manufacturing (Khan et al., 2024). The inappropriate usage and disposal of chemicals in manufacturing industries pose significant risks to ecosystems, human health, and environmental stability. Industrial chemicals capable of interacting with the endocrine system are referred to as toxic or those requiring brute force (Cooper et al., 2011). In the production of numerous goods, "monstrous hybrids" and "culture of monoculture," e.g., palm or soya plantations, are also common. For example, an ordinary juice container is constructed of many polymers, cardboard, and glue and lacks easily disassembled elements (Suárez-Eiroa et al., 2019). Ecological leaders aim to establish a production system that is truly good for the environment, as opposed to promoting affluence through the excavation, harvesting, and burning of natural resources as well as the erosion of species diversity and cultural practices (Urbinati et al., 2017). Using the variations in the soil and climate, resources, and local knowledge, ecological leaders would aim to counteract the previous management approaches that promoted such wasteful output (McDonough & Braungart, 2002). Ecological leaders aim to establish a production system that is truly good for the environment, as opposed to promoting affluence through the excavation, harvesting, and burning of natural resources as well as the erosion of species diversity and cultural practices (Moktadir et al., 2020).

The current study addresses the gap in our understanding by examining the mediating role that circular economy and green innovation actions play in the relationship between ecological leadership and sustainable performance. As green innovation actions are the most established concept while introducing ecological leadership will help to improve innovation actions (He et al., 2023; Khanra et al., 2022) in manufacturing firms with the well utilized of resources and minimize waste (RBV). Specifically, it has created new insights by examining the boundary conditions of green HRM and ecological leadership, green innovation actions, circular economy, and sustainable performance linkages. This research has made significant contributions to the academic literature. The study's findings contribute to the global discussion on sustainable development by tackling well-known challenges, including integrating leadership, innovation, and sustainability practices. The global literature is supplemented by providing a model that can be tailored to fit various contexts and sectors.

The research brings together various strands of information, thereby broadening academic knowledge of sustainability frameworks while also offering practical methods for companies to attain their sustainability objectives, thereby making a significant contribution to both theoretical and applied fields. RBV theory has been used for these linkages to explain the best theoretical background and the best usage of organizational resources. Through data collection from Pakistani manufacturing companies, the present study aimed to investigate the following research inquiries: 1) To what extent do green innovation actions and circular economy operate as a mediator in the relationship between ecological leadership and sustainable performance? 2) How far does green HRM highlight the connection between ecological leadership and green innovation actions, and the circular economy? Furthermore, to what degree do green innovation actions and circular economy contribute to long-term sustainable performance? The extremely polluting manufacturing sector, which is the subject of this research, is responsible for a significant quantity of pollution in Pakistan (Muisyo & Qin, 2021) and is growing annually. According to Hannah et al. (2020), the manufacturing industry generated 55.6 million carbon dioxide (CO_2) emissions in 2018, indicating a decrease from 52.6 million tons and 46.47 million tons in 2017 and 2016, respectively. We believe that this strategy would help minimize the environmental impact that manufacturing organizations create and show the connection between the circular economy, green innovation efforts, sustainable performance, ecological leadership, and green HRM.

The remainder of the work is organized as follows: section 1 presents the derived hypotheses and the literature review. Section 2 covers the research methodology. The results and analysis are shown in section 3. The conclusions, restrictions, and recommendations for further study round up in the last section.

1 Theoretical background

1.1 Resource-based view theory

The pioneers of the resource-based theory (RBV) were Barney (1996) and Barney (1991). It outlined the company's assets, competencies, and connection to competitive advantages. Hart (1995) expounded upon the fundamental idea of this theory, indicating that companies allocate their resources to enhance their capacity to attain a competitive edge. The term resource-based view (RBV) is a strategic management concept that emphasizes the importance of an organization's internal resources in gaining and maintaining a competitive edge. Resources that are rare, precious, unique, and non-substitutable (VRIN) can help businesses outperform their rivals. Together with intangible assets like intellectual property, brand recognition, organizational culture, or specialized skills, these resources might also comprise tangible assets like property or machinery. As per the RBV, companies that efficiently utilize these resources can generate distinctive competencies, hence enabling them to surpass rivals in the long run. According to the concept, which is not all resources result in a competitive advantage; only those that are difficult for rivals to copy or replace offer long-term value. In contrast to Michael Porter's five forces model, which emphasizes external market variables and industry structure, RBV places more emphasis on the internal capabilities of the company, contending that a company's performance is determined by its particular combination of assets and skills. The resource-based view (RBV) theory links green innovation activities by showing how companies can utilise their distinctive resources and skills to develop environmentally friendly innovations, resulting in both environmental and competitive benefits. Manufacturing firms can build distinctive capabilities in resource optimisation, environmental innovation, and the design of sustainable products. These features are in line with industry objectives set by CE and can serve as potential sources of competitive advantage. The current analysis aligns with the resource-based perspective theorem. Similarly, the resources and abilities of the businesses to attain circular economy benefits as a result of sustainable performance are how ecological leadership, green HRM, and GI actions are classified in the current research.

1.2 Hypothesis development

Ecological leadership and sustainable performance

The capacity to persuade people and organize groups to realize a goal of long-term ecological sustainability is known as ecological leadership (Egri & Herman, 2000). In order to address ecological concerns, executives must proactively participate in and modify their strategies, internal practices, and management systems in response to ecological challenges faced by businesses (Boiral, 2009). Considering that senior management plays a critical role in encouraging employees to participate in the company's ecological initiatives without having a detrimental impact on the environment, based on striking a balance between the environment and the economy (Boiral, 2009). Ecological leadership demonstrates a strong commitment to sustainable development and ecological preservation. Firms that exhibit strong ecological leadership are better equipped to handle the challenges posed by external ecological pressures (Afsar et al., 2018), conserve energy and resources, reduce greenhouse gas emissions, and fulfil their social and ethical obligations (Jiang et al., 2020). By doing this, businesses will be better equipped to comprehend and identify opportunities for innovation and development as well as external ecological pressure, leading to the eventual acceleration of low-carbon development to significant levels

(Xu et al., 2018). Moreover, companies can enhance their green innovation skills, integrate low-carbon innovation to strategic heights, and incorporate internal innovation resources with the support of strong top management ecological leadership (Aftab et al., 2023). According to Biedenkopf et al. (2020), innovative ideas, products, and techniques can be developed, implemented, and promoted by companies with strong ecological leadership, thereby strengthening their eco-friendly initiatives. Ecological leaders are dedicated to organisational change, which includes finding eco-friendly production processes, setting up contamination monitoring systems, and improving workers' ecological knowledge. They also better understand the value of ecological management and pay particular attention to stakeholder expectations (Papagiannakis & Lioukas, 2012).

Therefore, we suggest that the presence of ecological leadership has a positive relationship with sustainable performance.

H1: Ecological leadership positively links with sustainable performance.

Green innovation action as a mediator

According to Peterson et al. (2003), the literature on green innovation actions has highlighted the importance of the top management's role in the process of making a strategic decision, which ultimately affects the outcome of the organisation. Lin Moe (2012) states that ecological leadership is a key factor that prevents businesses from implementing management methods. The top managers' environmental consciousness and actions send a strong message to their subordinates that green innovation methods that improve overall organisational performance will be supported. According to Aldieri et al. (2021), implementing green innovations will increase productivity. The goal of green innovation initiatives is to reduce harmful environmental effects such as product dumping, material waste, and air pollution. A well-thought-out plan can help to improve environmental performance, according to an earlier study (Wagner & Schaltegger, 2004). More specifically, a company's environmental image can be established with the aid of green innovation methods, which can improve the company's positive organisational reputation, boost sales, and create a new market for hidden capital (Fraj-Andrés et al., 2009). Green innovation techniques help to increase resource productivity and find new revenue streams by making better use of labour, energy, and raw materials. In addition to achieving higher sustainable performance, it can offset the expense of environmental preservation entirely or in part (Aldieri et al., 2021). Furthermore, taking action in the area of green innovation is crucial for enhancing an organization's reputation. A positive corporate image can boost government funding, increase consumer inclination to buy, increase worker satisfaction, and assist businesses in achieving sustainable performance. Therefore, this research suggests the following hypothesis:

H2: Green innovation actions mediate the relationship between ecological leadership and sustainable performance.

Circular economy as a mediator

Ecological leadership committed to the circular economy establishes metrics to track waste reduction, recycling rates, and resource efficiency, thereby ensuring transparency and accountability. Initiatives focused on a circular economy are being reported on to illustrate a company's commitment and showcase its progress (Irawan & Widodo, 2024; Zhou et al., 2024). To reduce the adverse effects on the environment, ecological leadership involves making tactical, operative, and strategic decisions in all business activities. Businesses have integrated commercial strategies with environmental management techniques (Tiwari et al., 2024). Circular economy decreases the flow of materials at each point of the value chain, prioritising resource and energy efficiency (Aranda-Usón et al., 2020). The circular economy aims to decrease natural resource waste and protect the environment, preserving biodiversity and mitigating climate change (Stewart & Niero, 2018). By reducing the number of resources or using recycled raw materials to maintain a consistent level of production, the circular economy model uses fewer resources (Figge et al., 2018). The principles of reduction, reuse, recycling, refurbishment, remanufacturing, and recovery underpin the circular economy (Pieroni et al., 2019). In order to help companies derive high economic value from their material life cycles, the circular economy is expanding the current ecological leadership management system (Stahel, 2019). In this context, businesses need to produce goods and services that meet the social and environmental requirements of the circular economy. As a result, the circular economy encourages sustainable management that occurs both within and between organisations (Korhonen et al., 2018). Environmental laws and government incentives have influenced the company's sustainable corporate environmental practices on a micro level (Aranda-Usón et al., 2024). Government-made legislation to the circular economy should, however, endorse design, evaluation, payment, and sorting mechanisms for recyclable goods at each step of the supply chain, in addition to waste disposal and recycling (Jia et al., 2020). Therefore, this research suggests the following hypothesis:

H3: Circular economy mediates the relationship between ecological leadership and sustainable performance.

GHRM as a moderator

According to Muisyo and Qin (2021), a few of the practices covered by GHRM are ecological leadership that creates a beneficial effect on the environment, performance evaluations, instruction, growth, and green hiring. Sustainable product development, process innovation, and environmental effectiveness are together referred to as GI actions. According to Singh et al. (2020), GHRM actively contributes to the creation of a GI action that results in environmental performance that is participatory and preserved. The positive correlation between GHRM and GI action was highlighted by Song et al. (2021), who also explained how GHRM is linked to high company management of environmental problems. The management GHRM exercises in green hiring, training, and development, as well as their impact on GI actions, were highlighted by Sobaih et al. (2020). Additionally, Mishra et al. (2014) emphasised how GHRM has an impact on ecological leadership, and GI actions have a good relationship that has advanced sustainable development in manufacturing firms. Ren et al. (2018) acknowledged that sustainable environmental performance and development are achieved by GHRM, which also develops green exercises and GI actions. Furthermore, it has been suggested by several previous studies (Khan et al., 2024) that companies that use GHRM and GI actions are very successful and respond to customers rapidly. Consequently, the following is the research hypothesis:

H4: GHRM moderates the relationship between ecological leadership and green innovation actions.

In a summary of the circular economy, Marrucci et al. (2023) found a correlation between performance outcomes and GHRM practices. Their results point to the potential for GHRM in high-performing companies to turn into an exclusive practice. The importance of GHRM initiatives and their connection to ecological leadership and circular economy were also proven by the study (Del Giudice et al., 2018; Dibia et al., 2020). Additionally, Popović (2020) went into detail about the connections with sustainable circular economy and the good relationship between green HRM practices and the green environmental approach. According to Sassanelli et al. (2019), these investigations supported the methodical relationship between circular economy, HR practices, and GHRM for firms. D'Adamo (2019), underlined the connection between human practices and the prospects of sustainable performance. As stated by Chau et al. (2024), and other environmentally conscious organisations, the circular economy is actually the closed-loop architecture that manufacturing companies have embraced for the post-consumption phase with GHRM practices. In response to social injustice, climate change, and worldwide limits of natural resources, sustainable development has produced a relationship between GHRM and circular economy (Khan et al., 2024). Green human resource management incorporates environmental principles into human resource practices, promoting a workforce that is environmentally aware and encouraging behaviors that support ecological leaders to promote the circular economy, which are valuable, rare, and unique resource for achieving a sustainable goal, as stated by the resource-based view theory. RBV theory advocates for harmonizing GHRM and circular economy approaches to meet stakeholder requirements, thereby boosting employee well-being, customer retention, and environmentally sustainable practices. Aligning strategies promotes a green work environment, enhances environmental results, and develops robustness within the manufacturing industry (Awan et al., 2023; Elshaer et al., 2024). So GHRM is important for the employees and managers to give them training on recycling and reusing waste while using the resources in a well-mannered way. Therefore, the scientists hypothesize that:

H5: GHRM moderates the relationship between ecological leadership and circular economy.

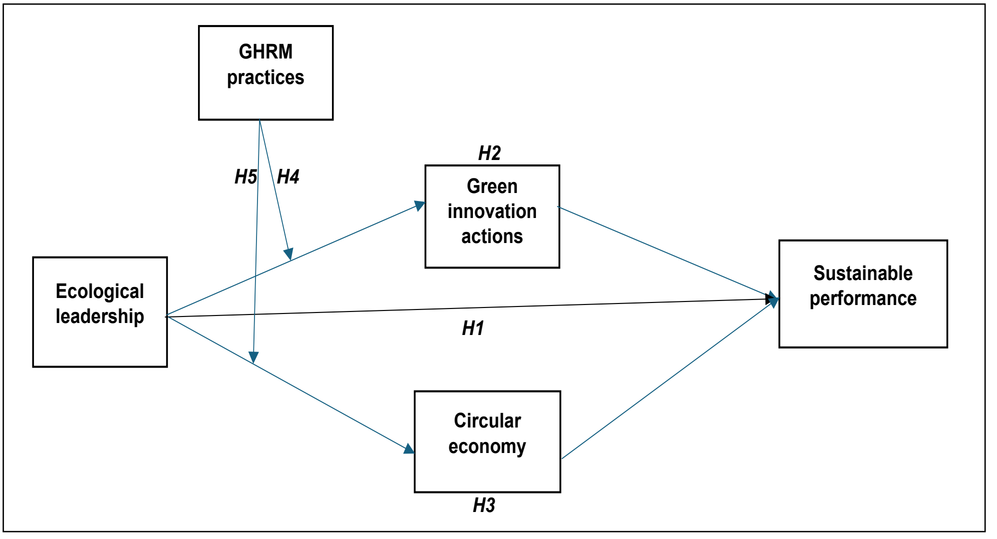

Fig. 1: Theoretical framework

Note: Blue arrows show mediation and moderation effects.

Source: own

Therefore, Fig. 1 serves as the basis for the theoretical framework that follows.

2 Methodology

2.1 Sampling and data collection

Pakistan's industry is particularly sensitive to changes in the internal working environment, making the context of small and medium-sized firms crucial (Awan et al., 2019). According to Dulock (1993), the study's descriptive research plan was centred on outlining and evaluating the hypotheses. Therefore, the present study used primary data for analysis (Hox & Boeije, 2005). In this study, simple probability random sampling technique was used. This makes it possible to choose a sample from any member of the target population (Olken & Rotem, 1995). Data were gathered using the survey questionnaire technique, which included a 7-point Likert scale (Harkness et al., 2004). SMEs in Pakistan's manufacturing industry were, hence, the study's target group. Using a Google form, managers of the SME businesses that served as informants provided the data. A total of 400 questionnaires were distributed and 300 data was collected from medium-sized firms. Ultimately, 234 samples were accepted, and 66 were discarded because of missing data. Data analysis techniques including confirmatory factor analysis, measurement model evaluation, structural model assessment, moderation analysis (interaction terms) and mediation analysis (indifference effect), were performed using Smart PLS software.

2.2 Measures

Every measurement used in the research was modified from earlier research and measure all items on 7-point Likert scale. Ecological leadership has 5-items adapted from Bass (1985). The GHRM consisted of thirteen items, drawn from Renwick et al. (2013) and Sun et al. (2007). In a similar vein, GI actions has 3-items, adapted from Zhang et al. (2015). Ten components that were modified from Zeng et al. (2017) made up the circular economy. Sustainable performance has 6-items adapted from Le et al. (2024). Furthermore, the research employed control variables such as the number of employees, respondent age, company age, management level, and educational attainment. The data was collected from the manufacturing firms having a minimum of 500–1,000 employees. Smaller companies or teams may exhibit distinct behavior compared to larger ones as a result of limited resources or varying levels of organizational hierarchy. Accounting for these variations guarantees that results are not skewed by the dimensions of the entities being studied. To verify the scale reliability, the survey questionnaires were also pre-tested on a small sample of the intended population before conducting a full-scale study.

3 Results

Ali et al. (2018), recognized as a cutting-edge, versatile, and adaptive measuring tool is partial least squares structural equation modeling (PLS-SEM). Similarly, PLS-SEM was recommended for widespread use in the analysis by Hair et al. (2011) and Ringle et al. (2009). However, when it comes to minimal requirements for data and data normality, PLS-SEM is also quite appropriate (Joseph et al., 2022). For assessment and hypothesis estimation, the study, therefore, used Smart PLS. It is advised to use a two-step approach, which is ideal for social science research, when summarising and emphasising the findings. Convergent validity and discriminant validity evaluation procedures are used in the first phase to deploy measurement model value through confirmatory factor investigation. In the following stage, path analysis (direct relationship), indirect effect analysis (mediation), and interaction term assessment (moderation) are used by the structural model valuation (SEM).

3.1 Common method bias

The data used in the research was provided by a few selected SMEs in Pakistan. It is advised to conduct collinearity test in this case to confirm that the dataset's collinearity continues in light of the previously supplied information, as there may be standard method bias. According to Kock (2015), if a score more than 3.3 indicates that there may be collinearity issues with the data. The findings of this study showed that there were no common biasness problems in the dataset, as indicated by the collinearity test score being less than 3.3. Harman's single-factor test was employed to tackle this issue. The KMO was above the accepted value at 0.908, and Bartlett's test of sphericity was also statistically significant (Field, 2013; Kaiser, 1974), indicating the exclusion of common source bias.

3.2 Data normality and descriptive statistics

Generally, PLS-SEM pays less attention to data normality, which is indicative of a non-parametric tool. In order to ensure that the data are normal (Hair et al., 2007), highlighted that only inferential statistical tests should be performed. Many methods, including histogram plots, kurtosis,

Tab. 1: Descriptive statistics and data normality

Sr.	Construct	Mean	SD	SK	KU	1	2	3	4	5	6	7	8	9
1	*EL*	2.870	1.102	0.169	−0.345	1								
2	*GHRM*	3.176	1.020	0.133	−0.148	0.271**	1							
3	*GIA*	2.523	1.150	0.750	0.143	0.359**	0.185**	1						
4	*CE*	2.588	0.909	0.044	−1.197	0.480**	0.246**	0.416**	1					
5	*SP*	3.074	1.181	0.169	−0.784	0.488**	0.475**	0.441**	0.524**	1				
6	*Education*	2.509	0.517	−0.221	−1.518	0.072	0.202**	0.109	0.119	0.203**	1			
7	*Firm size*	1.295	0.465	1.033	−0.591	−0.019	0.052	0.050	0.050	0.100	−0.019	1		
8	*Firm age*	4.295	2.141	0.080	−0.819	0.158*	−0.032	0.142*	0.063	0.032	0.158	−0.032	1	
9	*Team size*	4.556	0.905	−1.819	2.316	−0.010	−0.166*	−0.025	0.051	−0.052	−0.010	−0.166*	−0.025	1

Note: *EL* – ecological leadership; *GHRM* – green human resource management; *GIA* – green innovation actions; *CE* – circular economy; SD – standard deviation; SK – skewness; KU – kurtosis; ** correlation at 0.01 level of significance; * correlation at 0.05 level of significance.

Source: own

and skewness, are used to establish the normality of the data (Munro, 2005). The data in Tab. 1 is considered normal when it meets the data normality criteria, which extends from −2 to +2. Tab. 1 illustrates how the data is consistently dispersed for SMEs. The descriptive statistical analysis for SMEs utilising different averages and the standard deviation is also highlighted in Tab. 1. A correlation analysis was also performed to confirm that the constructs were mutually associated. The findings showed that correlation outcomes are acceptable for SMEs and range from −1 to +1 (Godfrey, 1988). Thus, PLS-SEM was used to perform additional inferential statistics.

3.3 Measurement model assessment

The validity and reliability of the items are confirmed by the measurement model assessment, which is evaluated using convergent and discriminant validity. Factor loading, average variance extracted (AVE), and composite reliability (CR) are assessed in order to demonstrate the convergent validity, which is carried out using a confirmatory factor analysis technique. Factor loading levels are more significant than 0.50 (Tab. 2). According to Hair et al. (2017), the loading values for both SMEs are legitimate and appropriate. However, CR is used to illustrate reliability. According to Hair Jr et al. (2014), the acceptable threshold should be greater than 0.70. According to a method proposed by Hair Jr et al. (2014), items with loadings ranging from 0.40 to 0.70 should be eliminated from evaluation if deleting the observed variable could increase the composite reliability in the reflective scales. As a result, due to the higher AVE values, item CE10 of the circular economy has been abolished. Factor loadings, CR, and AVE computations will be greater than the recommended cut-off values if certain components are removed. CR values are significant and appropriate for SMEs, as Tab. 2 demonstrates. In a similar vein, AVE presents internal validity. Tab. 3 shows that significant or acceptable AVE values for SMEs are larger than 0.50 (Cheung & Wang, 2017).

Tab. 2: Confirmatory factor analysis (convergent validity) – Part 1

Constructs	Items	FL	CR	AVE
Ecological leadership	*EL1*	0.836	0.906	0.659
	EL2	0.855		
	EL3	0.796		
	EL4	0.826		
	EL5	0.741		
Green human resource management practices	*GHRM1*	0.784	0.938	0.539
	GHRM2	0.741		
	GHRM3	0.798		
	GHRM4	0.726		
	GHRM5	0.761		
	GHRM6	0.692		
	GHRM7	0.712		
	GHRM8	0.761		
	GHRM9	0.745		
	GHRM10	0.643		
	GHRM11	0.783		
	GHRM12	0.712		
	GHRM13	0.669		

Tab. 2: Confirmatory factor analysis (convergent validity) – Part 2

Constructs	Items	FL	CR	AVE
Green innovation actions	*GIA1*	0.869	0.908	0.767
	GIA2	0.897		
	GIA3	0.861		
Circular economy	*CE1*	0.762	0.929	0.593
	CE2	0.739		
	CE3	0.754		
	CE4	0.772		
	CE5	0.764		
	CE6	0.829		
	CE7	0.741		
	CE8	0.783		
	CE9	0.781		
Sustainable performance	*SP1*	0.785	0.897	0.594
	SP2	0.723		
	SP3	0.785		
	SP4	0.753		
	SP5	0.816		
	SP6	0.757		

Note: FL – factor loading; CR – composite reliability; AVE – average variance extracted.

Source: own

Additionally, the heterotrait-monotrait criteria (HTMT) are used to emphasise the examination of discriminant validity. According to Kline (2012), construct values less than 0.85 signify that the variables' validity is acceptable. The HTMT requirements for the constructs are less than 0.85 and significant, as Tab. 3 demonstrates.

Tab. 3: HTMT ratio

Constructs	*EL*	*GHRM*	*GIA*	*CE*	*SP*
EL					
GHRM	0.305				
GIA	0.418	0.209			
CE	0.543	0.272	0.475		
SP	0.562	0.527	0.518	0.658	

Note: *EL* – ecological leadership; *GHRM* – green human resource management; *GIA* – green innovation actions; *CE* – circular economy.

Source: own

3.4 Structural model assessment

The structural model (PLS-SEM) assessment includes path analysis, mediation, moderation, and slope analysis. The framework of SP for SMEs (Gudergan et al., 2008) incorporates the validation of models and the verification of hypotheses. Moreover, the validation of β, standard error (SD), and *t*-values reflects the authenticity of the hypothesis. The values of t > 1.495 and $p < 0.05$ suggest that the hypotheses are accepted. The relationships between the variables in the hypotheses in the scenarios of direct, indirect, and moderation impact on SP were supported by Tab. 4, Fig. 2. The findings demonstrated that practically every hypothesis has strong support, else one moderation.

Tab. 4: Path analysis (structural equation modelling)

Hypothesis	Relationship	β	SD	*t*	Decision
H1	*EL → SP*	0.262	0.064	4.121	Supported
H2	*EL → GIA → SP*	0.072	0.025	2.812	Supported
H3	*EL → CE → SP*	0.140	0.034	4.130	Supported
H4	*EL * GHRM → GIA*	0.144	0.067	2.154	Supported
H5	*EL * GHRM → CE*	0.101	0.067	1.496	Not Supported

Note: *EL* – ecological leadership; *GHRM* – green human resource management; *GIA* – green innovation actions; *CE* – circular economy.

Source: own

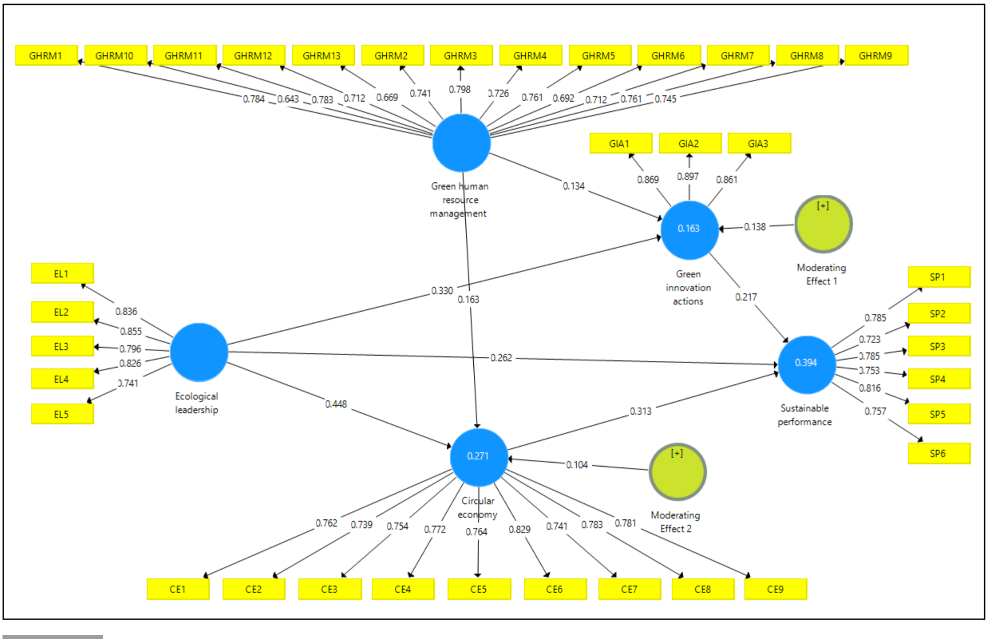

Fig. 2: Structural equation modelling

Source: own

As a result, the findings demonstrated the following relationships: EL with SP for SMEs ($\beta = 0.262$; $t = 4.121$), hypothesis *H1* supported and mediation of GIA between EL and SP ($\beta = 0.072$; $t = 2.182$), *H2* supported and for second mediation with CE between EL and SP ($\beta = 0.140$; $t = 4.130$), *H3* supported. As well as for moderation analysis of GHRM between EL and GIA ($\beta = 0.144$; $t = 2.154$), *H4* is supported, and for other moderation analysis of GHRM between EL and CE ($\beta = 0.101$; $t = 1.696$), *H5* is not supported as the *t*-value is less than 1.90.

Conclusions and discussion

This study applied the SEM method to explore ecological leadership in circular economy and sustainable manufacturing. This study examined ecological leadership's impact on sustainable performance. The study further examined how green human resources management practices influenced the green innovation and the circular economy on Pakistan's manufacturing sectors' sustainability. Ecological leadership positively impacts sustainable performance. The results showed that all factor loadings, composite reliability (CR), and average variance extracted (AVE) met the required standards, thereby validating the construct's validity and reliability, and the hypothesis testing results also strongly supported the proposed model, which exhibited statistically significant and positive correlations between the variables else one. This discovery adds to the existing research on this connection in other contexts. Top managers who effectively implement environmental practices can successfully balance the demands of other financial stakeholders and environmental protection for sustained economic growth (Kim & Stepchenkova, 2018). Green innovation actions mediate the relationship between ecological leadership and sustainable performance. According to previous findings in manufacturing firms by Aldieri et al. (2019), ecological leadership is positively associated with sustainable performance through making environmental conservation a top priority and business value. The association established by Roh et al. (2021) between green innovation initiatives and a greener organization supports the proposition that adopting eco-friendly practices is promoted by such initiatives. The circular economy's influence on ecological leadership promotes sustainable performance (*H3*). The study's findings provide evidence for the positive association between ecological leadership and sustainable performance (Obeidat et al., 2023). *H4* reveals how GHRM practices contribute to green innovation actions and enhance sustainable performance in manufacturing firms, in alignment with Elsamahy et al. (2023) research. Green human resource management techniques positively reduce the negative effect of environmental management on sustainable performance (O'Donohue & Torugsa, 2016). This finding strengthens the assertions of other researchers (Bhatti et al., 2022) that green HRM practices promote sustainability via green innovation actions and programs. This study introduces a novel link between ecological leadership and circular economy through the moderate role of GHRM practices in hypothesis *H5*. In the manufacturing sector of developing countries, the circular economy is a novel concept. So, the hypothesis was not supported. Our findings are in line with the previous research (Dhir et al., 2021). In several emerging economies, particularly in Pakistan, the circular economy remains a developing concept. Insufficient infrastructure, resources, and government backing may impede its integration, thus lessening the importance of GHRM as a moderator.

Theoretical contribution. This study significantly contributes to the literature and theory. First, by doing extensive data research, this study advances our understanding of green projects. The main focus is that manufacturing companies may fully utilise GI actions and CE by implementing GHRM practices, especially if they depend more on sustainable performance. Second, we propose that company resources, as shown in ecological leadership and GHRM practices, affect firm green innovation actions and circular economy, which in turn affect sustainable performance, based on RBV theory. Likewise, the research has established a unique relationship with the resource-based view theory. Its application gave Pakistani small and medium-sized businesses in the manufacturing industry a competitive edge in the CE framework. The study identifies a moderating role for GHRM practices in the relationship between ecological leadership and GI actions, specifically in the context of small and medium-sized businesses. The study emphasizes the role of GHRM practices in strengthening the relationship between ecological leadership and CE, notably for small and medium-sized enterprises. In the agenda for improving CE in the 21st century digitalization era. All of the study's constructs are essentially strategic environmental toolkits that provide researchers additional avenues to pursue.

Practical implications. The study has practical ramifications in addition to theoretical ones. This study, focusing on circular economy performance and UN sustainable development goals, particularly benefits small and medium-sized manufacturing enterprises. Ecological leadership and green innovation activities are crucial for achieving sustainable performance. We propose that managers should take into account the impact of integrating green innovation into operations. GHRM produces a fundamental change in GI, which is why managers need to understand that GI includes product sharing, recycling, repairing, reusing, and remanufacturing. Our research suggests that in order to generate GI and CE, practitioners should talk about the operational level responsibilities of environmental leaders and GHRM. The study's application, efficacy, implementation, efficiency, and functionality of CE in the manufacturing sector make it crucial. By developing a strategic environmental toolbox, the study would assist in creating a green HR environment and boost CE. It would also help provide the foundation for policy texts. The study's conclusion, therefore, provides senior management in the textile industry with enlightening guidance on how to deviate from conventional HR practices and emphasize GHRM as a way to advance the interests of the company and the community. The research aims to enable managers of comparable small and medium-sized firms to effectively convey the significance of the circular economy and its environmental conservation implications. This study can enhance the effectiveness, practicality, safety, and productivity of CE programs for SME employees. The current study, due to its emphasis on environmental safety, is suitable for waste recycling, repair, reuse, and remanufacturing.

Future direction and limitations. The study includes both theoretical and practical implications, the research has some limitations, and offers of recommendations for the future. Pakistan and other developing economies are the subject of the current study. However, for comparison, future studies need to concentrate on developed economies under CE conditions. The current study, which focuses on SMEs, is significant for businesses in the industry. According to this, future research should be done with a focus on different industrial sectors in different companies in order to achieve more comprehensive results. The current study focused on the moderator roles of GHRM practices and the mediator function of GI actions and CE to emphasise the distinct conceptual structure of ecological leadership about the sustainable performance. As a result, in order to expand on new links, further research should focus on different methodology approaches. should be conducted employing other criteria and different industries, such as moderating major data investment. Future research in GHRM and CE should integrate knowledge management practices. Future research could also examine the mediating influence of pro-environmental consciousness and socially responsible actions in the context of GHRM adoption and sustainable outcomes.

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Appendix

Discriminant validity – Fornell-Larcker criterion

Tab. A1: Fornell-Larcker criterion

Constructs	*EL*	*GHRM*	*GIA*	*CE*	*SP*
EL	0.819				
GHRM	0.496	0.778			
GIA	0.302	0.271	0.701		
CE	0.496	0.499	0.509	0.752	
SP	0.354	0.435	0.253	0.472	0.836

Note: *EL* – ecological leadership; *GHRM* – green human resource management; *GIA* – green innovation actions; – circular economy.

Source: own

From innovativeness to sustainable transportation: Managing electric vehicles adoption in a circular economy progressor

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Abstract: *Although numerous studies have explored the electric vehicles (EVs) adoption, the theory of reasoned action (TRA) is underutilized, while the role of consumer innovativeness in predicting purchase intent and behavior remains unclear. This study focuses on the interplay among attitude towards EVs, subjective norm, consumer innovativeness, purchase intention and actual behavior. A structured survey was applied in 2024 to collect data, and a sample composed of 212 respondents from the United Arab Emirates was properly balanced across various characteristics. TRA was extended using the consumer innovativeness construct, which resulted in a new hypothetical model. Once evidence was provided for both validity and reliability of the measures, the hypotheses were tested. Structural equation modelling (SEM) results show that subjective norm does not have significant direct effects on purchase intention, while the consumer innovativeness affects attitude towards EVs. While both attitude towards EVs and consumer innovativeness appear to be direct predictors of purchase intention, attitude towards EVs played a significant mediating role in a relationship between consumer innovativeness and purchase intention. The results of logistics regression revealed that purchase intention directly affects purchase behavior. The paper contributes to significant theoretical and practical implications, which are further discussed.*

Keywords: *Subjective norm, attitude towards electric vehicles (EVs), consumer innovativeness, purchase intention, purchase behavior, electric vehicles, United Arab Emirates (UAE).*

JEL Classification: *M30, M38, O32, O33, O36, O39.*

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Introduction

Climate changes are more noticeable all over the world, and there is no doubt that significant reliance on non-renewable energy is one of the factors, as it directly results in air pollution, acid rain and greenhouse effects (Radhi, 2010). One of the ways to respond to this is utilizing a more efficient system of transportation and green mobility to minimize pollution coming from transportation systems powered by conventional sources (Ismail et al., 2023). Considering sustainability concerns, especially the imperative to reduce greenhouse gas emissions, it is not surprising that the global focus is increasingly shifting towards the adoption of electric vehicles (Rahma et al., 2024). However, the one must be aware that electric vehicles (EVs) are attractive products, gaining lots of attention among consumers because of their cutting-edge innovative features. Moon (2021) stated that purchasing an EV is not only eco-friendly behavior, but also a behavior that denotes someone's openness towards innovation. This is a particularly interesting variable to study in the United Arab Emirates (UAE), a country ranked 31st globally (World Intellectual Property Organization, 2024) and first among Arab countries in the Global Innovation Index (WAM, 2022).

When observing total number of cars sold in UAE, the share of electric vehicles increases as compared to internal combustion engines. PwC (2024) estimates that EVs will take over 15% of new passenger cars and light commercial vehicles, while by 2035, the share will go up to 25% in UAE. UAE has Circular Economy Policy 2021–2031 which aims to achieve sustainable and efficient use of natural resources, promotes circular economy and considers sustainable transportation as one of the four priority sectors. Some of the initiatives promoted by the policy makers range from developing the charging infrastructure to support electric vehicles ensuring the legal and regulatory frameworks support for electric vehicles and understanding how to encourage public transport or uptake of electric vehicles (Government of UAE, 2021). Considering the above-mentioned UAE's regional leadership in innovation (WAM, 2022), sustainable increase in share of EVs and its efforts to support electric vehicles, ensuring the legal and regulatory frameworks support, we find it a very interesting country to study and reveal additional insights into EVs adoption.

Although studies have established a direct relationship between consumer innovativeness and the intention to purchase new products, Li et al. (2021) alarmed that the mechanism underlying this relationship remained unexplained, particularly when it comes to sustainable products (Li et al., 2021). On the other hand, while purchase intention has been extensively studied, only a few studies investigated actual adoption behavior of electric vehicles (Hoang et al., 2022). According to Otieno et al. (2016), despite being underutilized in technology adoption and diffusion, the theory of reasoned action was found to be a robust framework for innovation adoption.

Accordingly, the theoretical contribution of this study is threefold. First, it moves beyond the purchase intention commonly examined construct of electric vehicle (EV) to investigate actual behavior, addressing a critical gap in the literature highlighted by Hoang et al. (2022). Second, this research applies the theory of reasoned action (TRA), which, despite its significant potential for understanding EV adoption, has remained underutilized in this context (Otieno et al., 2016). By doing so, the study not only validates the applicability of TRA but also bridges an existing gap in the body of knowledge. Finally, the study extends TRA by incorporating the consumer innovativeness construct, thereby proposing a novel theoretical framework. This extension offers a more nuanced understanding of EV adoption, addressing a third gap in the literature as identified by Li et al. (2021). We believe that there is a need for answering the following research question (*RQ*): *What is the role of consumer innovativeness as predictor of EV purchase behavior and actual behavior in an extended TRA framework?* This study aims to explain the interplay between customer innovativeness, subjective norm, attitudes, purchase intention and actual behavior. Findings of this study may help initiatives proposed by UAE Circular Economy Policy 2021–2031 in providing a better understanding on how to encourage adoption of EVs. Besides scientific researchers and policymakers, companies dealing with EVs, especially car dealers and marketers may benefit from a deeper understanding of EVs adoption by adjusting their response to the unique market of UAE.

1 Theoretical background and hypotheses

1.1 Theory of reasoned action

The proposition that attitude and subjective norm are major determinants of intention to perform a behavior led to the conclusion that a person's behavioral intention can be observed as a function of two: attitude towards behavior and subjective norm. This is today known as a theory of reasoned action (TRA) proposed by Fishbein and Ajzen (1975). These authors believed that attitude has three basic features: attitude is learned, it predisposes action, and such actions are favorable or unfavorable toward the object. Fishbein and Ajzen (1975) believed that most researchers would agree with defining attitude as a learned predisposition to respond in a consistently favorable or unfavorable manner with respect to a given object. This theory raises another important issue, saying that a person may or may not be motivated to comply with the given referent, belief that he should or should not perform certain behavior. In fact, the normative beliefs and motivation to conform lead to normative pressures which could, in overall, be defined as subjective norm (Fishbein & Ajzen, 1975).

The theory of reasoned action might be very helpful to understand if individual behavior, such as utilizing an innovation, is pushed by behavioral intentions which are considered a function of someone's attitude towards the behavior, the subjective norms, and his/her perceptions of easiness to do behavior. Even though the theory has potential to be expanded to further conceptualize the behavioral patterns in the decision-making regarding the use of a new innovation or technology, it was not extensively utilized in studies dealing with the assessment of technology adoption and diffusion (Otieno et al., 2016). However, it was highlighted by Otieno et al. (2016) that TRA has strong explanatory power to investigate adoption of innovation, as compared with other theories suitable for technological innovation.

1.2 Diffusion of innovation theory

In his diffusion of innovation theory, Rogers (1983), proposes that innovativeness is a very important factor to consider in technology adoption, and he classified adopters on the basis of innovativeness, coming up with following categories: innovators, early adopters, early majority, late majority and laggards. Moreover, he discussed innovativeness as one of the key characteristics of opinion leaders.

According to Rogers (1983), innovativeness refers to the degree to which an individual or unit of adoption is relatively earlier in adopting new ideas compared to other members of a system. Moreover, he defined norms as the established behavior patterns for the members of a social system. Norms define a range of tolerable behavior and serve as a guide or a standard, which therefore can be a barrier to change (Rogers, 1983). Being aware of the high importance of innovativeness in technology adoption as explained by Rogers (1983), as well as having on mind importance of subjective norm and attitude as proposed by Fishbein and Ajzen (1975), this study proposes a new theoretical framework incorporating consumer innovativeness into the TRA, explained in the coming paragraphs, and presented in Fig. 1.

1.3 Context of the study – EVs in UAE

As stated earlier, the share of EVs grows compared to traditional internal combustion engines in UAE. PwC (2024) estimates that by 2035, the share of EVs will go up to 25% in UAE, which will contribute to over 10% reduction in overall CO_2 emissions.

UAE adopted a Circular Economy Policy 2021–2031, which sees sustainable transportation as one of the four priority sectors. This policy is very supportive towards electrification and some of its initiatives are as follows: i) continue developing circular mobility system with more transportation options, such as electrified ones; ii) further improve the charging infrastructure for EVs; iii) expand new, eco-friendly concepts in mobility, such as e-scooters or biking and build more designated infrastructure to support it, especially within the facilities of universities; and iv) economic initiatives, such as how penalties and rewards could be used to improve transport sector efficiency, are to be assessed to encourage the use of public transport and transition to EVs (Government of UAE, 2021).

Saleh (2024) reported that UAE implements variety of policies to stimulate EV adoption, such as, e.g., subsidies, free charging, and lower registration costs for EV's owners. Moreover, in 2023, the number of registered green vehicles (EV or hybrid) in Dubai was over 47,000, and the UAE has goal to assure that half of all new cars sold by 2030 to be green. Even though Tesla holds position of a leader in the UAE's EV market, Chinese manufacturers, particularly BYD and NIO are becoming increasingly popular.

Another important aspect of UAE, which makes it interesting to study EVs adoption is the fact that, according to World Intellectual Property Organization's (WIPO) Global Innovation Index 2022, UAE remained at the top among Arab nations for the seventh consecutive year (WAM, 2022). The situation did not change much in 2024, and the UAE achieved 32nd position globally among 133 ranked economies. The UAE scored particularly high in several criteria: institutions, human capital and research, infrastructure and business sophistication (World Intellectual Property Organization, 2024).

However, it is important to bear in mind that in the UAE, cars are more than just a means of transportation, as they symbolize an owner's status and modernity (Saleh, 2024). Considering all the above, it is not surprising that there are aspirations of M Glory Holding to establish an automotive manufacturing industry in UAE. The company has plans to invest in a new assembly and production facility for EVs, which conforms to the UAE's national strategy for economic diversification and sustainability (Alkaabi & Alazazi, 2023). This company aims to manufacture 55,000 EVs per year in Dubai Industrial City. The facility, whose investment is worth AED 1.5 billion, will manufacture various electric vehicles, whose types and details will be revealed in the future (Dubai Industrial City, 2022). Considering recent research on entrepreneurial mindset, which found that opportunity alertness and dispositional optimism affected entrepreneurial mindset in UAE, the EVs manufacturing may become a direction on the agenda to push electrification forward (Ramadani et al., 2023).

1.4 Subjective norm and purchase intention

Fishbein and Ajzen (1975), in their TRA theory, assumed that subjective norms concerning behavior affect the intention to perform behavior. Dong et al. (2020) utilized a structural equation model to analyze survey data collected from eight economic regions in China and provided evidence of the relationship between subjective norm and intention to perform behavior in the context of electric vehicles. Moreover, the authors found that subjective norms significantly affected urban households purchase intention in buying an electric vehicle. Another evidence comes from the Malaysian electric vehicles market. Vafaei-Zadeh et al. (2022) reported that subjective norms affected purchase intention of consumers in Malaysia. These mentioned effects are confirmed by Ji et al. (2024) who used a sample of 867 participants to investigate the impact of subjective norm on EVs' purchase intention. Results of the study were statistically significant. Yusha (2023) focused on the impact of subjective norm on the green purchase intention of people living in Beijing to purchase one of the three brands BYD (Build Your Dream), Tesla and Wuling. The findings of the study supported that subjective norm affects EVs purchase intention. However, not all the authors would agree with this statement, e.g., Handarujati (2024) found that the impact of subjective norm on EVs' purchase intention was insignificant. Wang et al. (2016) investigated mediating role of subjective norm in a relationship between environmental concern and hybrid electric vehicles adoption intention, and found that subjective norm positively affected purchase intention. Dutta and Hwang (2021) provided evidence from Taiwan and reported that subjective norm significantly influenced users' sustainable consumption intentions for green electric vehicles. Based on all these arguments, we propose the first hypothesis of our study as follows:

H1: Subjective norm has a positive effect on purchase intention.

1.5 Consumer innovativeness and attitude towards EV

Rogers (1983) emphasized importance of consumer innovativeness in adopting innovations, stressing out that not everyone adopt innovation at the same time, but in a time sequence, which may be classify them into different categories depending on their approach to using a new idea. Saleem et al. (2022) conducted a study using TRA and technology acceptance model (TAM) with the aim to investigate factors of e-shopping among Pakistani consumers. It was reported that personal innovativeness had positive and significant effects on attitude towards online purchasing as well as purchase intention. Liu et al. (2015) reported that consumer innovativeness has a positive impact on perceived economic benefits, and therefore significantly contributes to the formation of positive attitudes and purchase decisions. According to He et al. (2018), consumers with higher personal innovativeness and environmental concerns are more inclined to purchase electric vehicles compared to those with lower personal innovativeness. They reported that innovative individuals are aware of the innovation related benefits. Accordingly, considering EVs an innovative technology, it can attract the attention of such innovative individuals. Their high personal innovativeness may lead consumers to believe that EVs are a trend replacing internal combustion vehicles, which may anticipate many benefits from early adoption. Contrary to previously reported evidence, Tu and Yang (2019) found that the personal innovativeness of consumer did not significantly affect attitude towards electric vehicles. Moreover, Moon (2021) found that innovative propensity influences consumers' attitudes towards EVs. Therefore, the second hypothesis of this study is as follows:

H2: Consumer innovativeness has a positive effect on attitude towards EV.

1.6 Attitude towards EV and purchase intention

According to Fishbein and Ajzen (1975), attitude represents a consistent inclination to respond to a specific object, while in the context of electric vehicles, it might refer to consumers' positive or negative emotional reactions toward them. Ajzen (1991) observed that attitude significantly influenced behavioral intentions, including the intention to purchase electric vehicles. This was further supported by Shakeel (2022). Chiou and Shen (2012) found that attitude affects consumers' intentions to use internet banking. The literature provides lots of evidence about the impact of attitudes on purchase intention in EV context. Vafaei-Zadeh et al. (2022) found significant direct effects of attitude on the purchase intention of electric vehicles by consumers in Malaysia. These findings are confirmed by Ji et al. (2024) who used a sample of 867 participants to investigate the impact of attitude towards EVs on purchase intention. Yusha (2023) investigated the impact of attitude on the green purchase intention of people living in Beijing to purchase one of the three brands BYD (Build Your Dream), Tesla and Wuling. The findings of the study supported that attitude affects EVs purchase intention. While investigating mediating role of attitude towards hybrid electric vehicles in a relationship between consumers' environmental concern and hybrid electric vehicles adoption intention, Wang et al. (2016) found that attitude positively affected adoption intention. However, despite of so many studies confirming the above mentioned relationship, Handarujati (2024) challenged the status quo and found that the impact of attitude towards EVs on purchase intention was insignificant. Ramadani et al. (2024) found that attitude towards EVs contributes to EVs purchasing behavior, suggesting the strengthening of efforts to improve attitudes towards EVs and consequently boost purchase intention of customers. Finally, Dutta and Hwang (2021) provided evidence from Taiwan to support that attitude significantly influenced users' sustainable consumption intentions for green electric vehicles. Based on these arguments, we propose hypothesis three as follows:

H3: Positive attitude towards EV has a positive effect on purchase intention.

1.7 Consumer innovativeness and purchase intention

The relationship between consumer innovativeness and purchase intention took attention of researchers in recent years (Al-Jundi et al., 2019; Esfahani & Reynolds, 2021; Flores & Jansson, 2021; He et al., 2018; Morton et al., 2016; Yildirim & Özdemir, 2021). Esfahani and Reynolds (2021) used a sample of 300 participants to find that motivational elements of innovation, with the exception of hedonic motivation, positively influence purchase intention (Esfahani & Reynolds, 2021). Another evidence comes from the Emirate of Abu Dhabi, where Al-Jundi et al. (2019) reported evidence of significant effects of consumer innovativeness on purchase intentions. Moreover, Morton et al. (2016) found innovativeness and attitudes related to the performance of EVs significantly influence the choice for hybrid or electric vehicles. Yildirim and Özdemir (2021) focused on the intentions of customers to purchase Turkish EV based on ethnocentrism and innovativeness of consumers. Results indicated positive effects of both consumer ethnocentrism and consumer innovativeness onto the purchase intention. Flores and Jansson (2021) focused on another segment of e-mobility and did a study of shared e-bikes and e-scooters. Results revealed evidence of a link between consumer innovativeness and shared e-scooter use. In addition, He et al. (2018) found that two types of personality, such as personal innovativeness and environmental concern, significantly affect EV purchase intention directly. Considering the literature presented above, we propose:

H4: Consumer innovativeness has a positive effect on purchase intention.

1.8 Purchase intention and purchase behavior

Many researchers contributed to a better understanding of the interplay between purchase intention and purchase behavior (Fishbein & Ajzen, 1975; Hoang et al., 2022; Peña-García et al., 2020; Tri Cuong, 2024; Wee et al., 2014). In the theory of reasoned action, Fishbein and Ajzen (1975) assume that behavioral intention will lead to actual behavior. Peña-García et al. (2020) provided evidence that the online purchase intention of customers affects their online purchase behavior. Wee et al. (2014) found that the actual purchase behavior of organic food products was significantly affected by the purchase intention of the products. On a case of food delivery applications, Tri Cuong (2024) found that customers' intentions significantly contributed to their actual behavior. Hoang et al. (2022) reported that even though there is a lot of evidence that purchase intention affected actual purchase behavior in context of many different products discussed above, the systematic literature review revealed that, talking of electric vehicles context, only a few studies examine actual adoption behavior (Hoang et al., 2022). Toraman et al. (2023) found a strong role of intention as a precursor to active usage of EVs in last mile delivery for fast-moving consumer goods. Therefore, we propose the following hypothesis:

H5: Purchase intention has a positive effect on purchase behavior.

1.9 Attitude towards EVs and consumer innovativeness

Even though many researchers provided evidence of direct effects when it comes to the interplay between attitude towards EVs, consumer innovativeness and purchase intention, there is a shortage of studies dealing with attitude towards EVs as a mediator between consumer innovativeness and purchase intention. Li et al., (2021) utilized the results from 1,853 consumers to do a mediation test, and found that sustainable products such as electric vehicles, attitude partially mediated the effects of social innovativeness on purchase intention, as well as the influence of hedonist innovativeness on purchase intention (Li et al., 2021). Despite the efforts of authors such as Ali and Naushad (2022) or Jaiswal et al. (2021) who considered attitude an interesting mediator between different predictors and EVs purchase intention, the mediating effects of attitude towards EVs between consumer innovativeness and purchase intention remained unclear. Considering evidence of the relationship between consumer innovativeness and attitude towards EVs (He et al., 2018; Moon, 2021; Tu & Yang, 2019), evidence of attitude towards EVs as predictor of purchase intention (Chiou & Shen, 2012; Dutta & Hwang,

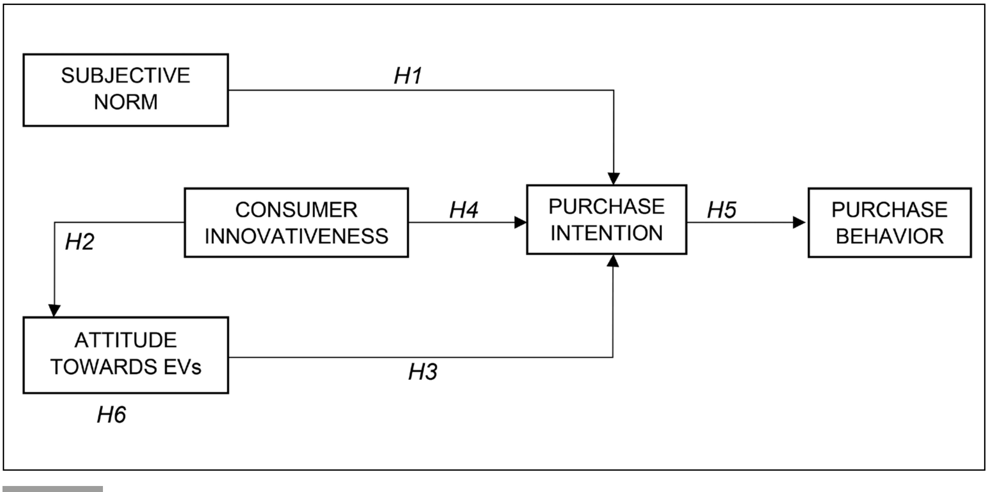

Fig. 1: Proposed theoretical framework

Source: own

2021; Ji et al., 2024; Shakeel, 2022; Vafaei-Zadeh et al., 2022; Wang et al., 2016; Yusha, 2023) as well as evidence of effects of consumer innovativeness on purchase intention (Al-Jundi et al., 2019; Esfahani & Reynolds, 2021; Morton et al., 2016; Yildirim & Özdemir, 2021), encouraged by the work of Li et al. (2021) it was decided to hypothesize mediating effects of consumer innovativeness in a relationship between attitude towards EVs and purchase intention. Accordingly, we propose:

H6: Attitude towards EVs mediates the effects of consumer innovativeness on EVs' purchase intention.

All hypothesized relationships are conceptualized into one theoretical framework illustrated in Fig. 1.

2 Research methodology

This section will explain the literature review methodology, sampling methods, respondent details, instrument development, and statistical techniques used. Literature review was completed according to "integrative literature review" guidelines of Torraco (2005) and Snyder (2019), in four phases, as presented in Tab. 1.

Population and sample. Population and sample were carefully addressed in this study. Car drivers, residents of United Arab Emirates (population), were invited to join the study. Random sampling was applied, and the sample was composed of 212 participants with different sociodemographic characteristics, such as, e.g., gender, age, education, and driving experience. Gender balance could be better, considering that 63.21% are male participants,

Tab. 1: Process of integrative literature review – Part 1

Phase	Activities
Design	Torraco (2005) and Snyder (2019) believe that integrative literature review results in advanced knowledge and theoretical frameworks. As our study proposes and validates a new theoretical framework, this argument makes it a relevant literature review methodology to follow. Most recent papers (2020–2024) from journals indexed in Scopus and Web of Science were prioritized over those published earlier.
Conduct	Final selection of papers ended up with 39 papers from Scopus and Web of Science database and only 3 papers from journals indexed in other databases such as Tubitak Ulakbim, Copernicus, Ulrich. The articles were researched using keywords such as: "electric vehicles," "technology adoption," "technology acceptance," "customer innovativeness," "theory of reasoned action," "EVs adoption," and "electric vehicles in UAE." Majority of sources selected for literature review are journal articles, even 42 papers. 39 of them are coming from Scopus indexed journals, while 37 of them are from Web of Science databases. Finally, the rest of the literature (18 references) are books, relevant websites and other sources. Scopus indexed articles are mostly selected papers from Q1 (30 out of 39). Only 5 (out of 39) articles are in Q2, and 4 (out of 39) papers are in Q3 of Scopus database. Web of Science database provided us with 26 papers are from journals indexed in Social Sciences Citation Index (SSCI), 13 papers from journals indexed in Science Citation Index Expanded (SCIE), 7 papers from journals indexed in Emerging Sources Citation Index (ESCI), and 11 papers from journals indexed in both SCIE and SSCI. When it comes to recency of papers, most of them, even 22 (59%) come from the recent 4 years period (2020–2024). Nine papers are published in the period from 2015 to 2019, while seven papers are coming from the period between 2003 and 2012. Finally, only four papers go back to the period 1951 to 1991.
Analysis	Thematic analysis was used to analyze selected papers, and articles are grouped into several subheadings, each reflecting a specific theme identified from the literature. After analyzing articles, the key findings of the studies are presented under the relevant subheading in theoretical background and hypotheses development section. Empirical evidence was reported discussed, and studies contributed to proposition of new theoretical framework.

Tab. 1: Process of integrative literature review – Part 2

Phase	Activities
Structuring and writing the review	Literature review was organized into 9 sections, whereby the first and second are explaining theory of reasoned action and diffusion of innovations theory. The third section provides information about UAE as a context of EVs adoption. The remaining six sections treat individual relationships among variables. The entire process is reported on 3 pages of literature review section, providing evidence for the hypothesized relationships in the model.

Note: Literature review methodology according to guidelines of Torraco (2005) and Snyder (2019).

Source: own

while 36.79% are female respondents. While 46.23% of participants are 36–50 years old, as compared to 38.68% of those 22–35 years old, the first category might be considered the dominant one in the sample. While most of the participants (even 56.6%) have had a driving license for over 12 years, only 19.34% reported having it for 6–12 years. Even though the largest group of respondents are those with a master's degree (38.68%), they only slightly outnumber those with a bachelor's degree (35.85%). The remaining respondents fall into three categories: college degree (11.32%), high school (8.02%) and PhD degree (6.13%). While 58.02% of the surveyed respondents are UAE expatriate residents, the UAE citizens account for 41.98% of the sample.

Measures. Measures are developed using valid and reliable scales from previous studies. Information about demographics and other characteristics of respondents was collected using questions with categorical responses. When it comes to latent variables, four scales were applied to measure four variables. Attitude towards EVs is unidimensional variable (playing multiple roles of both dependent, mediating and independent variable in the model) with total of 5 items adjusted from the original scale developed by Tybout et al. (2005). Consumer innovativeness is also unidimensional variable (playing multiple roles of both dependent, mediating and independent variable in the model) with six items, based on the work of Hirschman (1980). Subjective norm (independent, unidimensional variable) was measured using five five-item scale adapted from the scale originally created by Ajzen (1991), and finally the purchase intention is measured using a three-item measurement instrument as reported by Rodgers (2003). All variables are measured using a 5-point Likert scale (1 – strongly disagree to 5 – strongly agree). The variable behavior is measured on a categorical basis whereby respondents were answering if they were owners of electric vehicles already (0 – I am not EV owner; 1 – I am EV owner).

Data collection. Data collection was conducted using a questionnaire in online form, and it took respondents approximately 15 minutes to complete. Before data collection, participants got information about the purpose of the study and instructions on completing the questionnaire. Moreover, respondents were informed about anonymity, and that the data collected will be used exclusively for scientific research purposes. In addition, it was communicated with participants that participation is on a voluntary basis, meaning that they have the right to withdraw at any time during the process.

Data analysis. Data analysis was conducted using the Microsoft Excel and SmartPLS4 software packages. Microsoft Excel was used for frequency analysis and descriptive statistics, while SmartPLS4 was utilized to evaluate reliability using Cronbach's alpha and composite reliability, but also to investigate the convergent and discriminant validity (Ringle et al., 2024). Another reason to use SmartPLS for data analysis in this study is the fact that PLS-SEM works efficiently with small sample sizes (Hair et al., 2022). Moreover, the bootstrapping algorithm in SmartPLS makes no assumptions on the shape of the distribution and can be applied to small sample sizes with more confidence (Hair et al., 2017). Considering the fact that the theoretical model was composed of 4 latent variables and 1 categorical binary endogenous variable, following the advice of Hair et al. (2012), caution in analysis was necessary. According to Hair et al. (2012), the utilization of binary categorical variable in structural equation is problematic as path coefficients are estimated by OLS regressions. Therefore, it is mandatory that the dependent latent variable is continuous. Not to violate OLS assumption, the theoretical model was divided into two models for statistical analysis as follows: a) SEM model (Fig. 2) composed of four latent continuous variables whose hypothesized effects were tested using bootstrapping algorithm at 10,000 subsamples (Ringle et al., 2024) and focused on the following hypotheses: *H1*, *H2*, *H3*, *H4*, *H6*; b) logistics regression model composed of one independent latent continuous variable and one dependent variable, which was tested using logistics regression in SmartPLS4, and it was applied to investigate the particular impact of purchase intention on actual behavior (*H5*). The outputs of the two statistical procedures are illustrated in Fig. 2.

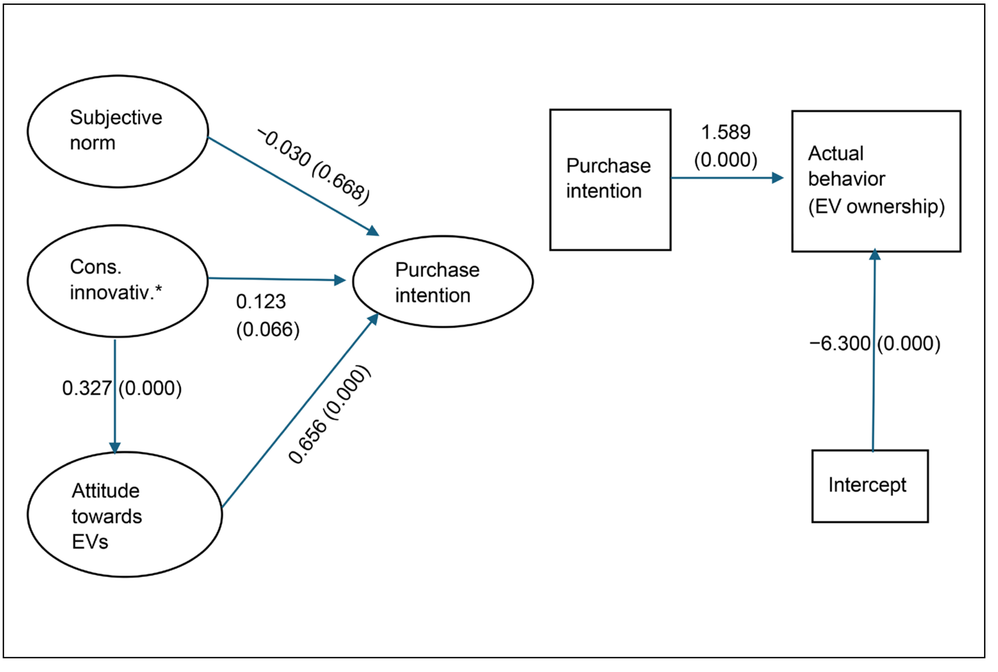

Fig. 2: Output of bootstrapping algorithm (left) and logistics regression (right)

Note: * consumer innovativeness.

Source: own

3 Results and discussion

Information on descriptive statistics results, data distribution, Cronbach's coefficients, and composite reliability tests are provided and discussed. Upon preliminary findings, the results of testing the measurement model are reported to demonstrate evidence of discriminant and convergent validity. Upon confirmation of acceptable levels of reliability and validity, the relationships from the structural model are tested and discussed.

3.1 Results

The investigated variables in this study had a range of mean values from 3.73 to 3.79, while a range of standard deviations was between 0.66 and 0.82 (Tab. 2). The lowest mean value observed was for the subjective norm construct (mean = 3.73; SD = 0.66), implying that respondents are exposed to some level of social pressure while thinking whether to purchase an electric vehicle. On the other hand, the highest value was recorded for attitude

Tab. 2: Descriptive analysis, normality, and reliability

Code	Variable	Mean	SD	Skewness	Kurtosis
SN	Subjective norm	3.73	0.66	−0.870	1.004
CI	Consumer innovativeness	3.79	0.69	−0.757	0.188
PI	Purchase intention	3.74	0.82	−0.854	0.750
ATT	Attitude towards EVs	3.84	0.67	−0.568	0.135

Note: SD – standard deviation.

Source: own

towards EVs (mean = 3.84; SD = 0.67), indicating that respondents have a positive attitude towards electric vehicles.

The skewness values ranged from −0.870 to −0.568, while kurtosis values ranged from −0.188 to 1.004, all within the acceptable boundaries of −2 to +2, therefore confirming normality of the data (Hair et al., 2022). The proposed model (both measurement and hypothetical model) is presented in Fig. 3, which shows some results of PLS-SEM algorithm, namely inner model correlations and factor loadings.

The results of the SmartPLS algorithm are detailed in Tabs. 3–4.

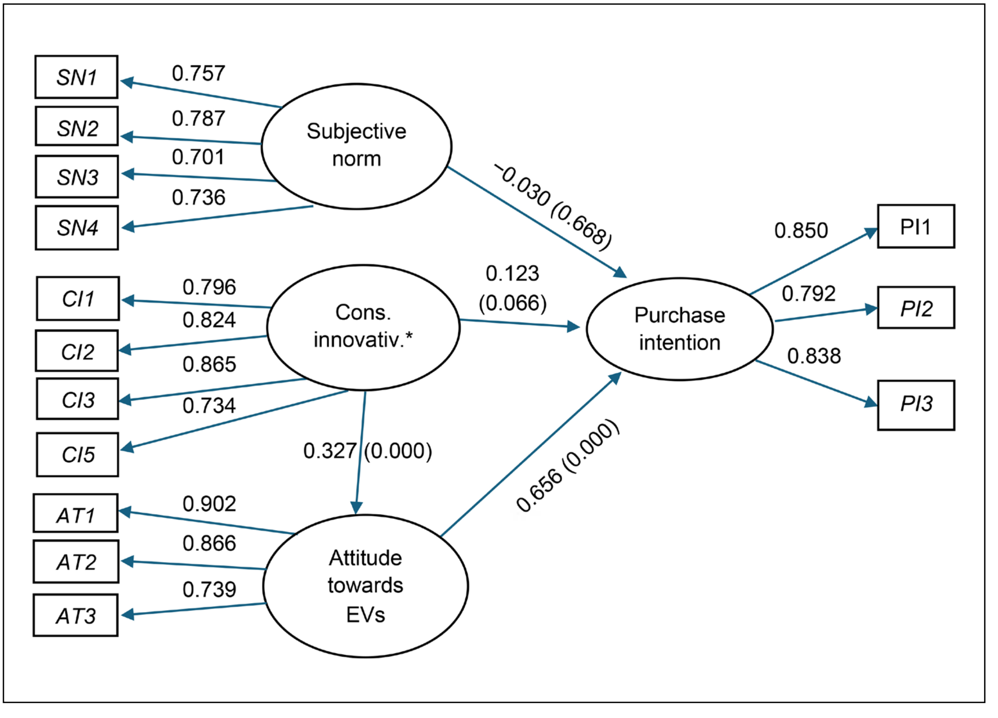

Fig. 3: Results of the PLS-SEM algorithm

Note: * consumer innovativeness.

Source: own

Tab. 3: Summary of the measurement model

Variables and dimensions	Items	Loadings	Composite reliability (CR)
Subjective norm (*SN*)	*SN1*	0.757	0.833
	SN2	0.787	
	SN3	0.701	
	SN4	0.736	
Consumer innovativeness (*CI*)	*CIN1*	0.796	0.881
	CIN2	0.824	
	CIN3	0.865	
	CIN5	0.734	
Attitude towards electric vehicles (*AT*)	*AT1*	0.902	0.876
	AT2	0.866	
	AT3	0.739	
Purchase intention (*PI*)	*PI1*	0.850	0.867
	PI2	0.792	
	PI3	0.838	

Note: Items *SN5*, *CIN4*, *CIN6*, *AT4*, *AT5* were removed due to insufficient loadings.

Source: own

The analysis indicated that items have sufficient loadings, consistent with the criteria set by Hair et al. (2022). According to Tab. 2, all variables demonstrated composite reliability values of 0.833 and above.

Tab. 4 shows that scores of Cronbach's alpha varied from 0.733 to 0.819, showing a sufficient internal consistency (Cronbach & Shavelson, 2004; Cronbach, 1951; Taber, 2018). The results of the Fornell-Larcker criterion (1981) test are presented in Tab. 4, and they demonstrate that the square root of the average variance extracted value (AVE) for each variable is higher than its highest correlation with any other variable, indicating that a variable shares more variance with its own indicators than it does with other variables (Fornell & Larcker, 1981). All constructs had average variance extracted (AVE) values above the threshold recommended by Hair et al. (2022), which is 0.5. Considering the discussed results, convergent validity has a satisfactory level.

A bootstrapping algorithm was applied in SmartPLS4 to test the structural model, and selected confidence level for hypotheses testing was 90%. Results are illustrated in Fig. 4, while the details are presented in Tab. 5. Out

Tab. 4: Construct validation

Variable	C's α	AVE	*AT*	*CIN*	*PI*	*SN*
AT	0.786	0.703	0.839			
CIN	0.819	0.650	0.327	0.806		
PI	0.769	0.684	0.681	0.324	0.827	
SN	0.733	0.556	0.528	0.473	0.375	0.746

Note: C's α – Cronbach's alpha.

Source: own

of seven hypotheses tested, five were supported (*H2*, *H3*, *H4*, *H5*, *H6*), while one was not supported (*H1*). The direct effects of subjective norm on purchase intention appear to be statistically insignificant (*H1*). Consumer innovativeness had significant direct effects on attitude towards EVs (*H2*), while attitude towards EVs significantly affected purchase intention (*H3*). The effects of consumer innovativeness on purchase intention were statistically significant (*H4*). Purchase intention demonstrated significant positive effects on purchase behavior (*H5*). Moreover, the attitude towards EVs was found to be significant mediator in the relationship between consumer innovativeness and purchase intention (*H6*).

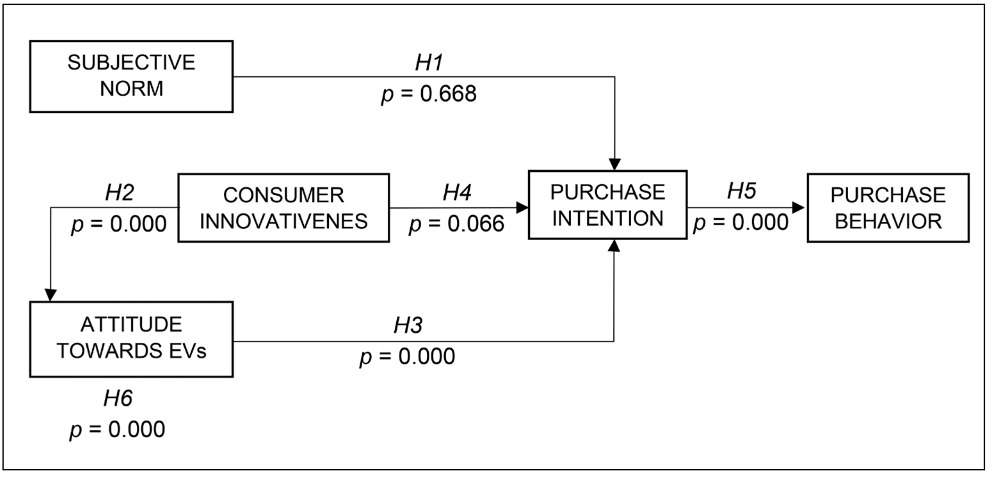

Fig. 4: Results of bootstrapping and logistics regression procedures in SmartPLS4

Source: own

3.2 Discussion

Tab. 5 reports findings on investigating direct effects and demonstrates that subjective norm has no statistically significant influence on purchase intention (*H1*) of consumers in UAE with a *t*-value of 0.429 and a *p*-value of 0.668. This is consistent with the results of Handarujati (2024), but at the same time, opposing results of many other studies (Dong et al., 2020; Dutta & Hwang, 2021; Vafaei-Zadeh et al., 2022; Yusha, 2023). However, it is interesting to notice that path coefficient is negative (−0.030), indicating insignificant (Fig. 3), but inverted influence, meaning that higher level of subjective norm led to lower level of purchase intention. In other words, the influence of friends and people important in life of customers towards purchasing EVs is negative, but statistically insignificant. This might be explained by the fact that even though trend of electrification is positive, the internal combustion engines are still significantly dominant in UAE and take 97% of share of cars sold in 2024, as reported by PwC (2024). It is important to either keep the negative impact of subjective norm on EVs purchase intention norm at insignificant level or try to convert it into positive impact by promoting EVs as a mobility solution. This, however, can be realized only if the implications or policy makers discussed in the coming paragraphs will be implemented.

Results revealed positive and statistically significant effects of consumer innovativeness on attitude towards EVs (*H2*) with *t*-value of 4.936 and *p*-value of 0.000, indicating that higher levels of consumer innovativeness led to significantly more positive attitudes towards EVs. This finding is consistent with most of the evidence from the literature (He et al., 2018; Liu et al., 2015; Moon, 2021; Saleem et al., 2022). Consumer innovativeness has a positive and significant impact on UAE residents' intention to purchase an EV (*H4*) with *t*-value of 1.838 and *p*-value of 0.066 (at 90% confidence level). This means that more innovative consumers are more likely to have intention to purchase an EV in UAE, which is consistent with the existing literature (Al-Jundi et al., 2019; Esfahani & Reynolds, 2021; Flores & Jansson, 2021; He et al., 2018; Morton et al., 2016; Yildirim & Özdemir, 2021). Accordingly, policy makers may consider providing more support for educational programs supporting the development of innovative mindsets in elementary schools, high schools and higher education institutions, but also strengthening innovation hubs, creating awards for outstanding innovations in various fields. Marketers should utilize this by promoting EVs as innovative solutions.

Attitude towards EVs had significant and positive effects on purchase intention (*H3*) with *t*-value of 11.553 and *p*-value of 0.000, demonstrating the strongest impact compared to other purchase intention predictors in the model. Finding that more positive attitude of UAE consumers have about EVs, the higher the probability that they will intent to purchase an EV supports existing evidence from the literature (Chiou & Shen, 2012; Dutta & Hwang, 2021; Ji et al., 2024; Vafaei-Zadeh et al., 2022; Wang et al., 2016; Yusha, 2023). Therefore, influencing attitudes towards EVs might be of great contribution for adoption, and following options might be considered: educational campaigns to inform people on EVs' benefits; offering opportunity for citizens to experience and try EVs; promote EVs through local communities; address the concerns of customers by providing them with more information and breaking potential stereotypes towards EVs.

Purchase intention was found to be significant predictor of purchase behavior (*H5*) with *p*-value of 0.000 and *t*-value of 4.634, indicating that the intention to purchase an EV of consumers in UAE will most likely lead to actual purchase. This supports the existing evidence available in the literature (Fishbein & Ajzen, 1975; Hoang et al., 2022; Peña-García et al., 2020; Tri Cuong, 2024; Wee et al., 2014). It is important to stress out that this finding is very significant as Hoang et al. (2022) reported that even though there is a lot of evidence that purchase intention affected actual purchase behavior in the context of many different products, only a few studies examine actual adoption behavior in the electric vehicles context. Policy makers can help customers convert their purchase intention into EVs purchase behavior by providing different financial options such as, e.g., attractive leasing/financing options, strengthening charging infrastructure and keeping the costs of charging low, providing subsidies, implement sales tax reduction, and keep enabling EVs' owners with free dedicated parking spots.

Speaking of indirect effects, attitude towards EVs played a significant mediating

Tab. 5: Results of testing the hypothetical model and logistics regression

H	Path in the model	*p*	*t*-value	Status
Direct effects				
H1	Subjective norm → purchase intention	0.668	0.429	Not supported
H2	Consumer innovativeness → attitude towards EVs	0.000*	4.936	Supported
H3	Attitude towards EVs → purchase intention	0.000*	11.553	Supported
H4	Consumer innovativeness → purchase intention	0.066*	1.838	Supported
H5	Purchase intention → purchase behavior	0.000*	5.892	Supported
Mediating effects				
H6	Consumer innovativeness → attitude towards EVs → Purchase intention	0.000*	4.634	Supported

Note: * significant at 90% confidence interval; *H1*, *H2*, *H3*, *H4*, *H6* were tested using bootstrapping algorithm (10,000 subsamples) in SmartPLS4; *H5* was tested using logistics regression in SmartPLS4.

Source: own

role in the relationship between consumer innovativeness and purchase intention (*H6*). The *t*-value of 4.634 and *p*-value of 0.000 indicate significant indirect effects. This leads to the conclusion that consumer innovativeness affects purchase intention not only directly, as reported earlier, but also indirectly through attitude towards EVs. Considering that all three paths, namely path a, path b, and path c are statistically significant in the triangular mediation model, according to the rules of Kenny et al. (1998), the mediation type in *H6* might be characterized as partial mediation. This finding supports the earlier work of Li et al. (2021).

According to Husain (2024) Dubai Electricity and Water Authority (DEWA) and Dubai's Roads and Transport Authority (RTA) already provided many incentives for EVs adoption such as: free parking (green parking spots available at public parking areas, many malls, offices, government centers), free salik tag; lower interest rates for electric vehicle loans, also known as "green loans," provided by many banks in UAE to reward eco-aware borrowers. According to Tabrez (2025), charging on the government-owned EV charging network (UAEV) will no longer be free, and EV charging tariffs are supposed to take effect from January 2025. The UAEV provides standardized and transparent fees for EV drivers and makes it easy for them to locate those by launching a user-friendly mobile app and 24/7 call center for instant support.

Conclusions

This study explored predictors of EVs purchase intention and purchase behavior, focusing on a mediating effect of attitude towards EVs between consumer innovativeness and purchase intention. We proposed that subjective norm, consumer innovativeness and attitude towards EVs affect purchase intention, which in turn affects purchase behavior.

While consumer innovativeness and attitude towards EVs had significant influence on purchase intention, the impact of subjective norm appears to be statistically insignificant. Consumer innovativeness had significant direct effects on attitude towards EVs, while purchase intention predicted purchase behavior. Moreover, the mediating effects of attitude towards EVs between consumer innovativeness and purchase intention are found to be statistically significant.

When it comes to theoretical contribution, results enrich the field by better understanding of the purchase intentions and actual behaviors of consumers, emphasizing that factors such as consumer innovativeness (directly) and attitude towards EVs (both directly and indirectly) can positively influence job satisfaction. In contrast, subjective norms, even though negative, do not significantly affect purchase intention of consumers in UAE.

Practical applications of these findings suggest that relevant stakeholders in UAE might revise their current approach to customers and think of ways to increase their level of consumer innovativeness and attitudes towards EVs, with the aim to influence their purchase behavior. Considering generally positive attitude of respondents towards EVs, it is important to make it sustainable towards EVs adoption, where following policy options might be helpful: a) promoting EVs as a better and socially responsible mobility solution to influence positive attitudes towards EVs; b) providing more support for educational programs supporting development of innovative mindsets in schools and universities to further improve consumer innovativeness of future EV customers; c) strengthening innovation hubs, create prizes and awards for outstanding innovations in various fields can be also helpful and benefit EV adoption in the long run; d) marketers should promote EVs as innovative mobility solutions to benefit from consumer innovativeness; e) educational campaigns with the aim of informing people on EVs' benefits, offer them opportunity to try EVs and address the concerns of customers by providing them with more information to confront potential stereotypes towards EVs; and f) to help people come from purchase intention to purchase behavior through even more attractive leasing/financing options and affordable charging costs. Going the extra mile may accelerate electrification by, e.g., providing more subsidies, implementing sales tax reduction/exemptions, and providing interest-free loans.

Sample size can be considered a limitation of the study, and it is advised to have it expanded for future research. It is also advised that future researchers consider the benefits of qualitative methods, such as focus groups, to focus deeper into the research problem. In addition, a regional comparison of UAE results with other countries could provide evidence on contextual effects that shape consumers' purchase intentions. Specific research questions (not limited to) that might be addressed by future researchers are as follows. Is there a difference in customers' attitudes towards EVs, subjective norms, consumer innovativeness, purchase intention and purchase behavior towards EVs across different generations, age groups, gender and education groups? Do predictors of EV adoption, and adoption itself differ among Gulf countries such as, e.g., Oman, Qatar, and Saudi Arabia? What are other variables that might be incorporated in the tested structural equation model to better explain purchase behavior towards EVs? What is EVs adoption across fleets in different industries. How much are EVs adopted by shipping companies?

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Responsible and sustainable consumption: Understanding drivers to circular economy practices among youth

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Abstract: *Waste generation is among Malaysia's most persistent environmental concerns, with both urban and rural regions trying to cope with the rising volume of waste. Circular economy is an economic model that aims to eliminate waste and pollution, circulate products and materials at their highest value, and regenerate natural systems. It is a shift from the traditional linear "take-make-waste" model to a more sustainable system where resources are used for as long as possible. The concept also reduces material use, redesigns materials and products to be less resource-intensive, and recaptures "waste" as a resource to manufacture new materials and products. This helps address climate change, biodiversity loss, waste, and pollution. One of the aims of the 12th Malaysia Plan is to promote sustainability and minimize waste in society. However, limited knowledge on circular economics is found in the literature in the context of youth in developing Asian countries. Youth are the target audience for this study, since they have a significant influence on future consumer attitudes and behaviors related to sustainability. Their perspectives are vital in advancing the circular economy and creating a more environmentally conscious society. This study aims to identify factors that influence youths' circular economy products adoption in the context of developing Asian countries. This study applied PLS-SEM using data from 154 respondents, consisting of youth in Sarawak, Malaysia. The results demonstrate that attitude, environmental concern, moral norm, perceived behavioral control, and subjective norm significantly influence circular economy products adoption. However, perceived sacrifice has an insignificant impact on the circular economy products adoption. This suggests that younger people value sustainable practices in their daily lives. This shows the adaptability of youth to future possibilities. This study also suggests that the transition to a circular economy is imperative for a country's economic progress and sustainable development.*

Keywords: *Circular economy, renewable energy, sustainable development.*

JEL Classification: *Q50, D16, Q01.*

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Introduction

Waste generation is among Malaysia's most persistent environmental concerns, with both urban and rural regions trying to cope with the rising volume of waste. Malaysia produces approximately 30,000 tons of solid waste daily, of which food is the largest component of waste (31%), followed by plastic, paper, and diapers

(Muhammad et al., 2023). With the growing rate of population, the problem of solid waste management continues to worsen (Song et al., 2014), thus negatively affecting the environment, such as climate change and health effects. The current population in Malaysia is 34.67 million, and with the growth rate of 1.06%, this would increase the issue of solid waste being produced daily. This results in landfills producing greenhouse gases (GHG) such as carbon dioxide and methane, affecting the atmosphere (Górka et al., 2021). These emissions are mainly produced by human-related activities such as industrial activities (Isella & Manca, 2022) and act as significant drivers that affect climate change and worsen global warming. If such a condition persists, this could affect Malaysia's Nationally Determined Contributions (NDCs) under the Paris Agreement to reduce carbon intensity against GDP by 45% by 2030 in comparison with the 2005 level.

The take-make-waste economy, also known as the linear economy, is a long-lasting system that aims at the extraction of resources, production of goods and services, and waste disposal. This system has been the root of economic success, pushes mass production, encourages consumerism, and propels industrial expansion as well as economic growth. Although it has its advantages, it also has disadvantages, including the depletion of resources, an increase in waste, and a decaying environment. This system is also heavily dependent on the existence of Earth's finite resources. Its effects on the deteriorating environment and how frail the system is based on its reliance on finite resources. The demand for these resources will not fade away (Tan et al., 2022). Instead, it escalates alongside population growth. Tan et al. (2022) stated that, as society is still greatly dependent on the linear economic model, the expectation is that the activities of extracting resources that produce GHG emissions are not expected to slow down anytime soon. This leads to the notion of a circular economy in achieving overall economic prosperity, social integration, and environmental sustainability. The system that circular economy (CE) exercises is a loop-like system where the resources are reused, recycled, and regenerated.

Similar to the concept of the 3Rs method, which focuses on waste management, CE elevates this concept by pushing the loop cycle system that advocates for reducing the extraction of resources, reprocessing them, and regenerating them into new energy (Rodríguez-Espíndola et al., 2022). The main idea of CE is the optimization of resources, waste prevention, where products are created with the intention of a longer lifecycle, as well as incorporating the concept of sustainability within the design of the products. This system values the concept of reusing or repurposing products and discourages the old tradition of waste disposal. Hollander et al. (2017) stated that there is no concept of waste in a circular economy as it is seen as one of the resources. The implementation of CE does well for the good of the environment, as well as encouraging novel ideas, innovations, and life enhancements. This concept provides solutions for resource scarcity and dependency (Di Stefano et al., 2023), as well as the overwhelming volume of wastage (Perey et al., 2018).

Malaysia's Ministry of Investment, Trade and Industry (MITI, 2024) has created the Circular Economy Policy Framework, which is a critical step in promoting green production methods while dealing with the ecological challenges connected with the traditional industrial models. The framework attempts to transition from processes that rely fully on non-renewable fossil fuels to a more sustainable value chain practice that would lessen environmental degradation. One of the efforts of policymakers is the Extended Producer Responsibility (EPR) program, which ensures producers are held responsible for their products' lifecycle, specifically for the environmental costs throughout their production processes. Such strategies would foster greater contribution to the country's GDP, as the producers gain from the value-added by-products in their value chain, and lower wastage and emissions to the environment. At present, the industry accounts for around 24% of GDP and 20% of national emissions (Ministry of Investment, Trade and Industry, 2024). This framework is consistent with the National Energy Transition Roadmap (NETR) to "navigate the complexity of energy transition on a large scale, especially the shift from a traditional fossil-fuel-based economy to a high-value green economy" (Ministry of Economy Malaysia, 2023). The circular economy movement has also been embedded in the major national development plan, namely the 12th Malaysia Plan (12MP). The 12MP goal is to achieve net-zero GHG by 2050 through strategic focus on energy transition and effective coordination. In particular, the main aim is to identify the complex and interrelated landscape of energy structures and accept the requirement to achieve equilibrium in the energy trilemma (Ministry of Economy Malaysia, 2023). These are in tandem with United Nations Sustainable Development Goals, Goal 12 Responsible Consumption and Production, as well as Goal 13 Climate Action.

Circular practices are an excellent substitute for the linear economy, and many have taken part in implementing them in the form of policies and frameworks. However, there is still a lack of comprehensive legal frameworks that are able to provide significant support for circular practices. Abdul-Hamid et al. (2023) stated that there is a lack of laws and policies, as well as financial constraints, that can support circular practices in Malaysia. The existing legal documents are the Environmental quality act of 1974 and the Solid waste and public cleansing management act of 2007, and they only offer minimal support towards a circular economy (Malaysia, 1974; Malaysia, 2007). Furthermore, low awareness among local communities results in less engagement in circular practices, thus slowing down the implementation of the circular economy. This is further supported by Kuah and Wang (2019), who highlighted that there is a low awareness of CE facilities and programs among Asian buyers.

The waste produced differs vastly depending on various factors such as an increase in population, greater economic activities, and consumer behavior. Such volatile patterns may burden the successful implementation of circular economy practices. In addition, the ambiguity surrounding the term "circular economy" among society may also delay its overall implementation. This could result in lower public awareness and a lower willingness to participate in any circular economic activity. Operators may find it difficult to make investments in environmentally friendly operations or technology if they are uncertain of customer demand for goods that are sustainable. Recognizing the increased need for green alternatives via circular economics, efforts could assist firms in matching their plans with client requirements. As mentioned by Krajnc et al. (2022), public awareness, in particular, among youth, is essential as their behavioral patterns are fundamental towards the successful transition to a circular economy in the long run. In this study, the term CE products adoption is used to represent responsible and sustainable CE practice, specifically the purchase and use of CE products. According to Vidal Ayuso et al. (2023), CE is considered as "shared use," "repair," "recycle," and "upcycle" within the purchasing process. Meanwhile, CE products are considered as upcycled fashion and accessories, circular footwear, biodegradable and composting products and recyclable electronics, particularly from palm-based practices. As a major global producer and exporter, Malaysia has made significant efforts in the circular economy in the palm oil industry. According to Aziz et al. (2021), the concept of circular practices is applied in the process of palm oil production, addressing the issues regarding its production, which are deforestation and waste management. Some instances include palm oil waste, such as empty fruit bunches, which are created after sterilizing and stripping, and can be used as compost and for the generation of energy. Another example is the palm oil mill effluent, which is mostly created during the sterilization and clarifying process, that can be reused and sprayed on the fiber to speed up bacterial breakdown in the compost facility. Oil palm fiber and oil palm shell are produced during the crushing and extraction of palm kernels after the nuts have been removed. The oil palm shell is also used as a coarse aggregate alternative in concrete to create lightweight palm oil-based concrete for green buildings (Cheah et al., 2023). More examples of palm-based products as a result of circular economy practices are nanocrystalline cellulose (NCC) that can be used as textile effluent contaminant remediation in upcycle fashion (Shanmugarajah et al., 2019), while polyol derived from palm oil can be utilized in circular footwear (Blasco et al., 2020). In addition, oil palm empty fruit bunch can be used to produce biodegradable bioplastic specifically in food packaging (Rahman et al., 2019), while palm fatty acid distillate (PFAD) is an environmentally friendly and renewable industrial lubricant (Golshokouh et al., 2014). Significant barriers in CE products adoption are a lack of ability among the general public to recognize and differentiate between conventional products and CE products. In the Malaysian context, certifications such as MyHijau Mark & SIRIM Eco-labelling serve as institutional tools to identify responsible and ecologically conscious products (Malaysian Green Technology Corporation, 2021).

There is a plethora of studies investigating factors influencing CE adoption due to rising interests in circular economy practices, which typically utilize the theory of planned behavior (TPB). This study utilizes extended TPB to investigate CE products adoption. The complex incentives and barriers unique to CE adoption may not be well-captured by the classical TPB framework. In theory, TPB concentrates on the rational decision-making but it often received critiques for disregarding moral effects on environmental behavior as well as lack of prediction of repeating behavior (Klockner, 2013). Furthermore, there are limited region-specific studies that explore the drivers or barriers for youth to embrace CE practices, which deters policy-makers, think tanks, education institutions and industry players to construct targeted interventions in promoting sustainable behavioral change. Ahmed et al. (2022) also stated that there are very limited studies on CE, particularly for emerging and developing countries. Furthermore, there is a critical gap in contextualizing this behavioral model from the perspective of a developing Asian country with a different institutional structure and socio-cultural norms than the west within the circular economy framework. Hence, the study adapts TPB by incorporating three additional factors, specifically perceived sacrifice, moral norms and environmental concern, to address these gaps. These factors are underexplored and have inconsistent evidence of a person's sense of morality and their environmental concern while complying with the sacrifices needed. It was shown that a person's morale can drive their personal sacrifices (O'Connor & Assaker, 2021), while another study asserts that circular activities engagement is due to a person's moral norms rather than a sense of environmental responsibility (Arias et al., 2022). Hence, an in-depth study is needed to identify the intricacies of those variables, especially within the youth group. Another research gap in this study is the population gap, focusing on the cultural gap between generations, specifically on the younger people. The perception of moral norms, environmental concern, and perceived sacrifices might differ from the older generation. This is due to the influences in their era, making them have different beliefs, values, financial conditions, and mindsets. For instance, a higher expense of circular activities is seen as a higher sacrifice for them, lowering their desire to participate (AlJaber et al., 2023), despite their beliefs. According to Maria (2022), the youth are more likely to participate in circular economic practices through knowledge sharing. This research focuses on the perspective of the youth that is included in the extended TPB to capture the key factors that drive younger people to engage in circular practices. Addressing these gaps will give a better understanding of youth behaviors and their decision-making processes, catering to better policies for each generation.

This integrated model provides a more holistic approach towards better understanding drivers of CE adoption among youth in the developing Asian region which leads to the following research questions (*RQ*). *RQ1: How does TPB constructs influence CE products adoption? RQ2*: *Are perceived sacrifice, moral norm and environmental concern significant determinants towards CE products adoption? RQ3*: *To what extent do the determinants influence CE products adoption among youth in the context of developing Asian country?*

In response to this, the research objective (*RO*) of this study is to investigate determinants of circular economy products adoption specifically: *RO1: To investigate the influence of TPB constructs towards CE products adoption. RO2: To assess the role of perceived sacrifice, moral norm and environmental concern towards CE products adoption. RO3: To provide empirical insight in the context of youth in developing Asian country.*

This study will focus on youth in the context of the developing Asian country, in this case, Sarawak, Malaysia. Youth and their age range vary throughout different organizations, but the identical characteristics that were agreed upon are that it is a phase of transition from teens to adulthood. Internationally, youth are defined as people in the age group of 15 to 24 years old. According to the Institute of Labour Market Information and Analysis (ILMIA, 2017), the youth categories are defined as those in the age range between 15 and 30 years old. The individual in this group grows up in the early years of the technology boom, seeing the revolutionized usage of social media, and these attributes make them well informed and up to date with events that are going on around the world. This proves that they are resilient in this modern environment and economic state, and challenges (Motti-Stefanidi et al., 2022). Despite that, action plans are required to bridge the gap between youth and multi-stakeholders. Circular economy is a complex mechanism that is relatively new to the Malaysian economy and industry. This encourages integrated cooperation from governments, industry, investors, non-governmental organizations, and youth to understand the drivers of circular economy implementation.

1 Theoretical background

1.1 Extended theory of planned behavior

This study utilizes the extended theory of planned behavior to investigate factors that influence CE products adoption among youth in a developing Asian country. The extended theory of planned behavior (ETPB) was developed based on TPB by integrating other factors that delve more into detailing human behavior. The well-known theory of planned behavior (TPB) is popular in explaining human behavior with three main factors, which are attitude, subjective norms, and perceived behavioral control. TPB was the result of expansion by Ajzen (1991) from the theory of reasoned action (TRA), introducing perceived behavior control into the equation, taking into account the influences that may accelerate or slow down certain behavioral performance. Outlining the key factors of TPB, attitude is known as a person's favorable and unfavorable aspects of the behavior. Subjective norm relates to the social influences expected for an individual to act or not engage in certain behavior. In the extended form of TRA, perceived behavioral control was introduced, and it refers to a person's beliefs in their capability to perform the behavior as intended. Collectively, these mentioned factors affect the intention behavior as well as the actual behavior. Although TPB is known to be an efficient framework in studying human behavior (Ajzen, 1991), it lacks a person's emotional aspect, past experience, and ethical standing (Sun, 2019). Therefore, this study introduced perceived sacrifice, moral norm, and environmental concern to the framework, extending it to see its effects on behavior. Perceived sacrifices are the risks taken, such as efforts, time taken, and these are known as the non-monetary cost (Johnstone & Tan, 2014). It also represents a personal judgement of the expected negative outcomes it may impose on the consumers that engage in the behavior (Peter & Tarpey, 1975). Moral norm (MN) is a set of values and doctrines that are affected by personal behaviors and beliefs (Harms & Skyrms, 2009). Developed from the Schwartz theory, the norm activation model (NAM) (Schwartz, 1977) and later enhanced by Stern et al. (1999) value-belief-norms (VBN) theory was proposed and asserts that an individual's action on eco-friendly activities is affected by moral norms that are based on past experiences.

As for environmental concern, it is related to the character of behavior and results in a certain situation and the creation of perceptions (Bamberg, 2003). According to the concept of environmental concern, which involves a person's knowledge, beliefs, opinions, and behaviors (Cruz & Manata, 2020), those who are concerned about the degrading environment are more prone to adopt a pro-environmental lifestyle. There are multiple important values defining an individual's environmental concern, especially those who strive to preserve the environment; they are more likely to behave in a pro-environmental manner. Through the integration of these factors, a more inclusive model is introduced, extending it as well as allowing for a more insightful understanding of human behaviors.

Despite offering an important framework to investigate CE adoption by extending the theory of planned behavior (TPB), the theoretical input applied in the study may generally appear subtle as a result of extensive usage in research on sustainability. The TPB framework is enhanced by incorporating additional constructs, including perceived sacrifice, moral norms and environmental concern, although the integration typically adds to the body of literature instead of providing new theoretical viewpoints. Nevertheless, the study delivers contributions by presenting nuanced perspectives on CE-based behaviors and establishing this extension within the CE framework.

1.2 Attitude towards behavior (ATB)

Ajzen (1991) has established that a positive attitude would make consumers more inclined to enact a particular behavior. Attitude is also known as a state of acceptance or readiness that is affected by a positive experience that the individual's action towards that particular action (Aishi et al., 2020). According to Amoako and Dzogbenuku (2020), attitude towards green behaviors is significant in the purchasing behavior of green products in Ghana.

This study will focus on individuals' attitudes and their relationship with the adoption of CE practices. Generally, the link between attitude and CE practices is from the effects of depletion of natural resources, the amount of waste generated, and GHG emissions (Rincón-Moreno et al., 2020), and this exhibits an urgency to the adoption of CE practices. Costa et al. (2021) investigated individuals who have experience with environmental consciousness and their attitudes toward the adoption of green products. The researchers found that attitude does impact the intention to adopt green products. This will create people who have an environmentally conscious mindset, where they will find ways to live their lives in accordance with a sustainable lifestyle, such as practicing reusing, recycling, and purchasing green products. This will indirectly drive up the demand for sustainable products as well as raise the number of individuals who are environmentally conscious. This is supported by Jan (2022), who states that attitudes have a positive influence on the purchase of CE products in Turkey. As for Alves et al. (2023), they found in their study that students showed different types of CE behavior and had a positive attitude toward CE. Jimenez-Fernandez et al. (2023) focus on the relationship between awareness and attitudes toward CE beliefs and found that attitudes are positively significant to the beliefs of CE. Individuals' attitude is a catalyst that accelerates changes, especially in terms of the adoption of CE practices. Globally, the transition towards CE is imperative considering the effects of increasing waste levels on climate change (Bilal et al., 2020).

H1: Attitude has a positive influence on CE products adoption.

1.3 Subjective norms (SN)

Subjective norm is the perception of an individual's understanding or perception of social influence to react in a certain way. Ackaah et al. (2021) described subjective norm as an individual's perceived social pressure to perform or not to perform a particular behavior. In short, it is the level of influence from their social circle that has an impact on individuals and their judgment of what others might perceive, and it is not necessarily the true thoughts of other people.

In this context, subjective norms are observed in terms of their relation to CE practices adoption. Subjective norms could be the actual behaviors of others who are acting on such purchasing green products, or just the perception of other thoughts and opinions on CE practices. Ting et al. (2023) mentioned that in a community, subjective norm decisions are impacted by others within the industry, considering whether to adopt the circular economy (CE) model. And this emphasizes that collective thoughts in a community have an influence on an individual. Hao et al. (2020) investigated the effects of elements on the readiness to engage in CE and found that subjective norm has a significant impact on individuals' readiness to participate in CE practices. However, according to Sauermann et al. (2020), it is firmly stated that community collective activities are important in transitioning to CE practices.

Centobelli et al. (2021) studied the relationship between factors that affect CE capability in small and medium enterprises (SMEs) and found that social influence affects the expectation of environmental commitment. While Lee (2022) found that subjective norm has a significant impact on news consumption and circular packaging. Jan (2022) stated that subjective norms have a positive influence on the purchasing intention of CE products in Turkey. This shows that subjective norms have an active role in individuals' acceptance of CE practices.

H2: Subjective norm has a positive influence on CE products adoption.

1.4 Perceived behavioral control (PBC)

Perceived behavioral control is the degree of confidence and control an individual has in performing certain behavior (Ajzen, 1991). While Wang et al. (2016) indicated that perceived behavioral control can be defined the perceived ease or the perceived issues of acting on the behavior. Schmalfuß et al. (2017) define perceived behavioral control as a person's perceived capability to achieve a behavior within their internal and external resources. Hence, the difficulty level of performing any CE practices specifically affects the adoption of CE products.

The study by Shin and Hancer (2016) shows a positive influence of perceived behavior control on the purchasing intention. Similarly, Berki-Kiss and Menrad (2021) examine the factors influencing the adoption of green products in Germany and note that perceived behavioral control significantly influences the adoption. In this context, perceived behavioral control influences the adoption of CE practices, such as the obstacles and risks that come with the adoption of CE practices. Jan (2022) stated that perceived behavioral control has a positive influence on the purchasing of CE products in Turkey. This shows that when people have adequate knowledge and the ability to engage in an environmentally friendly act, they are more likely to adopt CE practices.

In the industry area, Tran-Thi-Thanh and Nguyen-Thi-Phuong (2023) focused on the factors that affect firms' adoption of circular business models (CBMs) and found that the most influential factor is perceived behavioral control. This reflects organizations' confidence in adopting CE practices, and this is due to their sufficient resources and being well educated on the matters of CE, enabling them to be in control. As Ham et al. (2015) stated, perceived behavioral control includes the capabilities to manage obstacles and risks and exhibits dominant control while adopting sustainable products. Ham et al. (2015) further mention that confidence can be influenced by experiences with green products, positive monetary barriers perception, and the perceived convenience it brings. While Adabre et al. (2022) stated that focusing on the transition to circular economy practices, perceived behavioral control can be affected by barrier factors such as risks, which will lower the adoption of circular practices, hence, slowing down the transition to circular economy. Therefore, this study will delve into understanding the perceived behavioral control stance in the adoption of CE practices.

H3: Perceived behavioral control has a positive influence on CE products adoption.

1.5 Perceived sacrifice (PS)

Perceived risk is an individual's expectation of a certain product's performance, bringing positive or negative outcomes; in other words, the costs that were given up acquiring another product (Shukla, 2010). Perceived risk is also known as a subjective evaluation of an individual to the degree of uncertainty that is involved in attaining or using the products, as well as the potential impacts related to it (Faqih, 2016). Moreover, it also embodies a personal judgement of the expected negative outcomes it may impose on the consumers who purchase and use the product (Peter & Tarpey, 1975). Wong et al. (2020) categorize perceived sacrifice into two aspects, which are monetary and non-monetary. Perceived sacrifices are the risks that were taken, such as efforts, time taken, and these are known as the non-monetary cost (Johnstone & Tan, 2014; Lai, 1995; Pura, 2005). It was further stated that comfort and convenience are also non-monetary factors in perceived sacrifice (Wong et al., 2020). As for monetary factors, Yang and Peterson (2004) stated that the costs incurred are evident factors, and this is also supported by Sánchez et al. (2005).

In terms of circular economy practices, sacrifices can look like purchasing green products is expensive, or if a person wants to recycle, but it takes time to accomplish. Ramayah et al. (2010) studied the intention to purchase green products and found that consumers' efforts and convenience negatively impact the intention to purchase green products. This can also be viewed as a type of risk. For instance, an individual might perceive that switching to solar panels is a financial burden, risking their existing convenience for a higher-priced product. Supported by Wong et al. (2020), identified that perceived sacrifice negatively impacts the adoption of green habits amongst airline passengers. This illustrates that people have to abandon their comfort and convenience to adopt sustainable practices, thus decreasing their intention to do so (Wong et al., 2020). This will create hesitation among people to accept circular economy practices, thus slowing the process of transitioning to a circular economy. Lobo et al. (2021) also stated that barriers such as finance, risk, information, and knowledge are the obstacles that necessitate further research. Therefore, perceived sacrifice added as a variable in the extended theory of planned behavior enables the strengthening of the understanding of the adoption of circular practices.

H4: Perceived sacrifice has a negative influence on CE products adoption.

1.6 Moral norm (MN)

Harms and Skyrms (2009) stated that a moral norm (MN) is a complex set of principles that goes beyond society and is affected by personal behaviors and beliefs. Moral norm is derived from the Schwartz theory, the norm activation model (NAM) (Schwartz, 1977). An individual's comprehension of the responsibility that they must bear through their certain actions is when their MN is triggered (Schwartz, 1977). This theory was later enhanced by Stern et al. (1999), who proposed a value-belief-norms (VBN) theory. This theory argues that an individual's action on pro-environmental behavior is affected by moral norms that are experienced in social interactions. In other words, moral norms are activated when people know their actions have consequences and take up the responsibility to mitigate those effects. In this study, moral norm is an added variable, expanding the theory of planned behavior (TPB). Many have addressed the importance of moral norms in regard to pro-environmental behavior (e.g., Yazdanpanah & Forouzani, 2015). Bamberg and Moser (2006) stated that there is an increase in curiosity in adding MN as one of the predictors in the original TPB framework and also observing it in its correlation to the pro-environmental behaviors. Thus, adding this factor would enhance the understanding of the role of moral norms in the adoption of circular economy CE practices.

He and Zhan (2017) did a study on factors that influence electric vehicle adoption and were able to identify that moral norms have a positive impact on the intention to adopt it. Yazdanpanah and Forouzani's (2015) findings in their study strengthen the statement that moral norms are an important factor in indicating people's intention to act on environmentally friendly behavior. The researchers also found that among the students in Iran, moral norm is an important factor that affects the purchase of organic food (Yazdanpanah & Forouzani, 2015). This stresses the crucial role of youth being the age group that is the most active in adopting CE practices. As for Liu et al. (2020), they stated that moral norms affect consumers' adoptions of green products and mediate between attitude and subjective norms. Similarly to Zhang et al. (2022), who studied moral norms as a mediating role regarding purchasing green electronics appliances and found that consumers who have a high moral standing are likely to purchase these products.

Additionally, moral norms also influence recycling behavior. Saphores et al. (2012) found that moral norms are able to explain an individual's willingness to recycle and to act on pro-environmental behaviors. In addition, Botetzagias et al. (2015) stated that moral norm plays an important role in the intention to recycle. Similarly to Miliute-Plepiene et al. (2016), who explored the drivers that affect the behavior of recycling and identified that moral norm has the most important influence on recycling behavior. This is supported by a recent study by Siringo et al. (2020) that agrees on the importance of moral norms as one of the variables that affects an individual's behavior on recycling, and the researchers also indicate that moral norms are a mediating variable to enhance the understanding of recycling behavior.

H5: Moral norm has a positive influence on CE products adoption.

1.7 Environmental concern (EC)

Bamberg (2003) stated that environmental concern is related to behavioral characteristics, and it impacts a certain situation and the generation of situation-specific cognitions. According to Cruz and Manata (2020), the idea of environmental concern consists of knowledge, beliefs, opinions, and behaviors. Therefore, those who believe and are concerned about the degrading environment are more likely to embrace a pro-environmental lifestyle. There are multiple important values defining an individual's environmental concern, especially those who strive to preserve the environment; they are more likely to behave in a pro-environmental manner.

Past studies indicated that individuals' environmental concerns are a driving force that promotes the transition to circular economy practice (Cruz & Manata, 2020; Patwa et al., 2020; Yue et al., 2020). Ratner et al. (2020) identified that those who have a high education level are more expressive regarding preserving the environment, thus making them more conscious of decisions that are in the environmentally friendly categories. While Akkalatham and Taghipour (2021) studied the barriers to green consumerism behavior and found that circular economy implementation led to pro-environmental behaviors. According to Pinho and Gomes (2023), more people have taken an interest in environmental concerns, which has raised the number of individuals who are more pro-environmental and make every effort to live sustainably, which positively affects the environment. This promotes the adoption of circular economics practices, which can focus on resource efficiency and decreasing waste. Similarly, Gomes and Lopes (2023) studied the effects of environmental concern on circular practices and found that environmental concern does influence different types of circular practices, such as water saving and zero plastics. In this study, environmental concern is added variable to the theory of planned behavior. As Minelgaitė and Liobikienė (2021) stated, there is still a lack of studies regarding this, where the increase of shifts in the adoption of practices in the circular economy by the pro-environmental. Therefore, this warrants in-depth research allowing an extensive observation of environmental concern on the individuals' behavior during the transition to the circular economy.

H6: Environmental concern has a positive influence on CE products adoption.

2 Research methodology

2.1 Respondents, procedures, and measurements

The sample size in this study was collected in 2024 and involved 154 respondents. The surveys were established using data gathering instruments and adopted closed-ended questions with predetermined response options. The surveys were employed to examine the adoption of CE products in Kota Samarahan city, Sarawak, Malaysia. The Likert scale was utilized to identify the degree of agreement among participants, ranging from 1, indicating significant disagreement, to 5, indicating strong

Tab. 1: Survey items – Part 1

Construct/factors	Items	Measurement indicators
Attitude towards behavior (ATB)	ATB1	I think CE products adoption is reasonable.
	ATB2	I find CE products adoption appropriate.
	ATB3	CE products adoption is beneficial for me.
	ATB4	I believe CE products adoption is good for my family.
	ATB5	CE products adoption makes me feel comfortable.
	ATB6	CE products adoption are very useful to my family.
Subjective norms (SN)	SN1	My parents support my CE products adoption.
	SN2	My siblings support my CE products adoption.
	SN3	My friends support my CE products adoption.
	SN4	Colleagues/peers support my CE products adoption.
Perceived behavioral control (PBC)	PBC1	I am confident on CE products adoption if I want.
	PBC2	For me, CE products adoption is easy.
	PBC3	The decision for CE products adoption is not out of my control.
	PBC4	Decision for CE products adoption or not is entirely up to me.
	PBC5	I can afford for CE products adoption.
Perceived sacrifice (PS)	PS1	I do not know about the CE products adoption, before I adopt it.
	PS2	If I opt for CE products adoption, the probability of waste is very high.
	PS3	I need more information about CE products adoption, before adopting it.
	PS4	I have to try it many times.
Moral norm (MN)	MN1	I believe I have a moral obligation for CE products adoption.
	MN2	CE products adoption is consistent with my moral principles.
	MN3	My personal values encourage me for CE products adoption.
	MN4	I have a moral responsibility for CE products adoption.

Tab. 1: Survey items – Part 2

Construct/factors	Items	Measurement indicators
Environmental concern (EC)	EC1	I adopt CE products because the balance of nature is very delicate and can be easily upset.
	EC2	I adopt CE products because human beings are severely abusing the environment.
	EC3	I adopt CE products because humans must maintain the balance with nature in order to survive.
	EC4	I adopt CE products because human interferences with nature often give a negative impact.
CE products adoption (CE)	PI1	I often opt for CE products adoption.
	PI2	My CE products practices are very high.
	PI3	I have purchased CE products (recyclable, reusable, upcycle products).
	PI4	I will continue to opt for CE products adoption.
	PI5	I am recommending to my relatives for CE products adoption.

Source: Ajzen (1991), Dodds et al. (1991), Dopico et al. (2009), Yadav and Pathak (2016), Shin and Hancer (2016), Liu et al. (2020)

agreement. Tab. 1 shows the survey items adapted from Ajzen (1991), Dodds et al. (1991), Dopico et al. (2009), Yadav and Pathak (2016), Shin and Hancer (2016) and Liu et al. (2020). Subject matter experts in the field of circular economy and sustainability have also reviewed and validated the survey regarding its relevance and content validity.

2.2 PLS-SEM

The collected data was evaluated using partial least squares structural equation modelling

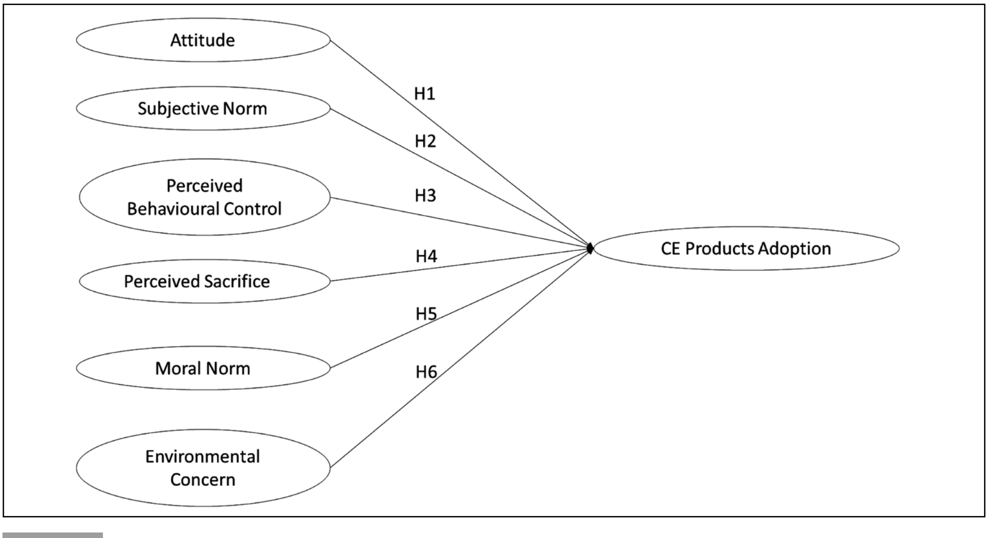

Fig. 1: Conceptual framework

Source: own (adaptation based on Ajzen (1991)

(PLS-SEM) to assess CE products adoption. PLS-SEM was used in this study because it is appropriate for investigating research objectives, considering the limited sample size, and accounting for probable non-normality in the dataset. The measuring model assesses the relationship between latent components and the indicators they represent, and its methods include composite reliability, indicator loadings, discriminant validity, and average variance extraction. The structural model assesses the course of connections between the independent and dependent factors/variables used in the research.

Fig. 1 shows the conceptual framework for this research, which studies the factors influencing CE products adoption. This study employs the main factors of the theory of planned behavior (TPB), which are attitude, subjective norm, and perceived behavior control. Additional factors integrated into this framework are perceived sacrifice, moral norms, and environmental concerns. The framework shows the construct hypothesis and its direct impact on the adoption of CE products.

3 Results and discussion

3.1 Descriptive statistics

The data provided shows a respondent's demographic breakdown (Tab. 2). 51% of respondents are female, while 49% are male. The respondents consist of Malay (27%), Iban (17%), and Chinese (28%), making up the three largest ethnic groupings. In terms of the highest form of education, approximately half of the respondents have pre-university or comparable credentials (53%), while a sizable fraction has a bachelor's degree and above (39%). The majority of households (63%) fall into the B40 group, which denotes lower-income households, in terms of household income, while 37% consist of middle to high levels of income (≥M40).

Tab. 2: Results for descriptive analysis

Demographic		Percentage (%)
Gender	Male	49
	Female	51
Ethnicity	Malay	27
	Chinese	28
	Indian	5
	Iban	17
	Bidayuh	7
	Melanau	6
	Other Bumiputera	9
Education	Primary and secondary education	1
	Pre-university/equivalent	53
	Diploma	8
	Bachelor's degree and above	39
Household income	B40 (<RM 4,850/EUR 982)	63
	≥M40 (≥RM 4,851/EUR 982)	37

Source: own

3.2 Measurement model

Using PLS-SEM, the measurement model was initially evaluated to confirm that the indicators accurately represent the latent variables or constructs. This evaluation comprised tests for the reliability of the measurement scales, as well as checks for convergent and discriminant validity. Based on Tab. 3, all item loadings exceeded 0.6, which is considered satisfactory. Each construct met the minimum requirements of 0.5 for average variance extracted (AVE) and 0.7 for composite reliability, as recommended by Hair et al. (2017) and Fornell and Larcker (1981). The discriminant validity values in Tab. 4 demonstrated that the square roots of the AVEs were higher than the correlations between the constructs and other constructs in the model. Therefore, all tests confirmed that the measurement model is satisfactory.

Tab. 3: Results for measurement model

Variable	Item	Outer loading	Composite reliability	Average variance extracted
Attitude	ATB1	0.875	0.948	0.751
	ATB2	0.812		
	ATB3	0.898		
	ATB4	0.863		
	ATB5	0.875		
	ATB6	0.872		
Environmental concern	EC1	0.848	0.906	0.707
	EC2	0.891		
	EC3	0.803		
	EC4	0.819		
Moral norm	MN1	0.846	0.914	0.727
	MN2	0.863		
	MN3	0.832		
	MN4	0.868		
Perceived behavioral control	PBC1	0.851	0.881	0.598
	PBC2	0.742		
	PBC3	0.808		
	PBC4	0.695		
	PBC5	0.761		
CE products adoption	CE1	0.845	0.935	0.742
	CE2	0.838		
	CE3	0.875		
	CE4	0.893		
	CE5	0.854		
Perceived sacrifice	PS1	0.613	0.801	0.577
	PS3	0.763		
	PS4	0.880		
Subjective norm	SN1	0.905	0.937	0.789
	SN2	0.883		
	SN3	0.900		
	SN4	0.863		

Source: own (based on the PLS-SEM model)

Tab. 4: Discriminant validity using Fornell and Lacker criterion

	Attitude	CE products adoption	Environmental concern	Moral norm	Perceived behavioral control	Perceived sacrifice	Subjective norm
Attitude	0.866						
CE products adoption	0.643	0.861					
Environmental concern	0.513	0.569	0.841				
Moral norm	0.536	0.676	0.449	0.852			
Perceived behavioral control	0.612	0.595	0.431	0.533	0.773		
Perceived sacrifice	0.478	0.420	0.386	0.448	0.415	0.760	
Subjective norm	0.693	0.641	0.387	0.607	0.511	0.491	0.888

Source: own (based on the PLS-SEM model)

3.3 Structural model

Based on the analysis in Tab. 5 and Fig. 2, attitude, environmental concern, moral norm, perceived behavioral control, and subjective norm are significant drivers towards circular economy products adoption. The R^2 value of 0.637 is above 0.26 value suggested by Cohen (1988), indicating a substantial model. The effect sizes (f^2) are also observed in this study. It is found that there is a small effect for attitude, environmental concern, moral norm, perceived behavioral control and subjective norm in producing the R^2 for CE products adoption. Five out of six relationships are found to have t-value ≥ 1.645, hence significant at 0.05 level of significance. The small effect size is rather a reflection of the complex nature of the study. It is a common phenomenon whereby all variables synergistically contribute towards the model, with individual variables having subtle roles but theoretically important part in the context of social science study.

Attitude has a substantial impact on purchasing circular economy items, with a coefficient of β = 0.140 and a p-value = 0.038. This shows that a favorable attitude toward these items might increase the chance of acquiring them. Consumers with positive attitudes about circular products are more likely to engage in sustainable purchasing activities. This is consistent with Jan's (2022) results, which emphasize the need to develop favorable user attitudes in order to effectively support circular economic activities. In the same way, Jimenez-Fernandez et al. (2023) also found a significant relationship between attitudes and circular economic beliefs, showing that a positive attitude is a driving force towards the acceptance and adoption of circular practices. This stresses that producers should highlight the advantages gained through circular economy products to enhance user attitudes and their purchase.

As evidenced by the results of β = 0.225 and a p-value = 0.000, environmental concern has a significant influence on the desire to buy circular economy items. This finding shows that environmentally conscious users are more likely to participate in circular economy-related purchases. Individuals who are concerned about the environment place a high value on sustainable activities and products, which causes them to favor green products to reduce environmental degradation and resource exploitation. This conclusion is similar to the work of Pagiaslis and Krontalis (2014), who emphasized the relevance of environmental awareness in influencing customer behavior toward green products. As a result, businesses could capitalise on this issue by highlighting the environmental benefits of their circular economy offerings in order to attract environmentally concerned customers. In a recent study by Pinho and Gomes (2023), they stated that the increased number of pro-environmentalists would increase the adoption of sustainable lifestyles, thus raising the circular practices among communities. Gomes and Lopes (2023) corroborate through their findings that environmental concern influences different types of circular practices, such as water saving and zero plastic.

The moral norm has a substantial impact on the propensity to acquire circular economy items (β = 0.305, *p*-value = 0.000). This outcome suggests that consumers who feel a moral duty to support sustainable practices are more inclined to purchase circular economy products. A society that upholds strong integrity and ethics would consider its purchase on the basis of benefiting the people and the environment. Hence, their purchase of circular economy products is considered one of the sustainable actions that morally aligns with their personal ethics and integrity. As a result, producers that highlight their ethical commitments to their circular economy-based goods and services would appeal to users and encourage them to make environmentally conscientious purchase decisions. Corroborated with past studies, moral norms reinforce people's intention to perform environmentally friendly activities and positively influence the intention to purchase organic food (Yazdanpanah & Forouzani, 2015). Moral norms also play a mediating role in affecting circular products, where consumers who have high moral standing are likely to engage in environmentally friendly activities (Liu et al., 2020; Zhang et al., 2022).

Perceived behavioral control has a substantial influence on acquiring circular economy items. This outcome (β = 0.160, *p*-value = 0.042) suggests that customers who believe that they possess the capacity to make sustainable-based decision-making are more likely to adopt circular economy products. This includes factors such as accessibility for the particular goods and services. When users think they can overcome the obstacles, such as access to CE facilities of CE adoption, they are more likely to do so. Validated by a recent study, the positive influence that perceived behavioral control brings towards the adoption of circular products (Jan, 2022). This result also corroborates with Tran-Thi-Thanh and Nguyen-Thi-Phuong (2023), who emphasize the need to increase consumers' perceived behavioral control in order to successfully encourage sustainable consumption practices.

Subjective norms have a substantial impact on the propensity to acquire circular economy items (β = 0.210, *p*-value = 0.005). This finding implies that users are significantly affected by the behaviors of their social circle, which may include their family, friends, colleagues, and acquaintances, in circular economic adoption decision making. Users are compelled to make similar decisions if their social circle possesses values that appreciate sustainable practices.

Tab. 5: Hypotheses testing

H	Relationship	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	*p*-values	f^2	R^2
H1	Attitude → CE products adoption	0.140	0.136	0.067	2.072	0.038**	0.021	0.637
H2	Environmental concern → CE products adoption	0.225	0.225	0.060	3.737	0.000**	0.094	
H3	Moral norm → CE products adoption	0.305	0.300	0.073	4.153	0.000**	0.136	
H4	Perceived behavioral control → CE products adoption	0.160	0.165	0.079	2.030	0.042**	0.039	
H5	Perceived sacrifice → CE products adoption	−0.039	−0.030	0.062	0.635	0.526	0.003	
H6	Subjective norm → CE products adoption	0.210	0.209	0.075	2.786	0.005**	0.052	

Note: Significance levels: ** $p < 0.05$.

Source: own (based on the PLS-SEM model)

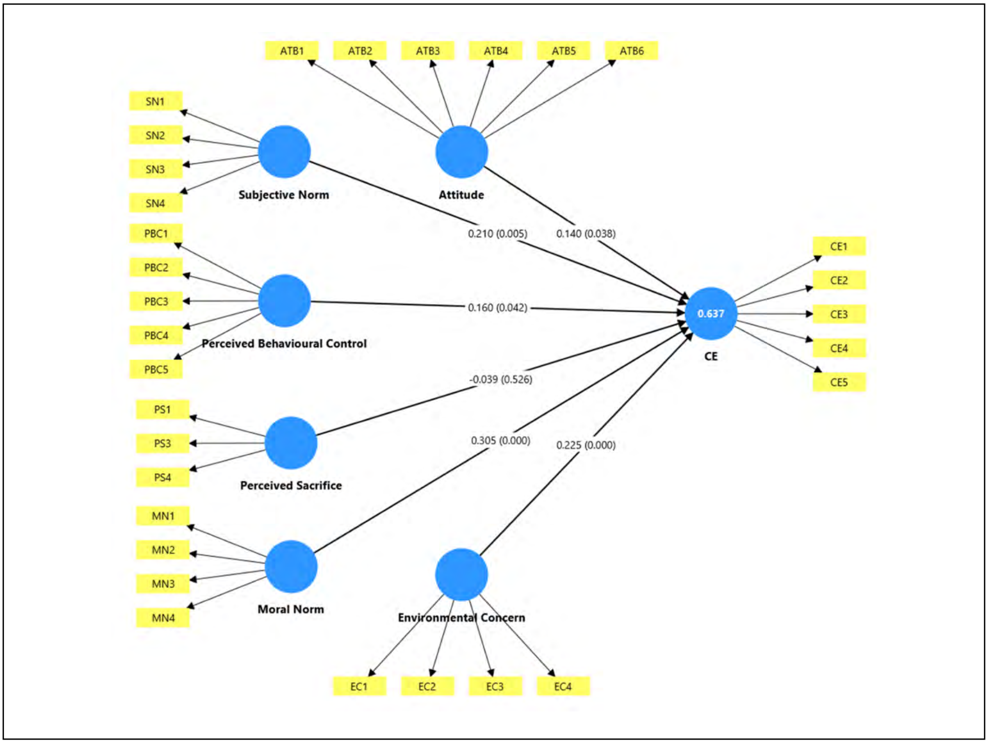

Fig. 2: PLS-SEM output

Source: own (based on the PLS-SEM model)

This aligns with Hao et al. (2020), who stress the role of the social environment in affecting customer behavior. Similarly, government agencies and producers may also initiate a culture or values that support circular economic activities, enabling more sustainable decision-making. Corroborated with recent studies that indicate subjective norms influence circular packaging adoption as well as having a positive impact on circular products purchase (Jan, 2022; Lee, 2022). This validates the idea that subjective norms heavily influence the circular economic products adoption.

Perceived sacrifice is not significant upon circular economic products adoption ($\beta = -0.039$, *p*-value = 0.526). In the case of normalization of circular economy adoption in society, people may perceive it as a socially expected behavior rather than a perceived sacrifice. The outcome also suggests that challenges, which may include financial factors or perceived convenience, are either compensated for by the benefits or insufficiently recognized by society.

3.4 Discussion

The significant role of attitude towards CE products adoption can be affected by dimensions of affective and symbolic, e.g., the sense of fulfillment of "doing good" as well as working in parallel with global movement such as the United Nation Sustainable Development Goals (UN SDG). Youth who associate with eco-conscious firms have stronger bonds with green products due to their emotional connections (Hartmann & Apaolaza-Ibáñez, 2012). Youths are more likely to participate in CE practices such as recycling, upcycling and selecting sustainable products if they perceive these initiatives as beneficial, rewarding, or in line with their identity (Kumar et al., 2021). The output of this study pointed out that CE practices are a result of a positive narrative driven by a sense of responsibility as well as a form of progressive and sustainable way of new thinking among the younger generation.

Youth behavior in a collectivist culture is formed by peer pressure, familial demand, and social standards, which pose a strong effect on subjective norms (Wang et al., 2020). Youth is more likely to perform CE practices that are endorsed or promoted by their members of society (Krajnc et al., 2022). Furthermore, social standards portray by social media influencers can also shape consumers' preferences by encouraging sustainable practices among younger generation (Confetto et al., 2023). The scenario also indicates that the road towards promoting and normalizing CE practices can be expediated by ensuring it to be a publicly-acknowledged and socially valuable behavior.

The role of perceived behavioral control confirms that it is an imperative position in the studies of sustainable based behavior and practices. Youth tend to perform CE practices when they believe they possess the capacity to involve in CE based behaviors (Paul et al., 2016). Lack of access to CE facilities may deter PBC and sustainable practices in Southeast Asia (Chinen & Matsumoto, 2020). Hence, the outcome stresses the neccessity for building supportive surroundings, for example, recycling facilities, repair and refurbishment centres, and remanufacturing facilities that foster youths' morale and readiness to take action on CE-based practices.

Generally, environmental concern is associated with pro-environmental behaviour (Schultz et al., 2005). Environmental concern can be locationally activated or repressed in regard to media, disaster outbreak and social culture (Liobikienė & Poškus, 2019). Severe and apparent environmental deterioration, for instance, water pollution in rivers as a result of waste disposal and air pollution due to industrial emissions in urban cities can be translated into strong behavioural action (Nguyen et al., 2019). In relation to this, the integration of sentimental and value-based attraction for CE stakeholders, such as youth, may improve salience for CE products adoption as a response to risky natural hazards.

Jusoh and Khalifah (2018) stated that personal norm is a significant predictor of recycling and reusing behaviour among youth in Malaysia. This further strengthens that CE products adoption is guided by internalized values as it is perceived as an ethical obligation for the next generation. Individual responsibility not only represents moral norm, but it also forms principle-based mindset, e.g., biosperic values and sense of altruism. Society's moral actions, according to Schwartz (1977), are influenced by their awareness of repercussions or aftermath and sense of responsibility. This is supporterd by de Groot and Steg (2008), who emphasize that biospheric value significantly influences moral responsibility towards pro-environmental behaviour. The internal motivation for CE products adoption can be further bolstered by including sustainable agendas in the academic curriculum and socio-cultural discourse among the younger generation.

Based on this study, it is found that perceived sacrifice is the only non-significance determinant of CE products adoption among youth. This shows that factors including rising costs, difficulties and lack of options in products' offerings may not strongly discourage youth in Asia to adopt CE practices. The scenario is mostly influenced by greater ecological awarenesss and moral duties which override the oppurtunity costs of CE products in younger generations. It is apparent that despite being overpriced and have very limited options, younger generations most likely are prepared to tolerate with these drawbacks so long as the action or behavior aligns with their cultural values and sense of belonging (Gomes et al., 2023). This leads to market paradigm shift in which environmental consciousness outweigh monetary and functional use, in the scenario where there is a growing influence of sustainability-based movements among youth.

Conclusions

Theoretical implications. This study identified significant variables, specifically attitude, perceived behavioral control, social norm, moral norm and environmental concern for the adoption of circular economy (CE) products for youth in Sarawak, Malaysia. This study makes several important contributions to theory by extending the theory of planned behavior (TPB) (Ajzen, 1991) to better explain the adoption of circular economy (CE) practices among youth in a developing country context. Environmental concern (EC) reflects the tendency towards preservation of the environment shaped by values, knowledge and emotional sensitivity

(Schultz, 2001). CE practices may involve shifting from habitual convenience to a more sustainable practices, such as purchasing upcycle clothes or footwear and waste-generated products that require efforts and sacrifice. However, society with strong environmental values are inclined to surpass their difficulties and monetary constraints as a result of the dedication to their environmental principles (Ko & Jin, 2017). Since Malaysia is a developing country where the awareness of CE practices is currently at a gradual pace, rising environmental concern may serve as a trigger for a behavioral paradigm shift. According to Schwartz (1977), moral norm is defined as an internalized sense of obligation to perform certain behavior despite facing external pressures or obstacles. Hence, actions such as lessening waste and refraining from overconsumption is ethical according to the principle of CE. The imperativeness of salience in moral obligation is significant considering Malaysia as a religiously influenced society. Interestingly, perceived sacrifice is not found to be significant in determining CE product adoption, which indicates that factors such as costs, time, energy, and space may compensate for the benefit and values gained among youth.

Practical implications. The results of the predictors, based on their relationship with CE products adoption, offer practical guidance. For attitude, as stated by Chou et al. (2020), marketing firms can showcase all the positive characteristics of CE products, such as their cost-effective aspects, durability, and their regenerative nature, which result in fostering positive perception within individuals, increasing their interest in adopting circular products. As for environmental concern, it is feasible to practice "design for repair (DfR)" as early as initial design in ensuring extended lifespan as well as reducing obsolescence of certain products to promote environmental conservation and reduce waste (Roskladka et al., 2025). Prominent figures can aid by strengthening moral norm by promoting ethical and sustainable practices via advocacies which influence younger generation to adopt CE products as it is considered as "the right thing to do." In addition to that, social norm can affect youth decision-making by establishing a socially-acceptable behavior by prioritizing "shared use," "repair," "recycle" and "upcycle" CE products over new products. CE-based initiatives (e.g., upskilling and re-skilling) must also integrate all social groups especially the marginalized part of society (e.g., underprivileged and disabled) in order to promote inclusiveness and equity. Younger generations are highly affected by perceived behavioral control specifically on the accessibility and visibility of CE products. This can be improved by providing access to CE-based or related facilities and providing clear communication and marketing of CE-based products (Salleh et al., 2024).

Policy implications. The outcome of this study leads to a number of imperative policy implications targeting youth in the developing Asian countries' context in promoting CE products adoption. Youth standpoints, particularly in policy discourses and strategies, continue to be understated despite the commendable development of various policies and roadmaps for a circular economy. Furthermore, this study stresses the critical need to harness favorable thoughts on CE products to encourage sustainable practice. Government, specifically policy-makers, should emphasize educational plans that highlight sustainability agendas. Malaysia's circular economy policies should be integrated into the national education blueprint, which spearheads knowledge and technological innovation in schools and higher institutions. This allows for an enabling condition for the curriculum by integrating circular economy philosophies in the academic curriculum and research environment. Early exposure, particularly among youth, to sustainable consumption, waste reduction, and the concept of recycling leads to lifelong pro-circular behavior, which is important for the long-run achievement of circular economics. This includes more collaboration among various stakeholders, specifically the government, industry, and academia, to ensure the success of the circular initiatives in the form of incentives, funds, knowledge sharing, apprenticeships, and internships. The youth's visions, likings, and innovations must be dynamically integrated into these policies with the aim of increasing their inclusivity in parallel with UN Sustainable Development Goals UNSDG10 to reduce inequalities. To support this, CE-related platforms for youth's consultation, co-creation and decision-making should also be institutionalized by policy-makers nationwide as well as at the state-level. Furthermore, youth is important as they serve as an agent of change through massive youth-based enterprises, inventions and various community-based efforts in building peer support towards sustainable consumption. It is known that there is a lack of ability among the general public to recognize and differentiate between conventional products and CE products. This can be done via tools to increase perceived behavioral control, for instance, mass CE products labelling and mobile applications on CE products identification. In addition, it is vital for policy-makers to incentivize the adoption of CE products by providing discounts, loyalty, and a recycling platform to ensure CE products are more appealing and rewarding among the public, particularly youth or younger generations.

Limitations. The limitation in this research, in terms of contextual outlooks, is constrained to one area, which is Kota Samarahan, thus limiting the demographic information as well as restricting the results from other economic and cultural viewpoints. Therefore, future studies can expand the socio-demographic research area and apply cross-cultural or cross-country comparisons that might showcase the role of economic and cultural differences affecting the adoption of CE. In addition, further studies should be conducted to understand the role of perceived sacrifices in circular economy adoption among youth. Addressing the non-significance could provide valuable insight and identify barriers in circular economy practice in the context of youth and developing Asian countries. This may include future studies on public policy reform and sector-specific cases to further validate the findings. Moreover, longitudinal studies can also be implemented to learn the long-term behavioral shifts between the factors and the CE adoption.

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Towards a greener future: Renewable energy and economic sustainability in Europe

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Abstract: *The transition towards the use of renewable energy sources has been considered for a long time concerning their capabilities in promoting economic sustainability. Therefore, this study aims to examine the role of renewable energy in achieving economic sustainability in the European region. Empirical data was collected with the help of Eurostat to analyze the proposed relationship. Macro-level data from twenty-eight (28) European countries is collected, and the final dataset contains statistics between 2014 and 2023. Analyzing the findings of ordinary least squares and system GMM regression tests, as well as the different proxies of both renewable energy and economic sustainability, a positive relationship is found between renewable energy and economic sustainability. Moreover, increased availability of renewable energy (for instance, wind, solar, and the like) is regarded as a way of enhancing economic performance, creating more jobs, and saving the cost of energy. The outcomes also indicate that upgrading renewable energy infrastructure improves economic growth, promotes innovation, and stabilizes the economy's growth in the long run. This study adds to the current discourse on the efficiency of renewable energy and opens up a new area of research for scholars and policymakers.*

Keywords: *Renewable energy, economic sustainability, European Union.*

JEL Classification: *Q01, Q20, Q42, Q43, O44.*

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Introduction

The transition to renewable energy is generating new economic opportunities for a sustainable future (Kabeyi & Olanrewaju, 2022). These opportunities include climate change mitigation measures, the transition to the circular economy, and environmental conservation (Brodny et al., 2021). The use and implementation of renewable energy resources lead to joint technological and socio-economic development (Maisanam et al., 2021; Quispe et al., 2024). The European countries use their economies not only to advance their industries but also to improve the environment and health of their populations (Kihombo et al., 2021). Policy support mechanisms such as public-private partnerships and carbon emissions can also support long-term sustainability (Lilliestam et al., 2021).

From the recent research, one can conclude that even some scale of the cost of renewables and the relationship with the limited use of fossil fuels can make a real difference (Olujobi et al., 2023). Furthermore, the various cleaner production policies, incentives for the utilization of renewable energy, and environmental regulation can minimize the emission of CO_2 into the environment as well as enhance the quality of the environment, thus supporting sustainable economic growth and development of the green economy and creating more employment opportunities for society (Mikhno et al., 2021).

The European Union (EU) considers sustainable development in the framework of the SDGs to address environmental sustainability in addressing environmental challenges, social cohesion and economic well-being (Szymańska, 2021). It can be seen that this path towards a low carbon future, conservation of biodiversity, and clean energy system is part of the journey towards a fairer future for all. Likewise, a tendency is observed for more EU countries to tap into clean power sources and raise the energy market's call for technology development to boost foreign investors in the renewable energy sector for the economic development of the countries concerned (Al-Shetwi, 2022). This integration also brings more equity and supply of the quality to support human survival and life, and more sustainable energy (Henderson & Loreau, 2023).

Policies in energy also have a very crucial role regarding the formulation of rules and directives and their impact on the realization of sustainable development (Ali et al., 2020; Lucchi et al., 2022). Therefore, a sustainable system that reuses and recycles materials to reduce waste is in line with social, economic, and environmental sustainability goals (Ogunmakinde et al., 2022; Ulanov, 2024). The continued growth and sustainability of renewable technologies can balance policy stability and long-term planning to improve economic efficiency (Riaz, 2024).

Renewable energy technologies that provide innovation in materials to enhance their performance and make them easy to recycle can minimize waste generation and cost, and then economic prosperity is decoupled from environmental degradation (Alcay et al., 2021; Nham & Ha, 2023). Furthermore, maximizing the recovery and recycling of valuable materials can create more sustainable development, mitigate pollution, empower people, and escape poverty (Gigauri et al., 2023; Ogunmakinde et al., 2022). Although attention to environmental problems is focused on mobilizing collective action and driving positive change, advancing environmental protection and climate action catalyzes efforts to protect the planet and encourages policymakers to prioritize decision-making and efficient economic growth and sustainability (Barth et al., 2021). Moreover, the EU's circular economy action plan can drive positive environmental, economic, and social outcomes. By adopting multidimensional eco-friendly strategies such as industrialization, urbanization, and agricultural practices, we can mitigate ecological pollution while supporting economic growth (Xuan et al., 2024).

The EU has substantially reduced the costs of renewable energy produced from wind and solar power and, therefore, makes them increasingly cost-competitive against fossil fuels and nuclear energy. Fossil fuels have higher price volatility because they are linked with the global oil market (Shafiee & Topal, 2010). Moreover, nuclear energy requires higher initial investments and long-term expenses regarding waste management expenses (Yüksel et al., 2024). As compared to the EU, China and India are heavily dependent on fossil fuels because of their lower initial investment and extensive availability of oil. However, the USA and Russia retain a diversified portfolio of energy sources, including significant investments in fossil fuels and nuclear energy as well (Siddi & Silvan, 2024; Singh et al., 2024). Such deviation in energy pricing and strategic decisions regarding energy mix have an impact on the competitiveness of these regions. The EU is taking benefits from sustainability gains, while countries dependent on fossil fuels face challenges of fuel price volatility and growing global demands.

Among different sources of renewable energy, solar and wind energy are considered the most sustainable among all, with fewer environmental side effects. Although the manufacturing and disposal of solar panels have some environmental concerns, but when installed, it produces electricity with no significant emissions. Similarly, the energy through wind power also produces lower emissions; however, it may disturb local ecosystems, including birds, bats, etc. (Bošnjaković et al., 2024). Overall, solar and wind energy emerge as the most environmentally sustainable choices, assuming their lifecycle impacts are effectively managed.

Energy policies play a crucial role in the formulation of rules and directives and their impact on achieving sustainable development (Ali et al., 2020; Lucchi et al., 2022). A sustainable system that reuses and recycles materials to reduce waste aligns with social, economic, and environmental sustainability goals (Ogunmakinde et al., 2022). The continued growth and sustainability of renewable technologies can balance policy stability and long-term planning, thereby improving economic efficiency. The aim of this study is to explore the role of renewable energy in achieving economic sustainability in the European region. This study is novel in multiple perspectives and thus makes significant contributions to the field of knowledge. First, it utilizes a comprehensive dataset covering twenty-eight (28) European countries. Second, the study employs the most recent dataset, spanning the years 2014 to 2023. Finally, it incorporates not only baseline regression models but also advanced endogenous models, such as system generalized method of moments (SGMM) regressions.

The EU aims to empower community engagement and unlock economic potential, thereby advancing social equity and cohesion across the region. By fostering collaboration among policymakers, businesses, civil society organizations, and citizens, there is a collective effort to transition from fossil fuels to clean energy, promoting economic sustainability and ensuring an equitable future for Europe and its citizens (Khan et al., 2022b; Määttä, 2021). Consequently, this study holds significant implications, particularly for countries within the euro region and, more broadly, for the rest of the world.

The rest of the paper is organized as follows: section 1 explains the philosophy of the study, followed by the methodology in section 2 and the empirical analysis in section 3. Lastly, the discussion and conclusions are presented in section 4 and concluding section.

1 Theoretical background and research hypothesis

The usage of renewable energy is an effective source to mitigate the potential of carbon emissions through increasing the life span of products, enhancing the efficiency of resources, and reducing the consumption of waste (Romero-Castro et al., 2023). The integration of circular economy practices into the supply chain and ecosystem can significantly reduce not only the dependence on fossil fuels but also pollution, which can drive positive environmental outcomes and contribute to the expansion of renewable energy infrastructure (Mutezo & Mulopo, 2021). Therefore, the circular economy presents enormous benefits for accelerating the exchange of knowledge, mobilizing investment, demonstrating strong commitments, and developing innovative circular economy solutions and technologies (Fernández-González et al., 2023; Ibrahim & Shirazi, 2021).

The circular economy model is repeatedly considered a sustainable approach in coping not only with the scarcity of resources but also with reducing waste. However, even the sustainability of the circular economy model is not without any flaws and needs to be examined critically. Firstly, recycling as a key factor in the circular economy model faces some inherent challenges, e.g., it requires a high level of energy consumption and presents inefficiencies of resources (Xu et al., 2018). Moreover, some of the materials (i.e., plastics and metals) usually endure downcycling because the quality declines with each reuse, therefore making perpetual recycling non-practical (Bertino et al., 2021). Secondly, the efficacy of recycling depends upon infrastructure and the participation of consumers, which by default vary widely across different regions and, therefore, create inconsistencies and inefficiencies (Velenturf & Purnell, 2021).

Some recent studies also documented the nexus between renewable energy and economic sustainability. For example, Yang and Long (2024) examined the impact of renewable energy on the extraction of natural resources. Using data from 10 countries, the results showed that renewable energy can stimulate the economy and thus improve environmental sustainability. Similarly, Zhang et al. (2024) developed a framework regarding renewable and economic sustainability. Moreover, the study of Khan et al. (2024) used data from developing economies and found a positive relationship between renewable energy and CO_2 emissions. Correspondingly, Qing et al. (2024) explored the impact of renewable energy investment and green financing on carbon neutrality and economic sustainability. By using data from the Asian region, the results provide supportive evidence regarding renewable energy and economic sustainability.

One of the most relevant studies on the topic is conducted by Armeanu et al. (2017), in which authors investigate how renewable energy drives sustainable economic growth in Europe. However, the current study is different from the said study in multiple perspectives. The said study only covers the data from 2003–2014, and we incorporate the most recent data on the topic, i.e., from 2014–2023. The said difference in time period is one of the major significant contributions of the current study from multiple perspectives. Firstly, the current study is also important, particularly in the context of the post-COVID era. COVID-19 is a global phenomenon that not only impacts the developed countries but also developing economies. Moreover, countries in the European regions had faced severe recession in their economies (Usman et al., 2020). Therefore, based on the said depression, OECD drops 2020 growth estimation from 1.1% to 0.8% (Weerasekara, 2020). Although such a depression was not good for the economy, it positively affected environmental consequences (Usman et al., 2021). However, soon after the epidemic, the world opened again, and it was needed to restructure the environmental policies; therefore, the nature and ecology can be preserved. European countries have successfully adopted such a new normal situation and extensively utilized renewable sources of energy. Secondly, the current study focuses on examining the endogenous relationship between renewable energy and economic sustainability using advanced econometric techniques. Lastly, there is a massive advancement in renewable energy that has happened in the last decade; therefore, this study offers a fresh perspective on the present state of renewable energy usage in Europe and its economic consequences.

The development of recycling technologies as a source of renewable energy can ensure resource conservation for future generations and reduce the demand for raw materials (Hagelüken & Goldmann, 2022). Although the process of recycling reduces CO_2 emissions, it also creates economic value by satisfying consumer demand for eco-friendly and socially responsible products (Akbar et al., 2020; Islam et al., 2022). Integrating cleaner energy production can improve corproate innovation and performance and thus mitigate the risks associated with environmental challenges. However, on the other hand, the adoption of clean energy can have benefits in the form of cost reductions regarding waste disposal and enhanced productivity and therefore capture new business opportunities in a much more sustainable manner (Arseculeratne & Yazdanifard, 2014).

The relationship between renewable energy and economic sustainability among European countries plays a crucial role, as the said nexus provides market certainty, reduces investment risks, and attracts financing. These outcomes can help achieve broader energy targets and climate goals (Qudrat-Ullah, 2024). Moreover, the aforementioned relationship can also facilitate market development and growth, leading to economies of scale, enhancing investor confidence, and reducing perceived risks. These factors will eventually help achieve economic growth and sustainability (Feyen et al., 2023).

The relationship between renewable energy and economic sustainability can also be explained through foreign direct investment (FDI) in Europe. Environmental regulations may influence investment decisions and encourage potential investors to invest in EU green industries (Siddik et al., 2023). Such energy-intensive investments can facilitate sectoral composition, international trade, and the green supply chain, and these strategies eventually promote sustainable investment and the economy (Liu et al., 2024).

Renewable energy and economic sustainability are interconnected and entail the subject of economic performance and job developments, corporate efficiency, and clean energy (Khan et al., 2021). Likewise, managing energy markets contributes to microeconomic stability, containing trade imbalances and also owning to better quality steady jobs and greater employment opportunities and more inclusion in the long run (Lin et al., 2023). Thus, they are favoring the local economies, and possible SME entrepreneurs by promoting the innovation and development of renewable energy technologies (Dianu et al., 2021; Fernández-González et al., 2022).

The technological advances in the defining components decrease the cost of renewable energies, which can help overcome some environmental concerns like pollution and climate change (Aziz & Sarwar, 2023). Stability in policies and long-term commitments additionally limits financial risks and increases the overall chances of achieving success within such projects (Felix et al., 2022; Li & Wang, 2023). This is beneficial for EU countries as it helps them to diversify and enhance their energy security and to attract consumers, energy service providers, and investors (Hysa et al., 2023; Mihailova, 2023). These processes can stimulate the demand for renewable electricity in the market and increase the overall competitiveness of renewable energy. In this regard, such policies can also help to respond to public concerns such as pollution, climatic change, or geopolitical risk factors, which have given rise to public demand for clean energy solutions (Alpaño, 2023). Most importantly, it is necessary to focus on the social acceptance of the policies, the intention to provide equal access to opportunities to all the citizens of the country and to all living organisms that are inhabitants of this planet, and the environmental justice of the policies for achieving the maximum amount of positive impact on society (Chang et al., 2024). Based on the discussion above, we can hypothesize that:

H: There is a positive impact of renewable energy on economic sustainability.

2 Research methodology

2.1 Sample and data source

The primary objective of this study is to investigate the impact of renewable energy on economic sustainability across twenty-eight (28) European countries from 2014 to 2023. This study's macroeconomic country-level data is extracted using the Eurostate database. The Eurostat database is an ideal source for this study as it provides reliable, harmonized data across European countries, offers a comprehensive range of relevant economic and energy indicators, and enables longitudinal analysis through its panel data structure. Our final dataset consists of 290 country-year observations. The methodological approach employs panel data analysis, and the scope of this research endeavor is to rigorously examine the interplay between renewable energy and economic sustainability, with the aim of providing the potential pathways for promoting sustainable economic and environmental outcomes in the European region.

This study particularly concentrates on European countries because the EU has been at the forefront regarding the implementation of renewable energy policies and thus offers a unique context to explore the relationship between renewable energy and economic sustainability (Włodarczyk et al., 2021). The EU's ambitious energy transition goals, robust policy frameworks, and diverse economies make it an ideal case to understand how renewable energy can contribute to sustainable economic development (Neofytou et al., 2020).

2.2 Variable descriptions

Explained variables. The dependent variable of this study is economic sustainability. We employ two variables to measure the said variable, i.e., the sustainable development goal (SDG-8) and gross domestic product per capita. The SDG-8 is a composite scale variable quantified by the United Nations. It measures economic sustainability and inclusive growth through a set of specific targets and indicators such as GDP growth rate, employment and decent work, labor productivity, resource efficiency, inclusive economic growth, access to financial services, trade and global value chains, labor rights, and tourism sustainability. Moreover, we also use gross domestic product per capita as a proxy for economic sustainability. These variables provide a comprehensive assessment of economic sustainability, highlighting the efficiency and effectiveness of overall economic performance, inclusivity, and productivity dimensions within the 28 European countries.

Explanatory variables. In this study, renewable energy is used as an independent variable and quantified by using multiple proxies, namely the share of renewable energy (electricity), the share of renewable energy (transport), and the overall share of renewable energy. These proxies serve as crucial indicators for evaluating the extent of renewable energy integration among the sample countries within the European region. A higher share of renewable energy sources not only contributes to mitigating climate change by reducing greenhouse gas emissions but also enhances energy diversity, thereby promoting economic sustainability (Chen et al., 2023). The countries' power sectors play a pivotal role in shaping a sustainable energy infrastructure for future generations. By transitioning towards renewable energy sources, countries can pave the way for a more environmentally conscious and sustainable energy landscape, ensuring the availability of clean and reliable energy resources for generations to come and eventually economic sustainability (Idoko et al., 2024).

Control variables. We use four different control variables in this study, namely government expenditure (Khan et al., 2022a), net lending and borrowing (Li et al., 2023), government revenue (Smirnova et al., 2021), and agriculture productivity (Lankoski & Thiem, 2020). These variables provide a comprehensive picture of the economy and impact economic sustainability. Therefore, these variables are essential for policymakers in designing and implementing strategies to enhance overall societal well-being.

2.3 Econometric model

Based on the nature of the dataset and the construction of variables, we have developed a baseline econometric model. The model consists of dependent, independent, and control variables with an incept and error term.

$$Economic\ Sustainability_{kt} = \\ = \beta_0 + \beta_1\ Renewable\ Energy_{kt} + \\ + \sum_{j=1}^{04} \beta_j\ Control\ Variables_{kt} + e_{kt} \quad (1)$$

The model above represents regression models where the dependent variable is *Economic Sustainability*$_{kt}$ and categorized into SDG-8 and gross domestic product per capita. The independent variable is *Renewable Energy*$_{kt}$ and classified as the share of renewable energy (electricity), the share of renewable energy (transport), and the overall share of renewable energy. Lastly, we have *Control Variables*$_{kt}$ e.g., government expenditure, net lending and borrowing, government revenue, and agriculture productivity. In the model, *k* denotes an individual country, and *t* denotes time. β_0 is an intercept term representing the expected value of economic sustainability when all other variables become zero. *e* is an error term, representing the difference between the observed value of economic sustainability and the value predicted by the models. It captures the effects of unobserved factors and random variation.

3 Empirical results and analysis

Tab. 1 presents the summary statistics of all the variables used in this study. We have a total of 290 observations divided into the panel of countries and years. SDG-8 shows a mean value of 7.37 with a minimum value of 5 and a maximum value of 8. Similarly, GDP per capita has values ranging from 8 (minimum) to 11 (maximum). Based on the descriptive statistics, the overall share of renewable energy, the share of renewable energy (electricity), and the share of renewable energy (transport) have mean values of 25.88, 36.90, and 8.58%, respectively.

Tab. 2 depicts the pairwise correlation coefficients between dependent, independent, and control variables. All values presented in Tab. 2 are acceptable and within the bounds required to establish that the data is free from collinearity issues that cause multicollinearity.

Tab. 1: Summary statistics

Variable	Unit	Obs.	Mean	Std. dev.	Min	Max
Sustainable development goal – 8	Scale	290	7.37	0.61	5.98	8.64
Gross domestic product per capita	USD	290	10.08	0.63	8.61	11.37
Overall share of renewable energy	Percentage	290	25.88	17.63	4.47	85.78
Share of renewable energy (electricity)	Percentage	290	36.90	25.90	3.33	120.01
Share of renewable energy (transport)	Percentage	290	8.58	7.37	0.41	92.55
Government expenditure	USD	290	239,779.00	396,918.00	3,523.00	2,003,380.00
Net lending and borrowing	USD	290	−11,274.00	36,260.00	−207,084.00	144,437.00
Government revenue	USD	290	228,554.00	375,350.00	3,390.00	1,901,807.00
Agriculture productivity	Yield	290	7,785.00	11,415.00	43.00	56,701.00

Source: own

Tab. 2: Correlation matrix

	1	2	3	4	5	6	7	8
2	0.520							
3	0.231	0.230						
4	0.351	0.350	0.892					
5	0.345	0.344	0.399	0.390				
6	0.241	0.242	−0.157	−0.012	0.065			
7	0.017	0.015	0.239	0.172	0.047	−0.624		
8	0.256	0.258	−0.143	0.005	0.074	0.697	−0.563	
9	0.061	0.063	−0.250	−0.102	−0.043	0.679	−0.716	0.761

Note: 1 – sustainable development goal – 8; 2 – gross domestic product per capita; 3 – overall share of renewable energy; 4 – share of renewable energy (electricity); 5 – share of renewable energy (transport); 6 – government expenditure; 7 – net lending and borrowing; 8 – government revenue; 9 – agriculture productivity.

Source: own

Tab. 3: Baseline regression estimates

	Coefficients		
Independent variables			
Overall share of renewable energy	0.0071***		
	(3.8800)		
Share of renewable energy (electricity)		0.0070***	
		(6.4100)	
Share of renewable energy (transport)			0.0228***
			(2.4800)
Control variables			
Government expenditure	0.0012***	0.0006***	0.0001***
	(−17.2400)	(−12.7700)	(−16.3400)
Net lending and borrowing	0.0001***	0.0013***	0.0021***
	(−14.4800)	(−11.4500)	(−14.1100)
Government revenue	0.0032***	0.0031***	0.0051***
	(17.9900)	(13.2400)	(16.8200)
Agriculture productivity	0.0022***	0.0055***	0.0058***
	(−3.8400)	(−3.9600)	(−3.9000)
Constant	7.1248***	7.0638***	7.1281
	(89.8900)	(102.8200)	(83.0200)
Model summary			
Number of observation	290	290	290
***F*-stats**	136.8800	126.8800	127.7000
Prob. > *F*	0.0000	0.0000	0.0000
***R*-squared**	0.2067	0.2507	0.2399

Note: Dependent variable – sustainable development goals – 8; country-year – panel dataset; ordinary least square – OLS; *** $p < 0.01$; t-stats in ( ).

Source: own

To dig out the nexus between renewable energy and economic sustainability, we use regression analysis, a particular multivariate regression analysis technique. Firstly, we incorporate ordinary least squares regression as a baseline tool using SDG-8 as a dependent variable. Moreover, we use three separate proxies of renewable energy, i.e., the overall share of renewable energy, the share of renewable energy (electricity), and the share of renewable energy (transport). The results reported in Tab. 3 represent a positive and statistically significant impact of renewable energy on economic sustainability. All the regression models are statistically fit based on the significance level of relevant *F*-statistics.

To further check the robustness of the results reported in Tab. 3, we change the proxy of economic sustainability from SDG-8 to GDP per capita. Based on the results reported in Tab. 4, all of the proxies of renewable energy show a positive relationship with GDP per capita and, therefore, are in line with our earlier results. These outcomes support the narrative that renewable energy as an alternate energy source provides new opportunities for sustainable economic growth.

Tab. 4: Baseline regression estimates (robust check)

	Coefficients		
Independent variables			
Overall share of renewable energy	0.0073***		
	(3.8900)		
Share of renewable energy (electricity)		0.0072***	
		(6.4100)	
Share of renewable energy (transport)			0.0233**
			(2.4900)
Control variables			
Government expenditure	0.0091***	0.0025***	0.0021***
	(−17.2300)	(−12.8100)	(−16.3300)
Net lending and borrowing	0.0023***	0.0712***	0.0007***
	(−14.4900)	(−11.4800)	(−14.1100)
Government revenue	0.0072***	0.0022***	0.0034***
	(17.9800)	(13.2700)	(16.8100)
Agriculture productivity	0.0184***	0.0075***	0.0026***
	(−3.8400)	(−3.9500)	(−3.8900)
Constant	9.8264	9.7641***	9.8297***
	(121.3100)	(138.8300)	(112.0200)
Model summary			
Number of observation	290	290	290
***F*-stats**	122.6800	125.2500	126.1100
Prob. > *F*	0.0000	0.0000	0.0000
***R*-squared**	0.2067	0.2503	0.2397

Note: Dependent variable – gross domestic product per capita; country-year – panel dataset; ordinary least square – OLS; *** $p < 0.01$; ** $p < 0.05$; *t*-stats in ( ).

Source: own

We move towards the system generalized method of moments (SGMM) model for the advanced regression estimates. The selection of the said technique is based on several reasons. Firstly, endogeneity is a great concern, particularly in panel datasets. SGMM addresses endogeneity caused by simultaneity, measurement errors, or omitted variable bias (Van Tran et al., 2019). Secondly, unobserved heterogeneity is also another challenge encountered in panel data. SGMM can provide consistent and efficient estimates even in the presence of heteroskedasticity. Lastly, SGMM exploits the panel data structure more

Tab. 5: Advanced regression estimates

	Coefficients		
Independent variables			
Overall share of renewable energy	0.0063***		
	(3.9400)		
Share of renewable energy (electricity)		0.0113***	
		(8.7400)	
Share of renewable energy (transport)			0.0057***
			(2.3300)
Control variables			
Government expenditure	0.0055**	0.0001**	0.0021**
	(1.7500)	(2.1000)	(−1.8100)
Net lending and borrowing	0.0001	0.0001**	−0.0001
	(0.3100)	(1.9900)	(−1.1300)
Government revenue	−0.0016	−0.0001**	0.0031
	(−0.3800)	(−2.0500)	(1.0800)
Agriculture productivity	−0.0001***	−0.0001***	−0.0001***
	(−15.2100)	(−13.5100)	(−14.2900)
Constant	7.3056***	7.1308***	7.4090***
	(156.9200)	(143.4600)	(182.3100)
Model summary			
Number of observations	290	290	290
Number of groups	29	29	29
Observations per group	10	10	10
Wald Chi^2	406,215.2400	307,259.4600	425,361.0100
Prob. > Chi^2	0.0000	0.0000	0.0000
Sargan test			
Chi^2	6.8600	5.1700	8.1200
Prob. > Chi^2	1.0000	1.0000	1.0000

Note: Dependent variable – sustainable development goals – 8; country-year – panel dataset; system generalized method of moment – SGMM;
*** $p < 0.01$; ** $p < 0.05$; *t*-stats in ( ).

Source: own

effectively than OLS, particularly for datasets with many individuals and few time periods (Lin & Lee, 2010).

Tab. 5 reports the regression results using the SGMM technique. As per the outcome, we found a positive and statistically significant impact of renewable energy on economic sustainability. All the models are statistically fit based on the significance of the respective values of chi-square. To verify the validity of the instruments, we conducted a Sargen test, and based on their statistical values, all the instruments proved to be valid for SGMM models. These findings are in line with the literature, support our hypothesis, and prove that a higher share of renewable energy leads to an increase

Tab. 6: Advanced regression estimates (robust check)

	Coefficients		
Independent variables			
Overall share of renewable energy	0.0064***		
	(3.9500)		
Share of renewable energy (electricity)		0.0116***	
		(8.7700)	
Share of renewable energy (transport)			0.0058***
			(2.3400)
Control variables			
Government expenditure	0.0001***	0.0001**	0.0012
	(2.4200)	(2.0800)	(−1.0400)
Net lending and borrowing	0.0021***	0.0001**	0.0001***
	(2.2800)	(1.9600)	(2.1700)
Government revenue	0.0001	−0.0001**	0.0001***
	(−0.3400)	(−2.0200)	(−2.1100)
Agriculture productivity	−0.0001***	−0.0001***	−0.0001***
	(−15.2000)	(−13.5300)	(−14.2500)
Constant	10.0095***	9.8311	10.1153***
	(210.4000)	(194.0500)	(243.0500)
Model summary			
Number of observations	290	290	290
Number of groups	29	29	29
Observations per group	10	10	10
Wald Chi^2	727,035.6800	552,717.8500	758,024.7000
Prob. > Chi^2	0.0000	0.0000	0.0000
Sargan test			
Chi^2	6.8500	5.2000	8.0900
Prob. > Chi^2	1.0000	1.0000	1.0000

Note: Dependent variable – gross domestic product per capita; country-year – panel dataset; system generalized method of moment (SGMM);
*** $p < 0.01$; ** $p < 0.05$; *t*-stats in ( ).

Source: own

in economic sustainability, particularly in the European region.

To check the robustness of the findings of SGMM reported in Tab. 5, we use an alternate proxy of economic sustainability, i.e., GDP per capita. The findings remain consistent and verify the study's hypothesis, i.e., that renewable energy positively impacts economic sustainability. These results in Tab. 6 show that the higher overall share of renewable energy and the share of renewable energy in the electricity and transport sectors subsequently enhance economic sustainability. All of the regression results are statistically significant (*t*-statistics, chi-square, and sargan-statistics) and in line with the previous studies.

4 Discussion

The findings of this study provide some valuable insights into the impact of renewable energy on economic sustainability, particularly in the context of the European region. The results of this study are not only aligned with the relevant theories, including the circular economy model, but also with the previous studies on the topic, e.g., Armeanu et al. (2017), Yang and Long (2024), and Zhang et al. (2024). A positive impact has been observed between these two variables, which align with the previous literature and provide the potential economic benefits of transitioning towards cleaner energy sources. Firstly, the results validate that investing in renewable energy can contribute to long-term economic sustainability. As countries within the European region shift from fossil fuel dependence towards alternate renewable sources, countries can mitigate the risks associated with volatile energy prices and supply disruptions. This stability in energy costs can have lasting implications for businesses, households, and overall economic stability. However, these findings are different in the context of developing countries, as mentioned in the study of Gyimah et al. (2023), where the author concluded that renewable energy consumption causes no effect on economic growth.

Furthermore, developing renewable energy infrastructure can also stimulate job creation and economic activity across various sectors. From manufacturing to operation, renewable energy can offer employment and skill development opportunities. This new green job can foster economic growth. Additionally, the positive relationship between renewable energy and economic sustainability could be attributed to the potential for energy cost savings over the long run. As renewable energy matures and achieves economies of scale, the energy cost from alternate sources (e.g., wind and solar) is expected to become increasingly competitive with traditional fossil fuels. Such a reduction in the cost can translate into lower energy bills for consumers and businesses, thus increasing investments and consumption.

It is, however, important to consider that the evolution to renewable energy requires significant initial investments, which may be a challenge. However, the long-term benefits suggested in this study show that these investments can eventually settle in the form of economic sustainability. Moreover, the findings of this study underscore the importance of rational and supportive policy frameworks to facilitate the adoption of renewable energy. Incentives, subsidies, and regulatory measures can also play an important role in accelerating the deployment of clean energy solutions, thereby amplifying their positive impact on economic sustainability.

Economic sustainability stresses retaining long-term economic growth without exhausting resources or even causing environmental damage. The said nexus is aligned with sustainable development, which integrates economic, social, and environmental aspects in fulfilling the needs. Moreover, ecological sustainability also focuses on preserving natural ecosystems and biodiversity and provides the foundation on which economic and social systems are dependent (Hariram et al., 2023). Similarly, ecological economics links the aforementioned concepts by considering the economy as a subsystem of the environment. Therefore, to achieve economic sustainability, it is required to build a holistic view that connects ecological sustainability and sustainable development to ensure a resilient future (Fuchsová, 2022).

Conclusions

The world faces numerous challenges regarding adopting renewable energy sources as an alternative to traditional fossil fuel-related energy sources. Traditional energy sources are not only harmful to human health but also detrimental to the environment. Therefore, studying the economic impact of renewable energy sources is of utmost importance. Keeping in view the said objectives, this study is designed to diagnose how renewable energy sources can play a role in achieving economic sustainability. For this study, we have chosen countries from the European region because these countries are swiftly moving from traditional energy sources towards renewable energy sources. Moreover, these initiatives can also motivate other countries to restructure their economies for more sustainable and green energy sources.

We have collected data from twenty-eight (28) European countries from 2014 to 2023 and used OLS and SGMM regression techniques. The empirical results provide supportive evidence about the positive impact of renewable energy on economic sustainability. These results are robust checked using different proxies for both renewable energy and economic sustainability. Therefore, based on the statistical analysis, we can suggest that renewable energy can be considered an alternate source to improve economic conditions and achieve sustainability.

The recommendations and policy implications of the study are multidimensional. Firstly, the positive results could prompt policymakers to establish and strengthen regulatory frameworks that authorize renewable energy targets. Secondly, as the current study uses recent empirical data, particularly in the context of the post-COVID situation, the policymakers could restructure the environmental policies; therefore, the nature and ecology can be preserved. Thirdly, as compared to the previous studies, the current study recommends an endogenous relationship among renewable energy consumption and economic sustainability and therefore opens a new arena for future studies. Because as the renewable energy sector expands, there could be an increasing demand for skilled workers. Therefore, policymakers could invest in workforce development programs, vocational training, and educational initiatives to equip the labor force with the necessary skills and knowledge to support the transition process. Lastly, public acceptance and support are important for successfully implementing renewable energy policies. Thus, policymakers could initiate public awareness campaigns and educational programs to highlight the economic and environmental benefits of renewable energy.

Apart from all the effective policy implications, this study also has some limitations. Firstly, we use the data from European countries; therefore, the findings can only be implemented in the countries having similar developmental status. Moreover, we consider Europe as a union and investigate a holistic view; therefore, investigating each sample country separately is beyond the scope of the study. Secondly, we use macro-level data for our analysis; therefore, the results could only be generalized to other countries, with the possibility that corporate-level data could bring different results. While the results of this study provide compelling evidence of the favorable relationship between renewable energy and economic sustainability, further research can be conducted to understand the other aspects of renewable energy, i.e., ethical concerns, education policies, environmental effects, etc. Furthermore, evaluating sample countries separately could also bring interesting results.

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Balancing urban growth and green solutions: Rooftop hydroponic farming in the Czech Republic

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Abstract: *The logistics sector has become an integral component of the urban fabric, significantly influencing the gateway areas of cities. In Central Europe, the rapid expansion of warehouse infrastructure has been particularly notable, with the total net warehouse area reaching 59 million square meters in 2023. This development contributes to the formation of urban heat islands, which adversely impact the microclimate of nearby cities, exacerbating environmental challenges. The need for sustainable solutions to balance urban not only logistics growth with environmental preservation is increasingly urgent. This article explores the benefits and challenges of rooftop hydroponic farming through a case study conducted in July and August 2024 in the Czech Republic. The presented research is based on the students' project "Lettuce on the roof" that integrates advanced hydroponic technology with the local rooftop environment and market conditions, contributing to sustainability, food security, and urban resilience. Key findings demonstrate that the hydroponic farm effectively reduced roof and surrounding temperatures, enhancing thermal regulation and building energy efficiency. The project achieved several months production of lettuce and herbs, with a short and efficient distribution chain ensuring fresh produce reached customers quickly. However, logistical complexities and the maintenance requirements of the selected concept present challenges, highlighting areas for improvement. These results underscore the potential of rooftop hydroponics as a viable urban agriculture solution, although future research should address operational scalability and optimization financial strategies for long-term sustainability.*

Keywords: *Sustainable agriculture, green production, environmental, social, and governance (ESG), resource efficiency.*

JEL Classification: *Q16, O13, Q56, D61.*

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Introduction and theoretical background

Urban agriculture was already known in ancient civilizations. Today, we are rediscovering it in the light of innovative hydroponic growing technology driven by climate change, the pressure to reduce CO_2 production and the search for new forms of cultivation due to population growth (Wirza & Nazir, 2021).

Rooftop hydroponic farming represents an innovative approach to urban agriculture, embodying the capacity to adapt to the conditions described by the VUCA framework (volatility, uncertainty, complexity, and ambiguity). Amid growing climate challenges, unstable supply chains, and population growth, rooftop hydroponics enhances urban resilience by reducing reliance on external food sources and minimizing environmental impacts (Sharma et al., 2024). The flexibility of the system allows for rapid adjustments in production to meet shifting demand and climatic conditions, addressing market volatility. It mitigates uncertainty by decentralizing food production, while the complexity and ambiguity of urban environments are managed through the integration of cultivation technologies within the city's infrastructure (Zu, 2023). Rooftop hydroponics serves as a practical tool for cities striving for sustainability and adaptability in a VUCA-shaped world.

Rooftop hydroponic farming can also help municipalities achieve circularity by integrating sustainable practices into urban infrastructure. It utilizes underused rooftop spaces, transforming them into productive areas that contribute to local food systems (Martin et al., 2019). The closed-loop hydroponic systems optimize water usage by recycling it within the system, significantly reducing waste (Buehler & Junge, 2016). By producing food locally, rooftop farms minimize transportation emissions and reduce dependency on external food supply chains (Hsieh et al., 2018). They also improve urban microclimates by mitigating the heat island effect, reducing energy demand for cooling buildings (Fussy & Papenbrock, 2022). These initiatives align with circular economy principles by creating systems that maximize resource efficiency, reduce waste, and promote environmental sustainability within municipalities (Wirza & Nazir, 2021).

Therefore, hydroponics represents a sustainable alternative to traditional agriculture as it maximizes overall output and minimizes using space, land, water and other resources. This method utilizes soilless cultivation techniques to grow crops in urban environments, effectively addressing space limitations and enhancing food security (Payen et al., 2022). Similarly, other research indicated that rooftop hydroponic systems can yield crops such as lettuce and other leafy vegetables, often with higher efficiency compared to traditional farming methods (Ezzaouia & Bulchand-Gidumal, 2021). For instance, another meta-analysis highlighted that the crop yields from hydroponic rooftop gardening can significantly exceed those from conventional urban gardening practices (Payen et al., 2022). These systems can also contribute to stormwater management and reduce urban heat through increased vegetation

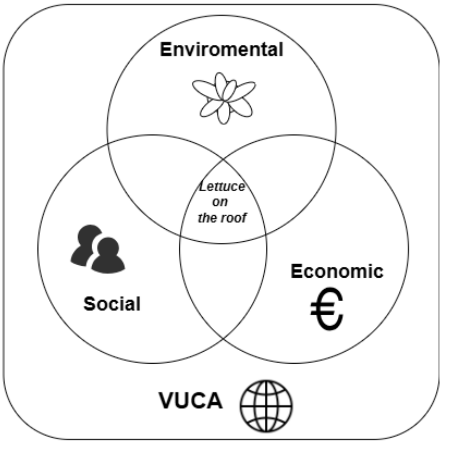

Fig. 1: Lettuce on the roof in VUCA world

Source: own

cover (Kong et al., 2015). Studies have shown that rooftop farms can be less contaminated than their ground-level counterparts, potentially reducing the carbon footprint associated with food transportation (Liu et al., 2016).

This article examines overall the benefits and challenges of rooftop hydroponic farming based on a case study carried out in the city of Liberec, in the Czech Republic. The study melds expertise in cutting-edge hydroponic cultivation technology with an understanding of the potential of the local rooftop environment and the local market. This convergence led to the conception of a regional network of open rooftop hydroponic farms, which was developed as a "Lettuce on the roof," the winning project at the Start-up student competition at the Technical University in Liberec in 2023. The main aspects of the case study are shown in Fig. 1.

The evaluation of the case study is based on data analysis in three crucial areas of sustainability: i) environmental aspects (measurement of temperature differences, recording of temperature maps); ii) social areas (public response – evaluation of media campaign, reactions at farmers' markets); and iii) economic consequences of the project (cost-benefit analysis (CBA) used for evaluation of a specific case).

From the environmental point of view, hydroponic farming generally requires significantly less water than traditional agriculture, with reductions of up to 90% in some instances (Thanushree, 2024). This water efficiency is particularly advantageous in areas experiencing water scarcity (Găgeanu et al., 2024). Furthermore, hydroponic systems can be designed to recycle water, thereby further minimizing overall water consumption (Sorrilla et al., 2023). The decreased demand for land and water can result in lower operational costs and a reduced environmental impact. Operating in controlled environments, hydroponic systems are less vulnerable to soil-borne pests and diseases, which can reduce the need for pesticides and result in healthier crops that can command premium prices (Sharma et al., 2024). The absence of soil also reduces the risk of contamination from pathogens, thereby enhancing food safety (Moschou et al., 2022). Additionally, hydroponics enables year-round cultivation, independent of seasonal variations, which can stabilize farmers' incomes and ensure a consistent supply of fresh produce to markets (Sharma et al., 2024; Thanushree, 2024). The capability to cultivate crops in urban areas also lowers transportation costs and reduces carbon emissions associated with food distribution (Naresh et al., 2024). Our case study considers expected benefits and potential challenges within the comprehensive research framework. To fulfil the submitted goals, in the second step, it was necessary to select a suitable case and establish appropriate measurement parameters concerning the main pillars of sustainability. During the entire research, continuous data collection occurred (e.g., temperature measurement, cost monitoring or evaluation of the media campaign), which was subsequently evaluated and reported in the Results section. The entire study is then assessed in the discussion and conclusion. Possible solutions to building issues are also offered, and research limits and future research directions are presented.

1 Research methodology

The examination of a specific unit within a particular topic can be achieved through a case study, offering a comprehensive perspective. Additionally, it can serve as a foundation for applying principles and guidance from a pilot study in certain instances (Yin, 2018). Since the topic of hydroponic farming on rooftops has not yet been sufficiently researched and is also not widely used in the commercial sphere, the case study appears to be an ideal research method for this type of project.

Researchers are faced with the critical decision of whether to conduct a case study, which encompasses defining the nature of the case and its constraints. A clear and thorough definition of the case is crucial at the outset. Limitations pertain to what is encompassed by the case in terms of time, structure, or additional perspectives (Epler, 2019).

Takahashi and Araujo (2019) also refuted certain criticisms related to the size of the sample. A case study typically involves a small sample of units, focusing on analysing the issue in depth rather than breadth to deepen theoretical and empirical knowledge. The approach and concepts adopted in a case study may also be subject to challenge and inquiry. This often arises due to the complex and extensive nature of the phenomenon being investigated, rather than any inherent limitations of the chosen method (Takahashi & Araujo, 2019).

The case study, found as a suitable tool for pilot research, was conducted in five main steps.

STEP 1: Definition of objectives

Since the entire case study is based on the fundamental pillars of sustainability, the defined objectives were divided into three primary groups. From an economic perspective, the case study focuses on achieving financial viability and long-term profitability. Begin by conducting a detailed cost analysis, estimating the capital investment required for setup and the ongoing operating expenses, including seeds, nutrients, and maintenance. It is crucial to set yield targets that reflect the potential of the rooftop space, factoring in market demand and the value of the crops being grown. A comprehensive economic overview is based on CBA, allowing for a structured decision-making approach and ensuring that all relevant factors are considered, which is essential for effective resource allocation.

On the environmental side, the emphasis should be on minimizing the farm's ecological footprint. First, assess the rooftop's environmental conditions, such as sunlight exposure, wind patterns, and temperature fluctuations, as these factors directly influence crop selection and system design. Water-use efficiency represents another key aspect, as hydroponic systems are known for using significantly less water than traditional farming methods. As part of the case study, temperatures were monitored outside and inside the building (under and outside the farm). Water consumption was also observed.

From a social sustainability perspective, the project should contribute to the well-being of the community while promoting urban agriculture. This can be done by implementing education and awareness initiatives, offering workshops, and engaging local residents in the practice of hydroponic farming. For this case study, several methods were used to verify the general public's interest: i) two workshops were held as part of the university teaching; ii) a media campaign was launched; and iii) the products were introduced on a pilot basis at farmers' markets.

STEP 2: Case selection

The pilot hydroponic farm was installed on the roof of the Technical University in Liberec's building, which was built in 1965 and is ready for reconstruction. Therefore, the selected structure and its roof represent an ideal space to verify the positive impacts and to test all possible challenges. The farm configuration consisted of four separate racks (2.5 m × 5 m × 1.5 m), each holding 200 slots, combining to a total area of 50 m^2 and a capacity of 800 slots, potentially yielding up to 800 units (lettuce/herbs) per month during the growing season from April to October. Water and nutrient replenishments were performed manually, and water quality, nutrient levels, and pH were monitored thrice weekly. The farm utilized municipal water from the building supply, with a weekly consumption of approximately 1,000 l. Maintenance required about 4 hours per week. The construction is shown in Fig. A1 (appendix).

Setting up a temporary seedling nursery directly in the building was also allowed. The pre-growing phase of the plants lasts about three weeks, and the plants in the racks on the roof need the same amount of time to mature fully. Seedlings were grown from seeds in propagation trays with cultivation fleece. The nursery facilitated experimentation with different lettuce and herb varieties. Fleece cultivation ensured clean production. Herb propagation was effectively achieved by rooting cuttings in cultivation fleece. The nursery's operational reliability was high, with only one electrical outage affecting pump operation. It adequately supported the entire farm's capacity (800 slots), with minimal water and nutrient replenishment requirements and UV lamps accounting for energy consumption. Fig. A2 (appendix) shows the design of the seedling nursery.

STEP 3: Setting up methods used for evaluation a case study

The case study evaluation relies on data analysis across three key sustainability areas: environmental factors, including monitoring temperature differences and mapping temperatures; social aspects, assessed through public feedback from media campaigns, workshops and farmers' markets; and economic impacts, evaluated using a cost-benefit analysis to determine the project's financial viability.

The measurement of temperature differences was also supplemented with a temperature map. Water consumption for the given period was also measured.

Temperatures were monitored at a total of 6 locations: i) in the room under the farm (1) × in the room not under the farm (2); ii) on the roof under the farm (3) × on the roof outside the farm (4); and iii) at a height of 1.2 m below the farm (5) × at a height of 1.2 m outside the farm (6).

The collected data were analysed using descriptive statistics to compare mean, median, and variability across these points, offering insights into temperature mitigation effects. Temperature maps were employed to visualize differences and fluctuations, reinforcing the findings. This comparison highlights the farm's impact on moderating indoor and outdoor temperatures, demonstrating its contribution to thermal regulation and resource efficiency.

From the point of view of CBA, offering an economic view of the selected case, costs and revenues were also monitored and studied in two months. The process of conducting a CBA typically encompasses several fundamental stages: defining the objectives of the analysis, identifying the available alternatives, and evaluating the anticipated costs and benefits associated with each option. Analysts often express the results in terms of NPV, benefit-cost ratios, or incremental cost-effectiveness ratios, which facilitate informed decision-making regarding resource allocation (Hoch et al., 2002). Furthermore, CBA extends beyond purely financial metrics to include social and environmental considerations. This comprehensive approach is crucial for capturing the full spectrum of a project's potential impacts on society, the environment, and human well-being (Ponomarenko & Friedman, 2017). Cost-benefit analysis in the context of hydroponic farming involves evaluating the economic viability of hydroponic systems compared to traditional soil-based agriculture. This analysis encompasses various factors, including initial setup costs, operational expenses, yield potential, and resource efficiency.

The media campaign launched in August 2024 can be quantitatively evaluated as part of social impact monitoring. In marketing and public relations, advertising value equivalent (AVE) is a widely used metric for quantifying the value of earned media coverage by equating it to the cost of purchasing an equivalent amount of advertising space or airtime. AVE is calculated by estimating how much it would have cost to buy the same space in a given media outlet if it had been used for an advertisement instead of editorial coverage. For example, if a company receives a half-page feature in a newspaper, AVE would approximate the cost of a paid advertisement occupying the same half-page in that publication (Kee & Hassan, 2006).

The results of the workshops and participation in farmers' markets can only be assessed qualitatively from a research point of view through interviews and feedback collection.

STEP 4: Data analysis and reporting of results

The collected data were thoroughly analysed to evaluate the environmental, social, and economic dimensions of the project. Descriptive statistics were applied to temperature data to assess the mean, median, and variability across six monitored locations, providing valuable insights into the farm's ability to mitigate temperature fluctuations. The use of temperature maps visually highlighted differences between shaded and unshaded areas, reinforcing the findings that the rooftop farm contributed to thermal regulation and improved energy efficiency.

From an economic perspective, a CBA was conducted over a two-month period, examining the balance between costs and revenues. Key financial indicators, such as NPV and benefit-cost ratios, were employed to assess the economic viability of hydroponic farming compared to traditional soil-based agriculture. The analysis also incorporated social and environmental benefits, ensuring a holistic view of the farm's overall impact.

The media campaign, launched in August 2024, was evaluated using AVE to quantify the value of earned media coverage. This metric allowed the project team to estimate the cost equivalent of the media exposure gained through editorial content. In addition, qualitative feedback from workshops and farmers' markets was gathered through interviews, providing insights into public perception and community engagement. The complete overview of obtained data offers section Results.

STEP 5: Conclusions and reflection of limitations

The main results are summed up in the conclusion part. The combination of quantitative and qualitative analysis offers a comprehensive understanding of the project's outcomes, demonstrating the rooftop farm's contribution to sustainability, economic efficiency, and social engagement. These findings form a solid foundation for future decisions regarding resource allocation and potential expansion of similar urban agriculture initiatives. As other similar projects, also this research has some limitation. Crucial limits are divided in a summary into two main parts: limits of the case study itself and limits of hydroponic rooftop farming in general.

2 Results

The outputs are presented based on the initial division into three main areas: environmental, social and economic.

2.1 Environmental area

Between July and August 2024, the rooftop farm endured extreme weather conditions, including hailstorms, strong winds, heatwaves surpassing 60°C, and cold, rainy periods, all without sustaining damage. Lettuce plants, in particular, demonstrated impressive resilience, though occasional flowering or leaf tip rot occurred due to the varying climate. Remarkably, no pests were found on the roof, while the presence of beneficial insects such as bees, wasps, ladybugs, and butterflies suggested improved biodiversity. During hot days, the area around the cultivation stands provided a more comfortable environment compared to the exposed sections of the rooftop.

Data from the thermometer pairs confirm these observations. The roof's surface temperature beneath the farm was up to 20°C cooler, primarily due to the shade and water evaporation, compared to unshaded areas. Fig. 2 offers the comparison made by a thermal camera.

The graphs in Figs. 3–4 show that the farm helped stabilize temperature variations across the roof.

Temperatures were measured at regular intervals. Temperatures measured at 9:00, 12:00, 15:00, 18:00 and 21:00 were selected for evaluation. In total, 310 values were collected for each place. Final outputs from two-months monitoring are summarized in Tab. 1.

The mean indoor temperature under the farm was 27.13°C, slightly lower than the 27.57°C measured in the room outside the farm. This indicated that the farm provided some thermal insulation or cooling benefits. The median temperatures were also comparable, with 26.47°C under the farm and 26.38°C outside, suggesting a similar range of temperature distributions. However, the standard deviation was 1.36°C under the farm, compared to 1.62°C outside, showing that the temperature under the farm was slightly more stable.

The average temperature on the roof under the farm was 24.43°C, significantly lower than the 27.17°C on the exposed roof, demonstrating the cooling effect of the hydroponic farm, likely due to shading and water evaporation. The median temperature was 23.77°C under the farm compared to 22.38°C

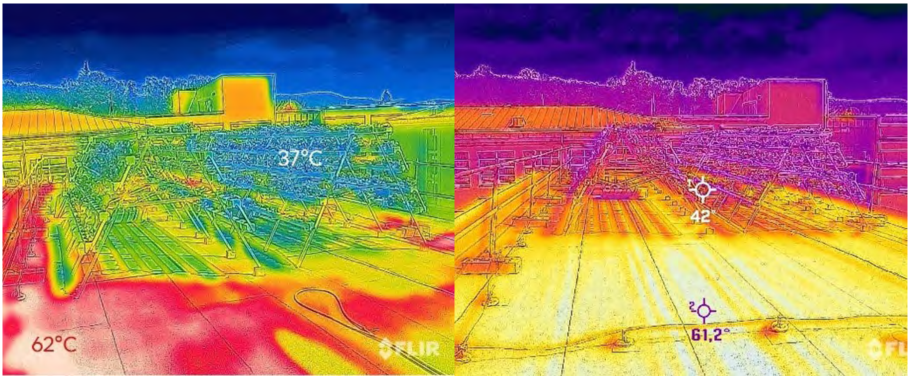

Fig. 2: Thermal camera image of the farm

Source: own

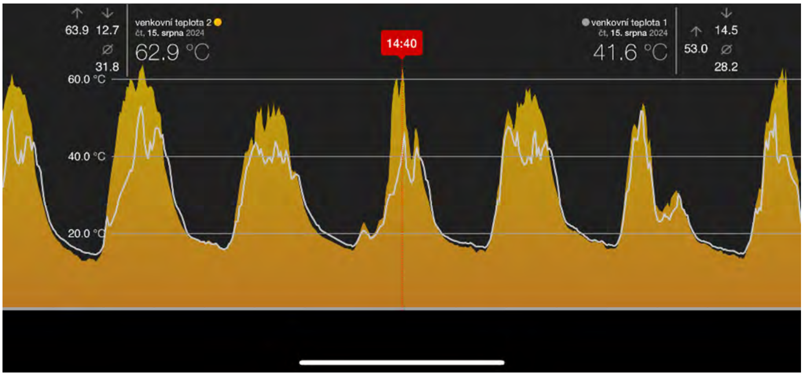

Fig. 3: **Thermal data – comparison of surface temperatures of an open roof and a roof under the farm**

Source: own

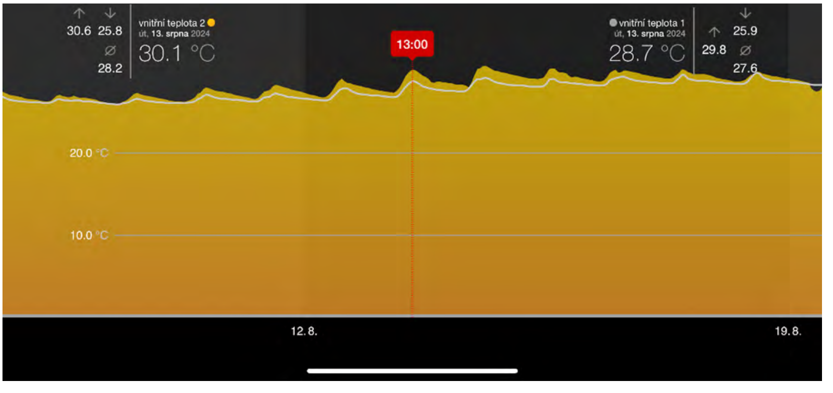

Fig. 4: **Thermal data – comparison of 2 identical offices interiors under the roof (lower under the farm)**

Source: own

Tab. 1: **Descriptive statistical values of temperature measurements (°C)**

Measurement points	Room under the farm (1)	Room not under the farm (2)	On the roof under the farm (3)	On the roof outside the farm (4)	At 1.2 m below the farm (5)	At 1.2 m outside the farm (6)
Mean	27.1268	27.5680	24.4284	27.1702	20.7884	22.1365
Median	26.4681	26.3806	23.7653	22.3764	25.1500	19.7979
Standard deviations	1.3580	1.6233	8.1975	12.3448	5.6609	5.7458

Source: own

outside, suggesting that the farm moderated temperature fluctuations. The standard deviation was 8.20°C under the farm and 12.34°C on the exposed roof, indicating that temperatures fluctuated more widely without the farm's cover.

At a height of 1.2 m, the mean temperature under the farm was 20.79°C, cooler than the 22.14°C measured outside. However, the median temperature was 25.15°C under the farm, higher than the 19.80°C recorded outside, suggesting that temperature fluctuations at this height were influenced by factors such as shading, airflow, or time of day. The standard deviations (5.66°C under the farm and 5.75°C outside) were comparable, indicating that temperature variability at this height remained similar in both environments.

2.2 Social aspects

In the first phase, workshops for university students were held in May 2024. Two seminars, each attended by 15 students from the 1st and 2nd year of the Faculty of Economics in Liberec, were conducted as part of the Business Processes course. The topic of the workshops was devoted to the presented case study, focusing on urban agriculture. Students were introduced to the project through a presentation, followed by a demo of the hydroponic rack with lettuce and a tour of the indoor seeding nursery. The primary objective was to engage students in creative thinking through a mind map, exploring the factors that could impact the project's success or failure.

The second group focused on developing practical manuals for seed planting in the seeding nursery. They participated in hands-on activities, gaining direct experience with the planting process. Through this combination of theory and practice, students evaluated the potential of the rooftop farming concept from both operational and entrepreneurial perspectives. The workshops encouraged creative problem-solving and practical learning, offering valuable insights into the challenges of sustainable urban projects.

After nearly two months of pilot farming, a targeted media campaign by the university's PR department garnered extensive coverage, highlighting significant public interest in the "Lettuce on the roof" project. The campaign emphasized the dual benefits of rooftop hydroponic farming: cooling urban environments and producing fresh food. Coverage included 32 media outputs with an estimated AVE of EUR 1.47 million. Notable outlets such as Czech Television, CNN Prima News, and Czech Radio featured the project across TV, radio, print, and online platforms. Articles and broadcasts detailed the innovation, environmental benefits, and potential for urban applications, inspiring discussion on utilizing industrial rooftops for sustainable farming.

As the third event aimed at evaluating the project's potential within the social pillar of sustainability, the "Lettuce on the roof" project participated in the farmers' market near OC Forum in Liberec on September 7, 2024. Over the course of just two hours, nearly 400 lettuce portions were distributed for free or in exchange for voluntary contributions. The event received immediate positive feedback from visitors, many of whom were already familiar with the project thanks to prior media coverage. This strong public response highlights the effectiveness of the promotional campaign and the growing interest in sustainable urban agriculture initiatives.

2.3 Financial area

The initial investment required for hydroponic systems can be greater than that for conventional agricultural practices. The profitability of a hydroponic farm hinges on various factors, including control over the growing environment, the efficiency of farming techniques, and the market demand for the produce. To calculate cost-effectiveness, the researchers divided costs into two categories – investment costs and operating costs. From the operating costs, it is necessary to separate variable costs directly related to production and directly corresponding to the quantity of products grown, and fixed costs related to the operation of the farm as such.

The CBA was based on the most common requirements of the private sector: farm area 100 m^2, 2,592 growing positions. The investment costs, as indicated in Tab. 2, consist of the rooftop hydroponic system as such (i.e., stands and irrigation equipment + automated fertilizer replenishment system), as well as the security of the working environment (work at height), i.e., the placement of safety railings around the entire farm. The farm also needs to be connected to the water and electricity supply. The investment costs also include the installation of the farm itself, i.e., the construction supervision, the work of the crane and the installation and connection of the stands themselves. We also assume that access to the roof is provided by sufficient and safe routes.

Tab. 2: Costs analysis for a rooftop farm (100 m², 2,592 positions)

Type of cost	Costs (EUR)
Fixed costs	
Racks and irrigation system	13,802
Railing	1,200
Windlass (electric hoist + arm)	240
Installation (transport + installation + construction supervision + crane	1,408
Administration (1 person, 4 h per week)	2,080
Total fixed costs	18,730
Variable costs	
Seedlings (0.12 EUR per piece)	1,866
Fertilizer (5 l per week)	624
Water (2.2 m² per week)	292
Electricity (67,2 kWh per week)	384
Distribution (0.12 EUR per piece)	1,866
Labor work (1 person, 8 h per week)	4,160
Autumn uninstallation + spring installation	256
Insurance premium	1,200
Total variable costs	10,649

Source: own

Tab. 3: CBA and NPV for three years

	Year 1 (EUR)	Year 2 (EUR)	Year 3 (EUR)
Costs			
Fixed	18,730	2,080	2,080
Variable	10,649	10,649	10,649
Total	29,379	12,729	12,729
Benefits			
Earnings from the sale of lettuce	18,000	18,000	18,000
Intangible benefits: PR, ESG	4,000	4,000	4,000
Total benefits	22,000	22,000	22,000
B-C	−7,380	9,270	9,270
B/C	0.749	1.728	1.728
Net present value	5,520		

Source: own

The setup costs for a hydroponic farm total EUR 18,730 in fixed expenses, including construction, equipment, installation, and administration. Variable costs for a six-month cycle, covering seedlings, fertilizer, water, electricity, labour, distribution, and insurance, amount to EUR 10,649. The projected lettuce price of 1.2 EUR per head reflects market trends for premium, eco-friendly produce, supported by urban farming's logistical advantages like lower transport costs and faster delivery. Intangible environmental, social, and governance (ESG) benefits, valued at EUR 4,000 annually, enhance the farm's public image, align with sustainability goals, and attract eco-conscious consumers and investors, boosting long-term viability.

The cost-benefit analysis for a rooftop hydroponic farm indicates that the project becomes more favourable over a three-year period. In the first year, total costs amount to EUR 29,379, due to the significant fixed costs of EUR 18,730 combined with variable costs of EUR 10,649. In the second and third years, fixed costs are reduced to EUR 2,080 annually, while variable costs remain consistent at EUR 10,649. The farm is expected to generate EUR 18,000 annually from lettuce sales, along with EUR 4,000 in intangible benefits, such as improved public relations (PR) and contributions to environmental, social, and governance (ESG) goals. This brings the total benefits to EUR 22,000 each year. Tab. 3 shows the financial plan dedicated for three years.

In terms of financial outcomes, the benefit-cost difference (B-C) is negative in the first year at −7,380 EUR, mainly due to the high initial setup costs. However, this shifts to a positive balance of EUR 9,270 in both the second and third years as costs decrease. The benefit-cost ratio (B/C) improves to 1.728 in the second and third years, indicating a return on investment. The NPV over the three-year period is EUR 5,520, demonstrating that the project offers a positive return in the medium term, making it financially sustainable and potentially attractive for long-term investment. We have considered a discount rate of 5% p.a. for a three-year investment horizon.

3 Discussion

The discussion of outputs is also structured into three main areas, following the case study strategy.

The rooftop hydroponic farm demonstrated significant benefits on the environment, particularly in terms of thermal regulation and biodiversity enhancement. The surface beneath the farm was up to 20°C cooler than the exposed areas, thanks to shading and water evaporation, reducing the impact of heat islands. Inside the building, the room under the farm was 0.5°C cooler than the control room, indicating potential energy savings by lowering the need for air conditioning. Additionally, the farm promoted biodiversity, with beneficial insects like bees, butterflies, and ladybugs observed on the roof, while no pests were detected. These findings highlight the potential of hydroponic systems to enhance urban resilience by mitigating temperature fluctuations and creating a more comfortable environment. The ability to control environmental conditions, including temperature, is one of the key benefits of hydroponic systems, making them particularly suitable for addressing the challenges posed by climate change and extreme weather events (Siddiq et al., 2020).

The hydroponic farm in this case study lowered outdoor temperatures and reduced fluctuations on the roof by minimizing heat exposure through shading and water evaporation. Indoors, the farm provided some cooling benefit, resulting in slightly more stable temperatures, which could contribute to energy savings for the building. At 1.2 m height, while the mean temperature under the farm was lower, the variability in median values suggested that microclimatic factors played a role, warranting further investigation to better understand daily temperature patterns. Our outputs confirm that the implementation of hydroponic systems on rooftops can lead to energy savings in buildings. As green structures can provide insulation and reduce heat absorption, thereby lowering cooling costs (Nadal et al., 2017). Additionally, rooftop hydroponics can contribute to environmental sustainability, which in turn has social implications. By utilizing otherwise unused urban spaces, these systems can help mitigate urban heat islands, improve air quality, and enhance biodiversity (Găgeanu et al., 2024).

One of the primary social impacts of rooftop hydroponics is its potential to improve food security in urban settings. As urban populations continue to grow, traditional agricultural practices often struggle to meet the increasing demand for fresh produce. Ngie and Sithole

(2023) highlighted initiatives in Johannesburg where hydroponic farms on rooftops are transforming urban food systems and improving livelihoods by providing access to fresh vegetables (Ngie & Sithole, 2023).

The implementation and promotion of the rooftop hydroponic farm in our case study yielded both educational and public engagement benefits, highlighting its potential for sustainable urban agriculture. Workshops for university students combined theory with practical activities, fostering creative problem-solving and offering hands-on experience with planting processes, while also encouraging entrepreneurial thinking. Media coverage across television, radio, print, and online platforms significantly amplified public interest, with 32 outputs reaching an AVE of EUR 1.47 million. The widespread media attention underscored the dual benefits of the project (cooling urban spaces and producing fresh food), while the distribution of lettuce at the farmers' market in Liberec further strengthened public engagement. The enthusiastic response to these activities suggests that rooftop farming initiatives can effectively resonate with both students and the public, contributing to the discourse on sustainable solutions for urban environments. The social dynamics of rooftop hydroponics can also promote social inclusion and cohesion. As highlighted by Sanyé-Mengual et al. (2015), rooftop farming initiatives can boost community empowerment and foster social interactions among diverse groups. These projects often bring together individuals from various backgrounds, creating opportunities for collaboration and shared learning experiences. This communal aspect can strengthen neighbourhood ties and enhance social capital, which is crucial for building resilient urban communities (Sanyé-Mengual et al., 2015). Gajbe (2020) further emphasizes that urban agriculture, including rooftop hydroponics, can safeguard livelihoods and enhance urban food security, thereby contributing to the overall well-being of communities (Gajbe, 2020).

The economic analysis indicates promising sustainability for rooftop hydroponics, highlighting potential for higher yields and lower transportation costs. However, initial investment and operational costs may hinder widespread adoption. The analysis of the rooftop hydroponic farm over three years suggests a promising financial model. While the hydroponic farm incurs high initial fixed costs (EUR 29,379 in the first year), these costs decrease substantially in subsequent years to EUR 12,729 annually. The annual revenue from lettuce sales, coupled with intangible benefits such as positive PR and ESG contributions, results in total benefits of 22,000 EUR per year. Although the project faces a negative balance in the first year due to start-up costs, it reaches profitability in years two and three with a positive B-C balance of EUR 9,270. The B/C ratio improves to 1.728 in the later years, and the three-year NPV of EUR 5,520 indicates a sustainable return on investment.

The financial analysis of rooftop hydroponic farms reveals a multifaceted landscape characterized by economic viability, environmental benefits, and social acceptance. Rooftop hydroponics presents a promising solution to urban food production challenges, particularly in areas with limited arable land. Other studies also indicate that rooftop hydroponic systems can produce leafy vegetables that are competitive in both cost and quality compared to traditional farm-grown produce, thereby enhancing food security in urban settings (Liu et al., 2016). Additionally, the hydroponic model allows for PR and ESG benefits, which can enhance the farm's reputation and appeal to eco-conscious investors (Yusoff et al., 2017). However, hydroponics also involves significantly higher initial setup costs and reliance on specialized infrastructure, such as irrigation systems and controlled environments, which may limit accessibility for some farmers (Fussy & Papenbrock, 2022). In contrast, conventional farming has lower initial setup costs and is less complex to establish, but it relies on seasonal limitations, higher land use, and greater environmental impact (Pomoni et al., 2023).

Accordingly, what recommendations for evaluating investment in hydroponic farms do the research studies suggest? To verify economic advantages, Sisodia et al. (2020) proposed to value the hydroponic farm strategy using approaches such as net present value or assessment of real options (Sisodia et al., 2020). It is essential to conduct an environmental assessment of hydroponic agriculture from the point of view of the production capacity and sustainability of such systems (Martin & Molin, 2019). The process also involves investigating the impact of hydroponic agriculture on water resources in order to ensure the required sustainability (Ajeng Setyoningrum et al., 2022; Wood et al., 2020). An expert group (Delphi method) to identify and mitigate risks can also be used for evaluation (Sakti & Thoriq, 2021). It is also critical to consider the economic feasibility and market potential of hydroponic farms in the long term (Banerjee & Adenaeuer, 2014).

As urban areas seek innovative solutions for sustainable food production, hydroponic rooftop farming offers a unique opportunity to align with circular economy (CE) principles. Much like how excess energy from household solar panels can be fed back into the grid to maximize efficiency, hydroponic systems can be designed to minimize waste and close resource loops in urban agriculture (Chowdhury & Asiabanpour, 2024). By integrating hydroponic farms with local food systems, organic waste from households, restaurants, and markets could be repurposed into bio-based nutrients, reducing reliance on synthetic fertilizers and contributing to a more sustainable urban ecosystem (Naresh et al., 2024). Surplus produce from hydroponic farms could be distributed to food banks or community-supported agriculture programs, ensuring that no resources go to waste while simultaneously addressing food security challenges (Aminullah et al., 2024).

For successful implementation, hydroponic systems must be strategically integrated into city planning and policy frameworks. Financial incentives, such as subsidies for green infrastructure or tax benefits for urban farmers, could lower the barrier to entry and encourage investment (Panotra et al., 2024). Advancements in technology, such as AI-driven climate control, automated nutrient recycling, and IoT-based monitoring, can also improve operational efficiency and economic feasibility (Rahman et al., 2024). Beyond financial and technological considerations, fostering public engagement through educational initiatives, urban farming cooperatives, and local food networks would enhance acceptance and long-term sustainability. By embedding hydroponic rooftop farms into the broader framework of circular and regenerative food systems, these initiatives can serve as a scalable model for both urban and peri-urban agricultural resilience (Appolloni et al., 2021).

Conclusions

The pilot hydroponic farm was established at the Technical University in Liberec. The configuration included four independent racks, resulting in a total farming area of 50 m^2 and a capacity of 800 slots. This rooftop farm provided an opportunity to investigate both the benefits and potential challenges associated with hydroponic urban agriculture. With this setup, the farm had the potential to produce up to 800 units of lettuce or herbs per month during the growing season from April to October, allowing for a substantial yield within a compact urban space. This case study aimed to evaluate not only the technical and financial viability of rooftop hydroponics but also its environmental and social impacts in an urban setting.

In conclusion, the rooftop hydroponic farm demonstrated significant advantages in urban sustainability, environmental impact, and social engagement. This model contributed to urban cooling by reducing temperatures on the roof surface and within the building itself, mitigating the urban heat island effect and potentially lowering energy costs for air conditioning. The farm also promoted urban biodiversity, attracting beneficial insects while maintaining a pest-free environment, thereby supporting urban ecological resilience. These findings underscore the potential of hydroponic systems not only to produce food but also to enhance urban environments, making them a valuable tool for addressing climate-related challenges in cities.

The financial analysis shows that while the hydroponic farm has high initial costs, it becomes increasingly profitable over a three-year period, reaching a positive net present value and a sustainable benefit-cost ratio. Additionally, the project's social and environmental benefits, such as public engagement, educational opportunities, and contributions to ESG goals, add intangible value that conventional agriculture may not provide. Compared to traditional farming, rooftop hydroponics offers unique advantages for urban areas with limited land and high environmental impact, positioning it as a forward-looking approach to sustainable agriculture. However, the success of such projects depends on addressing initial financial and infrastructure challenges, as well as engaging the public in sustainable practices.

The research and pilot hydroponic rooftop farm itself have several limitations. From a research perspective, this case study provides insights based only on a single case, limiting generalizability to other urban environments or building types. Additionally, only one hydroponic farming technology was tested, potentially excluding other viable approaches. The measurements were conducted over a two-month period, which restricts understanding of seasonal or long-term impacts. Furthermore, not all indicators, particularly social aspects, could be quantitatively assessed. CBA is not without its disadvantages as well. One of the main criticisms of CBA is the difficulty of accurately quantifying certain benefits and costs, especially intangible factors such as social justice or environmental impacts. This difficulty can result in either an underestimation or overestimation of the project's true value.

Despite encouraging findings, challenges also remain in terms of the pilot farm itself, including technical barriers and regulatory hurdles. Collaboration among local governments, urban planners, and agricultural experts is essential to overcome these obstacles. Ongoing research is also needed to integrate rooftop hydroponics with other urban sustainability initiatives. Logistical challenges related to distribution and sales were not included in the evaluation, as these aspects were managed by project. The farm also involved high initial costs, which may pose a barrier to scaling or replicating the model. There is also a risk that initial public enthusiasm could wane, impacting long-term demand and willingness to pay higher prices for produce grown on urban rooftop farms.

Regardless of its limitations, this study provided valuable insights into the feasibility and potential benefits of rooftop hydroponic farming in urban settings. As cities face population growth and climate change, investing in such practices is crucial for developing resilient urban food systems. The pilot project demonstrated that rooftop hydroponics can effectively contribute to urban cooling, enhance biodiversity, and produce fresh, locally sourced vegetables, all while utilizing otherwise unused space. The environmental advantages, such as temperature regulation and reduced urban heat island effect, alongside social benefits like increased public engagement and educational outreach, highlight the significant impact that urban agriculture can have on city sustainability. This pilot study has set a foundational understanding that can inform future efforts in urban food security, environmental sustainability, and community-building initiatives.

Future research could address several areas to further explore and refine this model. Long-term studies over multiple growing seasons would provide a more comprehensive understanding of the farm's environmental and economic impact. Additionally, testing a variety of hydroponic technologies and plant species would help determine the most efficient configurations for diverse urban environments. Further research could also quantify social impacts, such as community engagement and educational outcomes, through more rigorous social science methods. Finally, integrating logistical and distribution challenges, as well as assessing consumer willingness to pay for urban-grown produce, would create a more complete picture of the economic viability of rooftop hydroponic farms, enhancing their scalability and attractiveness as a sustainable solution for urban food systems.

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Appendix

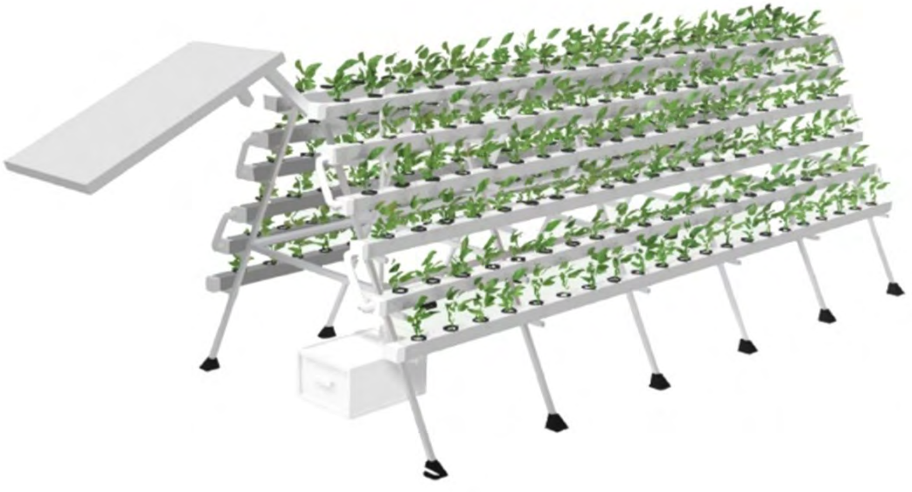

Fig. A1: **Prototype of the rack**

Source: own

Fig. A2: **Indoor seedling nursery**

Source: own

Examining remittances, emissions, and tourism as drivers of financial well-being and sustainability in post-Soviet nations

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Abstract: *This study aims to analyse the importance of inward remittances, greenhouse gas emissions, and international tourism in mitigating income disparity in post-Soviet countries, thus improving financial well-being and fostering sustainable practices. Panel data analysis was conducted using annual data from 15 post-Soviet nations, covering the period from 2000 to 2023. The key findings are that a positive shock in greenhouse gas emissions leads to increased income inequality, thereby reducing financial well-being and sustainable adoption. On the other hand, a positive shock in international tourism reduces income inequality and enhances financial well-being, promoting sustainable adoption among the post-Soviet population. Lastly, a positive shock in inward remittances promotes income inequality and reduces financial well-being, although this effect was not statistically significant. The study adds to the limited literature on financial well-being and sustainable adoption. The articles contextually focus on the post-Soviet nations, which are still in the early development phase and thus offer useful implications for developing countries. The study offers useful implications for policymakers, who can leverage the findings to reduce greenhouse gas emissions and promote international tourism. This can help reduce the prevalent income disparity, thereby promoting financial well-being, which is aligned with UNSDG 8.1. Enhanced financial well-being is linked to sustainable consumption, which is a key element of the circular economy.*

Keywords: *Inward remittance, greenhouse gas emissions, international tourism, panel data, post-Soviet nations.*

JEL Classification: *Q54, F24, Z32, O15.*

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Introduction

Economic, environmental, and social variables have become essential determinants of sustainable development in recent years, continually garnering attention to achieve balanced and sustainable growth. All major global economies consistently emphasise the promotion of inclusive and sustainable growth through policies that tackle income inequality, environmental sustainability, and economic resilience, extending beyond their own jurisdictions to a global context (Terra dos Santos et al., 2023). Nonetheless, to maintain it as a priority, initiatives must be undertaken by all nations across all global areas, irrespective of their developmental phases. Numerous countries, particularly post-Soviet states, remain very nascent following their independence and have had just a few decades of existence, encountering distinct problems after their dissolution that have influenced their sustainable development aspirations. Their function must be considered in the proper execution of sustainability initiatives. In contrast to wealthy nations, post-Soviet countries are comparatively nascent in sustainable growth and development (Dabrowski, 2022; IMF, 2020; Li & Zhou, 2016). These nations experienced significant political and economic transformations following the dissolution of the Soviet Union. The initial objective was to achieve economic equilibrium, execute market-oriented reforms for stability, and foster growth and development (Dabrowski, 2022). The importance of sustainability has been more evident in post-Soviet countries in recent years (Matiiuk et al., 2020). The primary priority areas among the many projects are the promotion of renewable energy, the reduction of inequality, the enhancement of energy efficiency, and the improvement of financial well-being (Sharif et al., 2024). These nations are now more engaged and regularly involved in international sustainability initiatives, working openly while striving to achieve social inclusion, effective environmental conservation, and enhanced economic development (Matiiuk et al., 2020).

It is particularly important for post-Soviet republics, as domestic economic stability concerns and external global dynamics influence their economic structure throughout the transition stages. Global trends are increasingly influencing post-Soviet countries in terms of remittances, environmental sustainability, and international tourism, all of which are pivotal to achieving the sustainable development goals (SDGs). They continue to confront the economic, social, and ecological issues that emerged with the fall of the Soviet Union (Batsaikhan & Dabrowski, 2017). To gain a deeper comprehension of the situation after over thirty years, particularly from economic, social, and environmental viewpoints, it is essential to examine the effects of remittances, greenhouse gas (GHG) emissions, and international tourism on sustainable economic savings and inequality for several reasons. Economic inequality has expanded in several post-Soviet governments, leading to an increasing disparity between urban and rural populations. This disparity undermines social cohesiveness, obstructs comprehensive economic growth, and diminishes financial well-being. The intricate, interrelated issues of economic development, inequality, and environmental sustainability confront post-Soviet states (Chancel et al., 2022; Gore, 2021). Remittances to post-Soviet republics started a notable increase quickly after the disintegration of the Soviet Union (Kakhkharov et al., 2017). Numerous countries have experienced a reduction in migrant remittances during and after the pandemic (Gurbanov et al., 2021). Policymakers must consider the ramifications of overseas remittance inflows, since they can significantly affect individuals' financial well-being and encourage sustainable practices (Tokhirov et al., 2021).

Remittances, a critical source of foreign finance for several post-Soviet countries, significantly contribute to financial well-being by increasing savings and diminishing income inequality (Abduvaliev & Bustillo, 2020). Remittances furnish households with supplementary income, which may be directed towards savings, education, and business investments, so promoting long-term financial stability (Barkat et al., 2024; Chand & Singh, 2024). The link between remittances and inequality is inversely correlated in most countries (Tokhirov et al., 2021). The degree to which remittances mitigate income inequality and foster sustainable adoption is contentious, as they may redistribute wealth or, conversely, intensify disparities by predominantly benefiting middle- and upper-income families (Borja & Hall, 2018; Koczan & Loyola, 2018). In this context, it is essential to analyse how remittances affect savings and inequality.

Greenhouse gas emissions have been identified as a substantial obstacle to sustainable development (Hsieh & Yeh, 2024; Yang et al., 2023). The post-Soviet states endeavour to reconcile economic growth with environmental sustainability (Atashov et al., 2023). Addressing greenhouse gas (GHG) emissions is essential and must be incorporated into economic, environmental, and social planning.

Elevated emissions levels can adversely affect long-term savings, as the expenses related to economic, social, and environmental degradation, health repercussions, and climate issues persistently escalate until they garner sufficient attention for mitigation measures (Osman et al., 2023). The repercussions of environmental degradation are frequently disproportionately experienced by various societal segments, particularly lower-income groups, hence exacerbating existing inequalities and confronting them with significant living issues (Gochfeld & Burger, 2011). Consequently, GHG emissions may adversely affect financial stability and impede sustainable growth and practices.

International tourism constitutes a significant aspect of economic growth for post-Soviet countries. The growth of the tourist industry contributes to economic advancement, enhances income and savings, and generates job possibilities across diverse groups and sectors of the business community, so promoting financial well-being (Khan et al., 2020; Li et al., 2018). Nonetheless, the allocation of these benefits requires scrutiny, as their impact on income disparity across various groups has yet to be ascertained. Tourism may foster inclusion by generating employment in rural and neglected regions. Yet, it may also result in economic inequality if the advantages are concentrated in specific locations or sectors (Bui Hoang, 2024; Liu et al., 2023).

This research aims to enhance the current literature on sustainable development by identifying the pivotal importance of independent factors and their alignment with global sustainable development goals, while also addressing their specific issues. The current study's findings elucidate the principal economic factors, including remittances, tourism, and greenhouse gas emissions, that influence savings and inequality, particularly in this comparably under-researched location. This research seeks to elucidate the individual and collective influences of remittances, greenhouse gas emissions, and international tourism on sustainable economic savings and inequality, specifically addressing how these factors have affected the savings and inequality of post-Soviet nations and how they can attain a more balanced and equitable trajectory in economic development.

The study encompasses a literature review, research methodology, data analysis, findings presentation, discussion, and conclusion, which includes limitations, a future research agenda, and policy implications.

1 Theoretical background

1.1 Sustainability and financial well-being

The literature focuses on the SDG goals of reducing inequality, poverty, and well-being. The study examines how inward remittances, reduction in carbon emissions, and increased tourism can reduce inequality and improve individuals' financial well-being. The connection between inward remittances, reduction in carbon emissions, and increased tourism can significantly enhance individuals' financial well-being through the increase in savings and reduction in income inequality. Inward remittances play a significant role in strengthening financial well-being by directly increasing household income, enabling individuals to meet basic needs, invest in education, reduce poverty, and consume sustainable products (Barkat et al., 2024; Borja & Hall, 2018; Masron & Subramaniam, 2018). This additional income often reduces financial vulnerability, particularly in developing economies, where remittances are a critical safety net. On a broader scale, countries with substantial remittance inflows usually experience improved financial systems, such as enhanced banking services, which further support individuals' financial stability and well-being (Ali Bare et al., 2022; Ofori et al., 2023).

According to the results of another study, a universal environmental approach that improves financial inclusion through robust and easily accessible financial systems is recommended, especially for low-income nations (Hussain et al., 2023), which hints that there is a kind of connection between financial well-being and environmental issues, financial well-being improves with financial inclusion (Fu, 2020). Environmental degradation caused by elevated emissions negatively affects health, leading to reduced productivity and increased medical expenses (Liu et al., 2021), which directly undermine an individual's financial stability, thereby hurting sustainable adoption (Cohen & Kirzinger, 2014). Additionally, tourism plays a vital role in enhancing financial well-being by contributing to local economies through job creation and entrepreneurial opportunities, particularly for individuals involved in tourism-related businesses (Nazir et al., 2021; UNCTAD, 2013). Job creation, increasing entrepreneurial activities, and the related positive impact of tourism lead to financial well-being (Gómez López & Barrón Arreola, 2019). Based on the above arguments, the following relationship has been tested to demonstrate how personal remittance, reduction of greenhouse gas emissions, and tourism contribute to improved savings and reduced income inequality, ultimately enhancing individuals' financial well-being.

1.2 Personal remittance and income inequality

For many households in developing economies, remittances have become a primary source of income (Song et al., 2021). The empirical literature on the impact of remittances on poverty reduction and income inequality presents mixed findings. Some scholars argue that migrant remittances effectively reduce income inequality and social discrimination through reduced poverty levels (Giannetti et al., 2009). Islam and Azad (2023) support the notion that remittances positively contribute to lowering the income gap by highlighting their direct effect of increasing the income of recipient households and promoting additional migration. Despite its positive impact on reducing income inequality, the magnitude is moderate (Ofori et al., 2022).

While Song et al. (2021) argue about the adverse effect of remittances on income disparities, explaining that most households receiving remittances are high-income. In another investigation into the impact of foreign remittances on poverty, inequality, and household welfare, Viet (2008) found that remittances significantly increased the income and consumption of the receiving households, leading to a reduction in poverty levels accompanied by a small magnitude increase in income inequality. Despite the evidence remaining inconsistent, the answer is likely to depend on three major factors: the average amount of remittance receipt, the proportion of households that receive transfers, and the share of welfare benefits and remittances allocated to individuals with fewer advantages (Giannetti et al., 2009). In addition, Anwar et al. (2024) findings show the contribution of remittances to the increase in income inequality in the South Asian region. In contrast, in areas such as Central Asia, East Asia and the Pacific, the Caribbean, Eastern Europe, Latin America, and Sub-Saharan Africa, it has the opposite effect, further supporting that the disparities among regions may have been caused by several factors such as initial economic status of migrant-sending households, the cost of migration and the extent of migrant community networks in the host country. Given the findings, further research is needed to explore the relationship between income inequality and remittances (Anwar et al., 2024). The rationale of the following hypothesis is to understand that remittances can serve as an additional source of household income, enabling increased savings and investment in sustainable economic activities.

H1: Higher remittance inflows are positively associated with increased savings and enhanced financial well-being in post-Soviet nations.

1.3 Greenhouse emissions and income inequality

All literature available is typically divided into two main perspectives. Some studies explored how income inequality affects greenhouse gas emissions, while others research how environmental degradation contributes to income inequality, particularly from CO_2 emissions. Many studies have found a statistically significant positive correlation between income inequality and CO_2 emissions (Baloch et al., 2020; Yang et al., 2022). Investigating the relationship between greenhouse gas emissions and income inequality reveals dependency on income levels (Grunewald et al., 2017). They suggest that in the case of middle and low-income countries, lower levels of CO_2 emissions are associated with higher income disparities. In contrast, countries with higher income disparities, particularly those in the high and upper-middle-income categories, exhibit greater emissions per capita. Parsons et al. (2024) also note that climate change will exacerbate the existing inequality, widening the gap between privileged and vulnerable communities, where the burden of health risks, loss of the means of financial support, and displacement will fall onto underprivileged children. Taconet et al. (2020) investigate the effect of reducing greenhouse gases on inequality by preventing climate damage and reducing the cost of mitigation. They highlight that damage estimates are the main dependents of reducing inequalities through reducing mitigation costs. The proposed hypothesis rationale is to understand how environmental degradation resulting from high GHG emissions may harm long-term economic sustainability, leading to reduced savings due to increased costs in public health and environmental mitigation.

H2: Higher GHG emissions levels are negatively associated with savings and reduced financial well-being in post-Soviet nations.

1.4 International tourism and income inequality

Tourism can impact income inequality differently. In a regime with lower economic development, it can help alleviate the burden of income inequality; however, in a regime with upper economic growth, it may worsen the disparity (Wang & Tziamalis, 2023). Zhang (2021) reports a positive relationship between income inequality and tourism, the effect of which is more pronounced in developing countries at an increasing magnitude. Camacho and Ramos-Herrera (2024) report that, in the short term, worldwide tourism contributes to an increase in income disparities, regardless of the country's degree of development. They argue that in developed countries, tourism tends to lead to a decrease in income disparity in the long run. Dossou et al. (2023) have examined the effect of tourism on income inequalities in developing Asian economies, including Central Asian countries such as Armenia, Azerbaijan, Georgia, Kazakhstan, the Kyrgyz Republic, and Tajikistan, which were previously part of the Soviet Union. Their investigation supports that tourism and income inequality have a statistically significant positive relationship.

Furthermore, Alam and Paramati's (2016) investigation of 49 developing countries across the world (including Armenia, Belarus, Kazakhstan, Kyrgyz Republic, Kyrgyzstan, Moldova, and Ukraine) confirms that in the long run, tourism leads to an increase in income inequality. The oligopolistic nature of selected countries can primarily drive such widening in societal disparity. Thus, small to medium enterprises will not be able to compete with them in the local market (Alam & Paramati, 2016). In addition, Ghosh and Mitra (2021) report that even in the early stages, the expansion of tourism negatively affects income inequality because of the markets' oligopolistic environments. Therefore, the rationale behind the proposed hypothesis is to understand that tourism generates foreign exchange, creates jobs, and stimulates economic activities, which can contribute to long-term savings and financial sustainability.

H3: Growth in international tourism positively impacts savings and enhances financial well-being in post-Soviet nations.

1.5 Research gap and the conceptual framework

The study intends to address two gaps: inward remittances, GHG emissions and international tourism, and their association with financial well-being and sustainability. The second gap focuses on the geographical context, the post-Soviet nations. Ofori et al. (2022), claim that remittances enhance income inequality, supported by Song et al. (2021) found the adverse effect of remittances on income disparities: remittances raise income inequality, while economic growth reduces, whereas Viet (2008) found that remittances significantly increase receiving households' income and consumption, leading to a reduction in poverty levels accompanied by a small magnitude increase in income inequality. Anwar et al. (2024) findings show the contribution of remittances to the rise in income inequality in the South Asian region. Since the oil industry dominates many nations and, in the recent past, has become independent, promoting renewable energy could be rather difficult, and their contribution to greenhouse gas is a critical factor to analyse. In the 1990s, Central Asia nations faced many of the same hardships during economic transition as Central and Eastern European and other formerly communist countries, such as sharp inflation, partial de-industrialization and the breakdown of welfare systems. Many still have not transitioned to a market economy (Batsaikhan & Dabrowski, 2017). However, most nations, specifically those like, e.g., Uzbekistan, Kyrgyzstan, have recently opened their borders and are promoting international tourism. Many have become part of Eastern Europe; in such a scenario, it becomes imperative to draw the attention of researchers toward inward remittance, greenhouse gas emissions, and international tourism, specifically in the context of post-Soviet nations.

Based on the above factors, inward remittances, greenhouse gas emissions, and international tourism might significantly increase savings, reduce inequality, and lead to more sustainable economic improvement. Therefore, the following conceptual framework has been framed and tested in the context of a post-Soviet nation.

2 Research methodology

The current examination uses a panel data framework to analyze the relationship between adjusted savings damages (ADS), remittances (REM), greenhouse gas emissions (CO_2), and international tourist receipts (ITR) as shown in Fig. 1. The study aims to investigate the influence of REM, CO_2, and ITR on ADS, a key indicator of financial well-being and income inequality in post-Soviet nations. The available empirical literature motivates the current research, documenting REM as a key influencer of well-being (Dey et al., 2024) and income inequality (Anwar et al., 2024), particularly in East Asia, Eastern Europe, and Latin America. The increasing levels of greenhouse gas emissions have also piqued the interest of policymakers and researchers, leading to numerous inquiries exploring the correlation between CO_2 and rising income inequality (Cevik & Jalles, 2023; Jorgenson et al., 2015). Similarly, researchers extensively explore international tourist receipts (ITR) as a key macroeconomic indicator influencing economic growth and income equality (Zhang, 2021). The authors were motivated to use adjusted savings deficit (ADS) as the outcome variable in the current research due to the need to explore a more comprehensive indicator of rising inequality and well-being beyond commonly used indicators such as GDP or GDP per capita. Researchers have consistently shown interest in the ADS or GINI% for a given country, as evidenced by available empirical examinations concerning income inequality and well-being (Ugur, 2021). The World Development Indicator (https://databank.worldbank.org/source/world-development-indicators) provides annual panel data for the 15 post-Soviet nations from 2000 to 2023. We use the data in logarithmic format. We can formulate the proposed model as follows:

$$ADS_{it} = \alpha_0 + \beta_1 REM_{it} + \beta_2 CO_{2it} + \\ + \beta_3 ITR_{it} + e_{it} \quad (1)$$

where: CO_{2it} – the total greenhouse gas emissions (kt of CO_2 equivalent) for country *i* at time *t*; ITR_{it} – the international tourist receipts (USD) for country *i* at time *t*; ADS_{it} – adjusted savings damage as a GINI% for country *i* at time *t*; REM_{it} – represents personal remittances received as a percentage of GDP; e_{it} – the error term

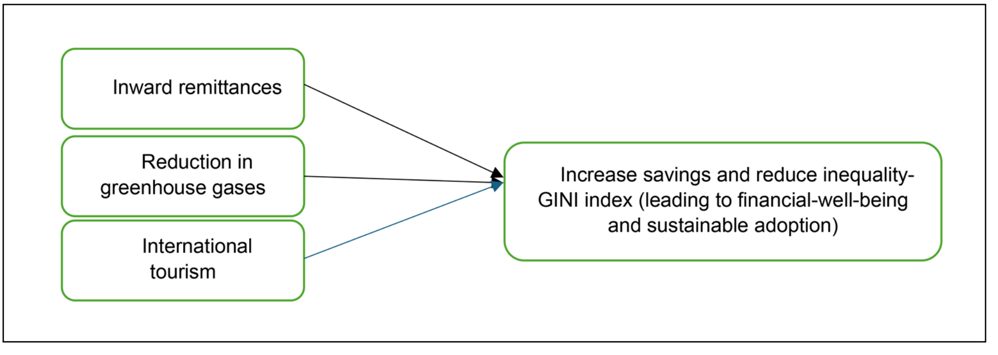

Fig. 1: Research model

Source: own

The logarithmic form of Equation (1) can be presented as:

$$\ln ADS_{it} = \alpha_0 + \beta_1 \ln REM_{it} + \\ + \beta_2 \ln CO_{2it} + \beta_3 \ln ITR_{it} + e_{it} \quad (2)$$

Tab. 1 presents the descriptive statistics of the variables included in the study. The ASD report shows a mean value of 1.21, yet a noticeable difference exists between the minimum and maximum values, suggesting a variation in income inequality and financial well-being among the post-Soviet countries.

In terms of remittances, the mean value is 1.28. Also, the variation between the 15 post-Soviet countries is visible from the minimum and maximum values reported by the analysis. Similarly, the mean value for CO_2 is 1.32, but there is a variation between the minimum and maximum values, suggesting that economic activities at the national level vary across all 15 post-Soviet countries. ITR has a mean value of 20.2, but the variation between minimum and maximum values is less than for other variables. This indicates that all the post-Soviet countries receive a decent number of tourists every year. Therefore, the descriptive analysis suggests that income inequality is prevalent and varies across all post-Soviet countries. Additionally, economic growth varies among these countries, as evidenced by the levels of CO_2 emissions. However, each of these countries welcomes a significant influx of tourists annually. Therefore, the descriptive analysis suggests a prevailing disparity that warrants further statistical examination.

Tab. 1: Descriptive statistics

Variable	Mean	Median	SD	Min	Max
ln*ASD*	1.21	1.25	0.83	−0.49	3.31
ln*REM*	1.28	1.34	1.58	−2.64	3.93
lnCO_2	1.32	1.32	0.93	−1.14	2.73
ln*ITR*	20.20	20.20	1.59	15.40	23.70

Source: own (using R-studio)

The current study applies several estimation techniques to ensure the robustness of the findings.

Cross-section dependence test. Baltagi et al. (2012) identify cross-sectional dependency in extensive macropanels with substantial time series as a significant issue. The spatial externalities among the units may result in erroneous interpretations and results. Consequently, the present investigation employs the Pesaran cross-section dependency (CD) test (Pesaran et al., 2004) and the Breusch-Pagan Lagrange multiplier tests (Breusch & Pagan, 1980). These tests examine the relationship among the panel's residuals. This can be expressed as:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{j=i+1}^{N} \hat{\rho}_{ij}\right) \sim (N\ (0,1) i\ j \quad (3)$$

$$N = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{j=i+1}^{N} \hat{\rho}_{ij}\right) \frac{(T-K)\widehat{\rho_{ij}^2} - E(T-K)\widehat{\rho_{ij}^2}}{Var\ (T-K)\widehat{\rho_{ij}^2}} \quad (4)$$

Panel unit root test. The robustness of the model is guaranteed by the stationarity of the variables, which ensures a reliable estimate, avoids incorrect statistical inferences, and suggests a stable trend (Dickey & Fuller, 1981; Levin et al., 2002). A second-generation test, the cross-sectionally augmented Dickey-Fuller unit root test (Pesaran, 2007), is employed in the current study. The cross-sectionally augmented Dickey-Fuller unit root test (CADF) can be represented as follows:

$$\Delta\gamma_{it} = \alpha_i + \beta_i \gamma_{it-1} + \Upsilon_i \bar{y}_{it-1} + + \theta_i \Delta\bar{\gamma}_t + \varepsilon_{it} \quad (5)$$

Estimation technique. A panel model can be estimated by applying either the fixed or random effect estimators. To choose between the two estimation techniques, a statistical technique, the Hausman test is applied. This test examines the relationship between individual effects and regressors, a crucial basis for applying random effect estimators (Hausman, 1978). We utilize the Hausman test with the following equation:

$$H = (\hat{\beta}_{FE} - \hat{\beta}_{RE})' [Var(\hat{\beta}_{FE}) - - Var(\hat{\beta}_{RE})]^{-1} (\hat{\beta}_{FE} - \hat{\beta}_{RE}) \quad (6)$$

Panel corrected standard error. The panel-corrected standard error approach guarantees the model's robustness, which addresses the issue related to cross-sectional dependence, heteroscedasticity, and autocorrelation. This research employs cluster standard errors that are effective in autocorrelation and heteroscedasticity in large panels, as Arellano (1987) and Arellano and Bond (1991) argued.

3 Results and discussion

With growing globalisation and increasing focus on regional cooperation, there is a growing interdependence among the countries. This may impact the statistical inferences drawn if it remains unaccounted. Therefore, the current study applies the Pesaran CSD test to check for cross-sectional dependence among the countries under examination. The results of the CSD test are reported in Tab. 2.

The given *p*-value is above the 5% significance threshold, leading us to fail to reject the null hypothesis of no cross-sectional dependency in the panel. Consequently, we can ascertain that there is no link among the panel's residuals. As a result, a positive or negative shock in one post-Soviet nation does not inherently impact another nation. This makes a lot of sense when examined with the results of descriptive analysis that pointed to existing variations among the post-Soviet nations.

Once it is confirmed that there is no statistically significant cross-sectional dependence among the countries under examination, the next step is to check if the variables are stationary. The current study applies the cross-sectional Dickey-Fuller augmented unit root test, and the findings are given in Tab. 3.

Tab. 2: CSD test result

Test	Statistics (*z*)	*p*-value	Average absolute correlation	Alternative hypothesis
Pesaran CD test	1.114	0.265	0.126	Cross-sectional dependence

Source: own (using R-studio)

Tab. 3: CADF unit root test result

Variable	Level	First difference	*p*-value
ln*ASD*	−3.639	−6.981	0.005*** I (0)
			0.000*** I (1)
ln*REM*	−3.279	−17.286	0.015*** I (0)
			0.000*** I (1)
lnCO_2	−3.475	−15.922	0.008*** I (0)
			0.000*** I (1)
ln*ITR*	−4.554	−12.905	0.0001*** I (0)
			0.000*** I (1)

Note: *, ** and *** indicate the statistical significance level at 10, 5 and 1%, respectively at I (0) – level, and I (1) – first difference.

Source: own (using R-studio)

The analysis revealed that all the variables under examination are stationary at both levels and first-difference, which further confirms the robustness of the statistical inferences drawn.

The next step after ensuring the stationarity of the variables and concluding that there is no unit root is to test for the estimation method. The current study applies the Hausman test to choose between the appropriateness of fixed

Tab. 4: Hausman test result

Chi-square	*p*-value
63.174	0.000***

Source: own (using R-studio)

Tab. 5: Panel regression model

Variable	Coefficient	Standard error	*p*-value	Hypotheses results
Constant	4.813	0.616	0.000***	
lnCO_2	0.362	0.087	0.000***	Supported
ln*ITR*	−0.200	0.035	0.000***	Supported
ln*REM*	0.008	0.030	0.792	Not supported
Observations	360			
Number of cross-sections	15			
R-squared	0.403			

Note: *, ** and *** indicate the statistical significance level at 10, 5 and 1%, respectively.

Source: own (using R-studio)

and random effect estimators. The results of the test are given in Tab. 4.

The results of the Hausman test revealed that the *p*-value is less than 5%, leading to the rejection of the null hypothesis that the random effect model is consistent. Thus, the current study applies fixed-effect estimators to examine the relationship between dependent and independent variables. Tab. 5 presents the statistical inferences drawn applying fixed effect estimators.

The results showed that a 1% increase in greenhouse gas emissions (CO_2) causes a 0.36% increase in adjusted savings damages (ADS), which in turn increases income inequality and decreases overall financial well-being. Further, the analysis revealed that a 1% rise in international tourist receipts (ITR) reduces the ADS by 0.20%. Thus, an increase in international tourism reduces income inequality and thereby enhances the financial well-being of the people in the post-Soviet nations. Lastly, the other key variable of the model, remittances (REM), depicted a statistically insignificant impact on income inequality with every 1% increase leading to only a 0.008% increase in ADS.

4 Discussion

This study examines the association between inward personal remittance, greenhouse gas emissions, and international tourism with individual savings and inequality. It investigated the significance of the three independent variables with individual savings and inequality using the GINI index. The study used the panel data analysis and concluded its findings, which align with similar results to those of the existing studies and add more to the existing literature on sustainability and financial well-being. The first hypothesis tested *H1*: higher remittance inflows are positively associated with sustainable economic savings in post-Soviet nations. The study found that the impact of remittances on income inequality is statistically negligible. The coefficient of 0.008 indicates that a 1% increase in personal remittances results in a 0.008% increase in adjusted savings damage, but this effect is not statistically significant (*p*-value = 0.7918). Thus, the tested hypothesis is not supported. This suggests that remittances do not significantly impact the improvement of savings or income inequality reduction. Therefore, do not increase savings and reduce income inequality among the people of post-Soviet nations. However, the existing literature has a mixed opinion and findings on it such as Anwar et al. (2024), León and Koechlin (2006), Song et al. (2021), and Tokhirov et al. (2021) found negative, marginal, or insignificant and many found it significant and positive, e.g., Borja and Hall (2018), Inoue (2024), and Islam and Azad (2024). Overall, the finding suggests no significant impact of inward remittances on decreasing income inequality and improving savings. The study found that the insignificance of inward remittances may reflect the structural realities of post-Soviet economies. Factors such as uneven income, wealth, and education distribution due to remittances may benefit selected households, failing to address broader inequality. Also, dependency risks such as high reliance on remittances can deter domestic economic initiatives and reinforce income disparities. Therefore, it suggests governments should focus on creating robust domestic employment opportunities to reduce dependency on remittance flows. The insignificant impact of REM may be due to many possible reasons, which need attention for further exploration such as a large portion of remittances is used for immediate consumption needs, such as housing, food, and healthcare, rather than being saved or invested, people migrate to move to overseas might be due to not having enough opportunity to earn so to fulfill necessities, and many of the soviet nations are still struggling with employment, it could be more severe in the bigger size families. Remittances can increase domestic income in many post-Soviet nations, rather than promoting local economic growth or self-sufficiency. This reliance on outside revenue may constrain the wider economic consequences that could lower inequality or increase national savings. Remittances are typically sent to needy families, which can help minimise immediate poverty for recipients, but do not address broader structural issues of wealth inequality in the country (Acosta et al., 2007; World Bank, 2005).

The lack of access to savings mechanisms or investment opportunities could also hinder remittances' ability to boost national savings or reduce income inequality in the long term (Olivié & Santillán, 2022). Another critical point is galloping inflation in some cases. The influx of remittances can lead to inflation, particularly in local housing markets, which may further exacerbate income inequality. As remittance-driven demand increases for goods and services, those without access to remittances may find it more difficult to afford necessities. In short, whereas remittances give many families much-needed temporary respite, they do not solve the systemic problems of income disparity or saving habits in post-Soviet countries.

The second hypothesis examines the higher GHG emissions levels negatively associated with sustainable economic savings in post-Soviet nations. The findings of our study support the second hypothesis, which posits that higher levels of greenhouse gas (GHG) emissions are negatively associated with sustainable economic savings and income inequality in post-Soviet nations. The coefficient of 0.3620 shows that a 1% increase in CO_2 emissions is associated with a 0.3620% increase in adjusted savings damage. This result is highly significant (*p*-value < 0.0001), indicating a strong and positive relationship between environmental degradation (in terms of CO_2 emissions) and sustainability concerns. As CO_2 emissions increase, adjusted savings, which account for environmental damage, are significantly reduced, increasing savings and reducing income inequality in the post-Soviet nations. Therefore, the tested hypothesis found support for GHG, which does not have a positive effect. The present findings support the existing studies (Ashenafi, 2022; Escamilla-García et al., 2024; Kelly et al., 2021; Yang et al., 2022). CO_2 emissions have a strong positive impact on adjusted savings damage. This result suggests that higher environmental degradation (in the form of CO_2 emissions) significantly worsens a country's ability to save sustainably, considering ecological damages and inequality. Therefore, there is a need to reduce greenhouse gas emissions for higher savings and lower income inequality in post-Soviet nations, as in other parts of the world. GHG emissions significantly influence economic outcomes, largely through their indirect effects on savings, inequality, and financial well-being. The implications for post-Soviet nations include environmental degradation costs: High emissions contribute to environmental damage, reducing adjusted savings by necessitating higher expenditures on mitigation and healthcare. This disproportionately affects low-income households, widening inequality. Lowering emissions through investments in green technologies and renewable energy can create new industries and job opportunities, fostering economic inclusivity. However, addressing emissions is critical for aligning with global climate goals as well.

The third hypothesis (*H3*) investigated that the growth in international tourism positively impacts sustainable economic savings by promoting economic diversification in post-Soviet nations. The study found that an increase in international tourism reduces income inequality and thereby enhances the financial well-being of the people in post-Soviet countries. The coefficient of −0.20 shows that a 1% increase in international tourism is associated with a 0.20% decrease in adjusted savings damage. This negative relationship is statistically significant (*p*-value < 0.0001), suggesting that higher tourism activity improves the sustainability of savings, possibly by contributing to economic growth and development, which offsets environmental and social costs. Therefore, the tested hypothesis was supported and revealed a positive association between tourism and income inequality reduction. This finding of the present examination has similarities with various existing studies (Bui Hoang, 2024; Subramaniam et al., 2022; Wang & Tziamalis, 2023).

International tourism significantly impacts economic inequality and sustainability in post-Soviet nations. The revenue generated through tourism can promote regional development, and tourism stimulates local economies, particularly in rural and less-developed regions, through increased employment and infrastructure development. It might help diversify economies; many post-Soviet nations, such as Georgia and Uzbekistan, rely heavily on commodity exports. Tourism offers an alternative revenue stream, reducing economic vulnerability. However, for tourism to effectively mitigate income inequality, policy measures must ensure its benefits are equitably distributed. This can be achieved through investments in skill development, local entrepreneurship, and community-based tourism initiatives.

Conclusions

The present study investigated the significance of inward remittance, greenhouse gas emissions, and international tourism in increasing savings and reducing income inequality. The present research framed three hypotheses: the significance of remittance in increasing savings and reducing income equality was insignificant, and the other two hypotheses found significant support in the analysis. The study highlighted the important roles of inward remittances, international tourism, and GHG emissions in influencing economic savings, inequality, and, thereby, financial well-being in post-Soviet nations. Policymakers should leverage the opportunities provided by tourism and green economy initiatives to foster sustainable and inclusive growth. These findings emphasise the need for holistic, evidence-based strategies to address these transitioning economies' unique challenges and opportunities. The existing literature has mixed opinions on the following; therefore, some studies support the results and keep the space open for further research and investigation in different contextual and regional frames. This study achieves its objective and adds to the sustainability and economic development literature. Though the study attempted to showcase the results with robust analysis, it is not free from limitations, such as the analysis may be constrained by the availability and reliability of data from post-Soviet nations. Inconsistent or incomplete data on inward remittances, GHG emissions, and tourism can affect the accuracy and robustness of the findings. For example, underreported emissions or informal tourism activities might not be adequately captured. Post-Soviet nations exhibit significant diversity in economic structures, resource endowments, and policy frameworks. Aggregating data from these nations may overlook country-specific nuances, limiting the generalizability of results to individual contexts. While the study identifies significant associations, it may not establish clear causal relationships between variables like GHG emissions and savings or income inequality. Reverse causation or omitted variable bias could influence the results. The study focuses on inward remittances, GHG emissions, and international tourism, potentially overlooking other critical factors influencing savings and inequality, such as education, governance quality, or social policies. The analysis might not differentiate between short-term and long-term impacts. For instance, international tourism may have immediate benefits, but its long-term effects on inequality and sustainability depend on consistent policy implementation.

The limitations give scope and direction for more rigorous research. Further research could explore the sectoral distribution of tourism benefits, the socio-economic impacts of green policies, and the role of institutional quality in moderating these relationships. Moreover, a micro-level analysis could provide a nuanced understanding of household-level savings and inequality dynamics, as well as disaggregate data analysis to explore regional and country-specific variations. Conduct longitudinal studies to examine dynamic relationships over time. Incorporate additional variables, such as institutional quality and labour market conditions, to provide a more comprehensive analysis. Employ mixed methods, including qualitative approaches, to understand the lived experiences of communities impacted by tourism and environmental policies. More so, future studies could incorporate micro-level household data to capture more granular insights into financial well-being and inequality dynamics. Additionally, examining the role of institutional quality, governance, and labour market conditions as moderating factors could further enrich the analysis. The study's findings give direction for further exploration, specifically focusing on inward remittances in developing economies in transition.

Policy implications and recommendations. The findings of this study provide valuable insights into the factors influencing income inequality and economic sustainability in post-Soviet nations. Specifically, while inward remittances were found to be insignificant, international tourism and greenhouse gas (GHG) emissions emerged as significant contributors. These results have theoretical and practical implications for understanding the dynamics of the GINI index, adjusted savings damage, savings growth, and income inequality in these transitioning economies. Policies should focus on sustainable tourism by investing in eco-tourism, infrastructure, and equitable profit-sharing mechanisms. Emphasis on reducing emissions through renewable energy projects, green technologies, and carbon trading markets can yield economic and environmental benefits. Reducing over-reliance on remittances and traditional industries by promoting entrepreneurship and innovation can help create a balanced economy. Ensuring transparency, reducing corruption, and improving governance will enhance the effectiveness of tourism and environmental policies. Reducing GHG emissions and promoting tourism are key for post-Soviet nations as they have a direct impact on prevalent financial disparities and overall financial well-being. Enhanced financial well-being not only facilitates the achievement of UNSDG 8.1 but also helps in promoting sustainable adoption.

Better access to financial services, ensuring that remittances are directed toward savings or business endeavours, tax breaks on inward remittances, and alluring government investment and savings programs are among the suggestions made in light of the findings. These measures could promote more sustainable growth. They also advise improving people's financial planning and money management abilities. The present study findings support international tourism and GHG emissions for reducing inequality; therefore, among the recommendations, the first is that governments and tourism boards should help local communities by providing training programs, financial incentives, and marketing assistance to develop community-led tourism initiatives that minimise environmental impact and maximise local benefits. Policymakers should allocate funds to build eco-friendly accommodations, renewable energy-powered transport options, and waste management systems in popular tourist destinations to reduce the carbon footprint of tourism. Encourage airlines, hotels, and tour operators to adopt carbon offset initiatives, such as tree-planting projects and conservation programs, to mitigate GHG emissions from international tourism. Encourage the use of electric and hybrid transportation options for tourists by offering subsidies for electric tour buses, boats, and rental vehicles while improving public transport connectivity to tourist sites. Introduce policies that ensure fair distribution of tourism revenues, particularly in rural and underserved areas, through revenue-sharing agreements, microfinance initiatives for local entrepreneurs, and incentives for businesses that prioritise local employment. Implement green tourism taxes that charge visitors a small fee for environmental conservation while offering tax breaks to companies that adopt sustainable practices. Offer training programs to equip workers in the tourism sector with green skills, improving their employability in an environmentally conscious industry. This could empower marginalised groups and enhance their economic mobility. Implement carbon taxes or cap-and-trade systems targeting the tourism sector to encourage sustainable practices and reduce emissions. The revenue generated could be reinvested into social programs that address inequality and promote financial well-being and sustainable consumption.

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Research on citizens' behavior in relation to the use of re-use centers and re-use points

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Abstract: *The article explores the attitudes and behavior of Czech consumers aged 18+ towards the adoption of secondhand goods within the framework of the circular economy. While the European Union's Circular economy action plan emphasizes sustainable production and consumption, consumer resistance to re-used goods remains a barrier. The exploratory study aims to identify the perception/attitude/relationship of the Czech population towards the purchase of used items. Detailed knowledge of the customer is an elementary base for the market of re-used products to grow. The research objective is divided into three partial objectives: identifying the main customer segments in secondhand markets, evaluating the reasons for and against purchasing re-used items, and assessing the perceived suitability of various product categories for secondhand trading. Conducted in June 2024, the research involved an online survey of 1,300 respondents across the Czech Republic. Ajzen's theory of planned behavior (TPB) was employed to structure the questionnaire, while data analysis utilized Pearson's χ^2-test of independence to examine relationships between categorical variables. In some instances, complementary methods were employed. The findings indicate that younger consumers and those actively employed are more inclined to purchase re-used goods, while older individuals and pensioners show higher reluctance. Cars, art, and books were viewed as highly suitable for secondhand markets, whereas casual footwear was ranked lower. The results also suggest that Czech consumers are generally open to the secondhand market and each product category has corresponding group of customers who find the product suitable to sell. This research contributes to the literature on the circular economy by highlighting how targeted business and marketing strategies can address consumer resistance, ultimately fostering sustainable consumption.*

Keywords: *Behavioral analyses, consumption patterns, environmental economics, marketing, product segments.*

JEL Classification: *Q53, Q56, O12, M31.*

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Introduction

The transition towards a sustainable future demands comprehensive strategies that address the complex nature of production and consumption. The European Union's new Circular Economy Action Plan represents a holistic framework aimed at fostering a cleaner and more competitive Europe (European Commission, 2020). This plan encompasses a series of interconnected initiatives designed to establish sustainable products, services, and business models as the norm. One aspect of this plan is the transformation of consumer habits to ensure that waste generation is minimized. By engaging economic actors, consumers, citizens, and civil society organizations, the plan seeks to create a collaborative effort towards sustainability and competitiveness, not only in Europe but globally.

However, the strategic policy of the European Union (EU) does not fully address the resistance of consumers towards circular economy (CE) objectives, particularly regarding re-used goods. Therefore, one of the challenges to fulfill this plan is to understand the relationship between purchase of new and re-used products and the conditions under which the consumer is willing to buy secondhand products and use them.

Despite the benefits, several barriers impede consumer acceptance of reused products. These include concerns about product quality and performance, risk aversion, lack of ownership, low value offer and access, hygiene, and social stigma associated with using secondhand goods (Camacho-Otero et al., 2017). But the overall change to circular economy also includes the consumer integration into process of the change. Studies of positive attitudes, driven by environmental consciousness and cost savings, show that consumers who perceive reused products as environmentally friendly and economically beneficial are more likely to engage in re-use behaviors (Camacho-Otero et al., 2017; Edbring et al., 2016). Based on theoretical background this research is divided into three objectives:

RO1: Identify the key customers of secondhand stores and find correlations between customer categories and product categories.

RO2: Evaluate the significance of reasons for and against purchasing used items.

RO3: Identify the suitability of different types of products for trading in the secondhand market and the shortcomings of used items as perceived by potential customers.

This research aims to explore whether, within the context of the CE, consumers in the Czech Republic are willing to adopt secondhand products, and if not, to identify the barriers that hinder their acceptance. Furthermore, this paper seeks to investigate potential strategies to enhance consumer openness and willingness to embrace re-used products, thereby supporting the broader goals of the CE.

1 Theoretical background

1.1 Re-use within circular economy

The concept of the CE encompasses various models, starting from the 3R approach (reduce, re-use, recycle) to the more expanded 4R model (reduce, re-use, recycle, recovery), and extending to the waste management pyramid. The waste management hierarchy is used also within EU bodies to prevent the waste in following order: prevention, preparing to use, recycling, other recovery and disposal (Directive 2008/98/EC, 2018). It must be noted that CE models include re-use as a strategy to extend the product lifecycle.

Despite these numerous frameworks, there is no unified definition, leading to what Kirchherr et al. (2017) describe as "circular economy babble." Moreover, many of these frameworks fail to adequately incorporate the role of the consumer and societal systems in the transition from a linear to a circular economy (Haberl et al., 2019).

Dolderer et al. (2021) argue that neoclassical economic theory struggles to address the ecological and social challenges of the 21st century, which might contribute to the lack of consensus on CE concepts. Some researchers assert that it is impossible to sustain economic growth while achieving environmental objectives, as economic growth is often linked to polluting activities (Fischer-Kowalski & Haberl, 2015; Haller, 2020). This suggests that maintaining current economic growth is a complex issue, and part of the solution for integrating a circular economy involves focusing on the consumer and changing their purchasing behavior.

The household resource consumption may be classified into six domains in which consumer goods (ICT/AV equipment, furniture, clothes, sports/entertainment, paper/stationery and other) create approximately 20% of all lifestyles total carbon footprints per capita per year in average in Finland (Lettenmeier et al., 2019). According to the Prosperity and Financial Health Index the level of the living environment in the Czech Republic (Czechia) has slightly improved year-on-year, the Czechia is currently ranked 22nd, while Finland is ranked 9th (Europe in Dates, 2023). Results show that Czechia still has work ahead to achieve an improvement.

EU bodies identified the key product value chains qualified for coordinated actions to address sustainability challenges and enhance markets for circular products. These value chains are electronics and ICT, batteries and vehicles, packaging, plastics, textiles, construction and buildings, food, water, and nutrients (EC, 2020). Based on the cross-correlation of the household consumption domains and the identified value chains the fields identified for re-use include consumer goods such as ICT/AV equipment, furniture, clothes, and sports/entertainment items, as well as packaging, textiles, and food-related products. These products constitute the basis for the development of the re-used market.

1.2 The role of customer in the circular economy

The socio-technical view emphasizes that change in consumption behavior arises from the interaction between daily actions and broader societal structures, rather than from individual decisions alone. Thus, understanding and altering consumption patterns requires focusing on the social and material contexts that shape consumer behavior, rather than merely attributing overconsumption to individual choices (Mylan et al., 2016). Therefore, the transition to a CE requires cooperation and coordination across multiple spheres of influence, including government policies, business practices (particularly within supply chains), societal norms, and ultimately consumer acceptance and action (Hazen et al., 2017).

The push-pull-mooring theory of migration (PPM) posits that individuals are compelled to change behavior due to negative macro-level push factors, such as increased housing costs, scarcity of essential resources such as electricity or fuel, oppressive conditions, epidemics, and natural disasters. Concurrently, they are attracted by positive macro-level pull factors, which include better living conditions, improved employment prospects, superior product performance, groundbreaking technologies, or governmental incentives and tax breaks, such as those for alternative-powered vehicles. However, the micro-level ground factors, encompassing personal, social, and cultural values, play an intensifying role in consumer's intention to migrate towards remanufactured products (Hazen et al., 2017).

While this perspective highlights the role of market offerings and infrastructures, it alone does not address the underlying concern that economic growth is linked to increased pollution. This view belongs to a group of opinions where consumers are often portrayed as passive (Wurster & Schulze, 2020) and their passive acceptance is considered crucial for the continuity of the CE (Hobson, 2021; Mylan et al., 2016). However, the CE encompasses more than just the delivery of new services or products; it involves extending product lifecycles through re-use, as emphasized in the new publication related to the implementation and further development of European Union (EU) waste legislation (EC, 2024). The perspective of simple "consumer acceptance" overlooks the significant socio-economic transformations that the CE aims to bring to society (Hobson, 2021). Instead, consumers should be actively involved, shaping market offerings and contributing to broader sustainability goals. This active involvement is essential for realizing the full potential of the CE in the fields of long use of products as well as the re-use or recycling.

In the concept of a CE, there is a crucial role for all stakeholders, including manufacturers, authorities, local communities, and consumers. During the transformative phase of both economics and society to CE, it is essential for consumers to actively participate in extending product lifecycles through re-use or prolonged use, thereby reducing overconsumption, and resisting the continuous demand for supposedly improved products that sometimes offer insignificant innovations. But to achieve so, one must firstly understand the positive attitudes but also the barriers which prevent consumer from accepting once re-used product and focus the offer on the acceptable products and build the environmental awareness slowly based on the positive experience.

1.3 The barriers in acceptance of re-used products

Social norms and cultural factors significantly impact consumer behavior towards re-used products (Ertz et al., 2021). In societies where sustainability is a valued norm, consumers are more likely to adopt re-used items (Camacho-Otero et al., 2017; Edbring et al., 2016), but in cultures with strong preferences for new products, promoting re-use requires substantial efforts to change deep-rooted consumption patterns (Bianchi & Birtwistle, 2012). Despite obvious efforts from the EU bodies, researchers point out the lack of sufficient awareness of the environmental advantages associated with re-used, repaired, and refurbished products (Abbey et al., 2017; Camilleri et al., 2023).

Studies have shown that, despite being aware of environmental problems and intending to address them, consumers often do not choose sustainable options and are unwilling to pay higher prices for sustainable products or logistics (Schleiden & Neiberger, 2020) and are driven by hedonistic motives (Tascioglu et al., 2019) or price (Bianchi & Gonzalez, 2021).

Secondhand products are an option, particularly when price and environmental value align. However, not all consumers have such strongly developed environmental values and have different barriers to adopt secondhand products. These include concerns about product quality and performance, risk aversion, lack of ownership, unidimensional value offering, and access, hygiene, and social stigma associated with using secondhand goods (Camacho-Otero et al., 2017).

Consumer willingness to pay for re-used products decreases when there is a perceived risk that these products may be of lower quality, either functionally or cosmetically. In this context, factors such as durability, features, performance, and usability are critical determinants of perceived quality (Abbey et al., 2017). Although re-used goods are often sold at lower prices, the savings are frequently not seen as sufficient to offset the perceived reduction in quality (Sheoran & Kumar, 2022).

Hazen et al. (2012) identified a significant relationship between consumer perceptions of ambiguity (arising from insufficient product information) and their willingness to pay for refurbished items. Tolerance for ambiguity was shown to influence perceptions of quality, which, in turn, affected price sensitivity. To address these concerns, Guiot and Roux (2010) advocated for greater consistency in seller claims and enhanced quality assurances, including the provision of detailed technical documentation. This call for clarity was further supported by Watson et al. (2017) who highlighted a general lack of consumer awareness regarding warranty periods and consumer protection rights, thus further impeding the uptake of refurbished goods. To overcome these barriers, targeted interventions are required. Quality assurance certifications, alongside well-orchestrated awareness campaigns, are essential in reshaping consumer perceptions (Khor & Hazen, 2017; Mugge et al., 2017; Watson et al., 2017). Moreover, companies are encouraged to enhance transparency by sharing the "story" of the product (emphasizing its prior use and the recycling processes it has undergone) thereby making the item more appealing to environmentally conscious consumers (Kamleitner et al., 2019).

In the realm of secondhand clothing, Sheoran and Kumar (2022) specified that concerns over cleanliness and safety play a significant role in deterring purchases, particularly within fashion and personal items, where consumers may associate used goods with poor hygiene or a diminished social status. Other barriers include the absence of size labels, limited sizing options, disorganized store layouts, and the unavailability of fashionable items, which often reflect outdated styles, thus making secondhand products less attractive compared to new ones (Farrant et al., 2010).

On the other hand, psychological ownership, as described by Etzioni (1991) and further elaborated by many influential authors in the field of psychology, sociology, economics, product design and others (Baxter et al., 2015; Kumar, 2021; Lee & Suh, 2015; Pierce et al., 2001) and possession of "property" become extensions of the self, embedding a sense of "mine" deeply within an individual's identity. This ownership provides emotional self-determination and control over one's environment, which are critical components of modern consumer behavior.

The abovementioned study proves that convincing consumers about the benefits of a purchase requires more than a simple appeal to the value of the environment. For environmental behavior (like re-use), motivation is often lacking, requiring interventions to first generate motivation and then focus on implementation (Ajzen & Schmidt, 2020) to encourage adoption of these sustainable practices. Change in attitude, subjective norm, or perceived behavioral control can only be expected if the intervention effectively alters the overall set of behavioral, normative, or control beliefs (Ajzen & Schmidt, 2020). One model for such interventions is the typology of interventions in proximal physical micro-environments (TIPPME) introduced by Hollands et al. (2017), which outlines six intervention types designed to modify either the properties or placement of objects or stimuli within sensory-perceptible physical micro-environments. Placement can be adjusted by altering the availability and position of objects, while properties can be modified in terms of functionality, presentation, size, and available information (Marteau et al., 2020). This change requires a complex understanding of customer perception of the re-used products purchase.

2 Research methodology

The research was conducted in June 2024 through an online survey targeting a representative sample of 1,300 respondents across the Czech Republic. The sampling (set by the Laboratory for the study of human behavior) reflects the overall population distribution, with quotas based on gender, age, education, income levels, size of place of residence, and economic activity (sometimes referred to as profession). These demographic variables were chosen to ensure a comprehensive analysis of the secondhand market and to capture key consumer segments.

The study employed Ajzen's theory of planned behavior (TPB) to frame the design of the questionnaire.

Ajzen's (1991) theoretical background, as expanded with Fishbein and Ajzen (2010), provides a comprehensive view of the theory of values from multiple perspectives, offering a robust foundation for understanding decision-making processes. Specifically, the theory of planned behavior (TPB) was selected for this study due to its well-established framework for exploring the determinants of behavioral intentions and actions. TPB identifies three core constructs that influence behavior: attitudes toward the behavior, subjective norms, and perceived behavioral control.

This framework is particularly relevant to the study as it aligns with the research objective of examining Czech consumers' attitudes and behaviors toward re-used goods. By structuring the questionnaire around TPB constructs, the study captures the psychological and social factors influencing consumer decision-making, offering insights into the drivers and barriers within the context of the circular economy.

Responses were collected using a 7-point Likert scale to mitigate the ceiling effect, as per Fishbein and Ajzen's (2010) guidelines. The survey aimed to answer three main research objectives, each with a set of specific questions. The research was meant to be exploratory, so there are no hypotheses tested.

Ajzen's TPB is commonly applied to test hypotheses related to its constructs; however, as this research is exploratory, we employed methods designed to uncover deeper insights and identify patterns rather than test predefined hypotheses. Therefore, data analysis was conducted using Pearson's χ^2-test of independence, which is apt for assessing the relationships between two categorical variables. This test was selected because it allows for the exploration of associations between demographic characteristics (such as gender, age, education, income) and behaviors related to secondhand purchases. The χ^2-test compares observed frequencies of responses within categories against expected frequencies derived under the assumption of independence between the variables. This method's capability to handle both nominal and ordinal variables enabled comprehensive insights into consumer behavior across various demographic segments. Employing this statistical test was crucial to effectively answer the research questions and identify statistically significant patterns in the data. For the final analysis, although many results showed significance at the 0.1 and 0.05 levels, it was decided to focus exclusively on those with a significance level of 0.01. This stricter threshold was applied to minimize the risk of false positives, ensuring that only the most robust relationships were considered. By excluding results with higher *p*-values (0.1 and 0.05), the analysis aimed to reduce the likelihood of interpreting relationships that may have occurred by chance. Additionally, the fact that all results were initially tested across the 0.1, 0.05, and 0.01 significance levels further validates the toughness of the findings, as it confirms that the chosen results met the most stringent criteria, ensuring greater confidence in the conclusions. In some instances, it was necessary to employ alternative methods. These included the use of graphical visualizations or mean correlation analysis, mostly in the form of a matrix.

This approach enhances the credibility of the analysis, confirming that the observed associations, whether between customer categories and their secondhand purchasing behavior or product suitability, are statistically robust and reliable and align with the explanatory method of the research.

3 Results and discussion

3.1 Results

To facilitate better orientation in the overall research and the data, which are quite extensive, the results are divided into three objectives and each of these is further segmented by the questions that were considered within each objective.

RO1: Identify key customer segments of secondhand stores and examine correlations between customer categories (such as gender, age, education, income) and product categories. The research objective is answered via a set of three research questions.

RQ1.1: Are there significant differences in purchasing secondhand items based on gender, age, place of residence, education, income, and economic activity?

Pearson's chi-square analysis did not find a significant correlation between gender, size of place of residence, education and income level and purchases of secondhand items. The respondents were answering the question of whether they buy used products. Significant correlations were found regarding age and economic activity related variables implying significant trends regarding the purchase of secondhand items (Tab. 1).

RQ1.2: Can specific activities be identified through which different population segments contribute to charitable causes via secondhand stores?

The matrix of Pearsons chi-square reveals specific preferences for engaging in charitable activities through secondhand stores, with notable trends showing that gender, age, and profession play the crucial role (Tab. 2).

In case of willingness based on the "good cause" appeal, the variables seem to play more significant role than in shopping behavior. To explain phenomena was used means comparison in matrix.

The matrix categorizes questions and corresponding variables into different percentile ranges. The variables without significance at a higher or lower level are not listed for clarity (Tab. 3). A simple look at the Tab. 3 indicates that a good cause is a strong motivator for women and parents at the maternity leave category.

The best option for every category is selling or donating items to such shops. The other option, shopping within walking distance, follows with a significant difference. The higher the distance or the bigger the effort, the significantly lower the desire to purchase for good cause. On the other hand, men rather donate money than travel or actively participate. Women prefer activities, even traveling or active participation over donating money. An interesting phenomenon is the behavior of people with the highest incomes who fall into lower categories in nearly all categories (except for doing nothing). The trend of social help does not seem to be important to them.

Tab. 1: Significance in purchasing behavior

	TC	Level of significance		
		0.1	0.05	0.01
Economic activity	23.924	9.236ˣ	11.070ˣ	15.086ˣ
Monthly income	5.031	12.017⁻	14.067⁻	18.475⁻
Size of place of residence	13.347	13.362⁻	15.507⁻	20.090⁻
Age	67.694	15.987ˣ	18.307ˣ	23.209ˣ
Education	5.854	10.645⁻	12.592⁻	16.812⁻
Gender	8.771	4.605ˣ	5.991ˣ	9.210⁻

Note: TC – tested criterion; the "x" represents significance found at particular level; the "–" represents no significance found at particular level.

Source: own

Tab. 2: Correlation of variances to the willingness to contribute to good case

Question/variable	Gender	Age 18–64 and 65+	Age	Size of place of residence	Education	Income level	Economic activity
If I knew that shops with re-used items were contributing to a good cause, I would be willing to do							
Shop at a secondhand shop within walking distance	x	x	x				x
Shop at a secondhand shop within 30 km	x	x	x				x
Shop in a secondhand shop over 30 km away	x	x	x	x	x		x
Donate unwanted items to such a shop	x						x
Sell unwanted items to such a shop	x						x
Donate a sum of money to such a shop	x	x	x				x
Actively participate in the running of the shop		x	x				
Nothing							

Note: The “x” represents significance found at 0.01 level.

Source: own

RQ1.3: Can connections be specified between customer categories and the types of products they prefer to purchase?

The analysis examines the purchasing behavior of 1,018 respondents who indicated that they shop at secondhand stores regularly or occasionally. This subset of the original sample was selected after excluding 22% of the total respondents who do not shop at secondhand stores at all.

The Pearson’s chi-square test results (Tab. 4) underscore that there are statistically significant differences between the groups for most product categories. Each demographic category exhibits distinct purchasing patterns, suggesting that demographic factors significantly influence secondhand purchase most of the products, except for art.

The following matrix of product groups and individual variables provides an overview of the groups that purchase products the most, highlighted in green (percentile ≥75%), and the least, highlighted in red (percentile ≤25%). Based on Tab. 5, it is evident that the mean purchases significantly differ across the categories. Tab. 5 is organized according to the means calculated based on participant responses on a 7-point scale, where 7 indicates the most frequent purchase and 1 indicates never.

The product matrix reveals that cars are the best commodity to sell, and the best customer is an entrepreneur or customer with a high income with residence in place up to 5,000 citizens and in age between 35–54 years. However, it should be noted that only three categories fall below the statistical deviation from the group average, appearing unsuitable for car sales, namely people from cities with over 100,000 inhabitants, pensioners, and the age group 65+.

Categories such as books, workshop tools, sports equipment, art, household appliances, and pet supplies exhibit very small standard deviations, indicating minimal overall differences in the mean responses. This suggests that these categories are generally consistent in terms of purchasing behavior. On the other hand, casual clothing, games and toys, children’s clothing, and equipment show a deviation of 0.4, reflecting greater variability in purchasing behavior.

The most variable category is footwear with a standard deviation of 0.5. It is primarily purchased by parents on maternity leave, students, individuals with lower incomes and education levels, and young people aged 18–34. In contrast, the lower percentiles for footwear

Tab. 3: Comparison of means in questions related to contribution to good cause

Question	Gender		Age	Size of place of residence (number of of inhabitants)			Education		Economic activity			Monthly income	
	Woman	Man	65+	1,001–5,000	5,001–20,000	20,001–100,000	Basic incl. incomplete	University degree	Pensioner	Maternity/parental leave	Student	Up to EUR 642	Over EUR 1,604
Shop at a secondhand shop within walking distance	4.54	4.00	4.27	4.25	4.24	4.24	4.20	4.25	4.28	4.36	4.28	4.28	4.24
Shop at a secondhand shop within 30 km	3.87	3.42	3.64	3.63	3.62	3.62	3.57	3.63	3.65	3.74	3.66	3.65	3.63
Shop in a secondhand shop over 30 km away	3.31	2.98	3.14	3.13	3.13	3.12	3.08	3.14	3.14	3.23	3.16	3.14	3.13
Donate unwanted items to such a shop	5.09	4.47	4.78	4.77	4.77	4.76	4.74	4.78	4.79	4.88	4.79	4.79	4.76
Sell unwanted items to such a shop	5.02	4.56	4.80	4.80	4.80	4.80	4.78	4.79	4.80	4.88	4.80	4.81	4.79
Donate a sum of money to such a shop	3.00	3.99	2.84	2.83	2.83	2.83	2.80	2.84	2.84	2.94	2.86	2.84	2.83
Actively participate in the running of the shop	3.26	2.92	3.08	3.08	3.07	3.07	3.05	3.08	3.08	3.19	3.09	3.09	3.08
Nothing	2.97	3.27	3.13	3.14	3.14	3.14	3.13	3.13	3.12	3.09	3.10	3.12	3.14

Note: Values represent mean responses on a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree). Coloring is applied row-wise to highlight relative positions of the means. A green box indicates that the mean is positioned in the sector with the highest agreement percentile (≥75%) and red indicates the lower agreement percentile (≤25%). Green shades indicate higher mean values (closer to strong agreement); red shades indicate lower mean values (closer to disagreement) in the row.

Source: own

Tab. 4: Pearson's chi-square results – Part 1

Question/variable	Gender	Age 18–64 and 65+	Age	Size of place of residence	Education	Income level	Economic activity
I personally buy							
Personal electronics (e.g., computers, mobile phones, notebooks)		x	x				x
Household appliances	x	x	x		x		
Household supplies		x			x		x
Home textiles		x	x		x		x
Clothing (casual)	x					x	x
Children's clothing	x	x	x	x			
Children's equipment		x	x	x			x

Tab. 4: Pearson's chi-square results – Part 2

Question/variable	Gender	Age 18–64 and 65+	Age	Size of place of residence	Education	Income level	Economic activity
I personally buy							
Specialised expensive clothing (e.g., sports, special occasion clothing)	x	x	x				x
Books, CDs, DVDs					x		
Footwear	x	x					x
Specialised expensive footwear (e.g., sports)		x	x				x
Sports equipment and tools		x	x				x
Games and toys	x	x	x				x
Furniture		x	x				x
Car	x	x	x	x			
Sanitary ceramics		x	x	x			x
Workshop tools	x			x	x		
Decoration and home accessories	x	x	x			x	
Gifts for family		x	x		x		x
Pet supplies		x	x				x
Art							

Note: The "x" represents significance found at 0.01 level.

Source: own

purchases include pensioners, entrepreneurs, high-income groups, individuals aged 55+, and, surprisingly, residents of towns with populations between 5,001 and 20,000.

RO2: Evaluate the significance of reasons for and against purchasing used items. The research objective starts with the first research question:

RQ2.1: What are the main reasons why people buy secondhand items?

The correlation of reasons to purchase and the socio-demographic group show (Tab. 6) that motivations for buying secondhand items are not driven by cost but by social and personal connections, as well as ethical considerations.

Knowing the seller personally is a crucial motivator across education and income differentiated groups. Similarly, meeting people changes with age education level. Additionally, the social aspects of shopping and altruistic reasons like environmental concern and aiding disadvantaged groups also play significant roles, particularly among younger consumers and women, which is proven by previous answers to research questions. The location plays a crucial role based on age, gender, and the size of place of residence.

RQ2.2: What are the barriers that prevent people from purchasing used goods?

The analysis encompasses responses from all 1,300 participants addressing various concerns that hinder the purchase of secondhand goods (Tab. 7). The correlations indicated in the matrix primarily revolve around age and profession, suggesting specific trends within these groups.

The chi-square analysis reveals that differences in the perception of challenges related to purchasing secondhand items are primarily associated with age and profession. The most significant disparities across categories are observed in the issue of a lack of product information (service, warranty or information about origin), which varies not only by age and profession but also by education level.

Tab. 5: Pearson's chi-square results

I personally buy	Gender		Age						Size of place of residence (number of inhabitants)					Education				Monthly income			Economic activity				
	Man	Woman	18–24	25–34	35–44	45–54	55–64	65+	Up to 1,000	1,001–5,000	5,001–20,000	20,001–100,000	over 100,000	Basic incl. incomplete	Apprenticeship certificate	Secondary and higher vocational	University degree	Up to 642 EUR	EUR 642–1,604	Over 1,604 EUR	Student	Entrepreneur	Employee	Pensioner	Maternity/parental leave
Personal electronics	3.15	2.57	3.54	3.33	3.00	2.81	2.71	2.23	2.97	3.01	2.52	2.96	2.67	3.26	2.97	2.68	2.59	3.13	2.82	2.86	3.46	3.14	3.01	2.29	2.60
Household appliances	2.72	2.62	2.89	3.08	2.82	2.68	2.63	2.16	2.77	2.91	2.42	2.62	2.55	3.09	2.82	2.50	2.39	2.98	2.71	2.44	2.82	2.68	2.82	2.27	3.00
Household supplies	2.30	2.52	2.90	2.70	2.49	2.32	2.40	2.08	2.38	2.68	2.15	2.47	2.38	2.96	2.44	2.34	2.13	3.11	2.47	2.07	2.70	2.17	2.52	2.16	2.97
Home textiles	2.30	2.65	3.10	2.84	2.56	2.40	2.43	2.06	2.51	2.75	2.26	2.52	2.34	3.01	2.60	2.31	2.19	3.06	2.54	2.14	3.18	2.32	2.60	2.10	3.20
Clothing (casual)	2.73	4.12	4.31	3.77	3.41	3.34	3.20	3.28	3.45	3.73	3.42	3.33	3.39	3.93	3.39	3.52	3.14	4.23	3.57	2.92	4.49	3.32	3.45	3.32	4.31
Children's clothing	2.74	3.43	2.93	3.26	3.55	3.38	2.87	2.53	3.30	3.25	3.03	3.09	2.81	3.32	3.02	3.13	3.04	3.38	3.13	2.94	2.94	2.81	3.32	2.50	4.66
Children's equipment	2.80	3.18	3.06	3.35	3.32	3.11	2.81	2.46	3.17	3.10	2.88	3.12	2.70	3.17	2.90	3.01	3.03	3.21	3.00	2.96	2.79	2.69	3.20	2.47	4.51
Specialized expensive clothing	2.19	2.59	3.16	2.72	2.51	2.45	2.32	1.85	2.44	2.53	2.26	2.46	2.30	2.69	2.31	2.43	2.31	2.87	2.39	2.34	2.82	2.36	2.57	1.88	2.91
Books, CDs, DVDs	3.43	3.81	3.34	3.64	3.65	3.75	3.81	3.47	3.54	3.49	3.44	3.71	3.91	3.18	3.47	3.79	3.94	3.30	3.69	3.52	3.76	3.62	3.72	3.42	3.43
Footwear	1.95	2.33	3.16	2.81	2.26	1.99	1.73	1.65	2.15	2.27	1.92	2.28	2.09	2.54	2.25	1.99	1.98	3.25	2.15	1.88	3.30	1.78	2.31	1.70	2.86
Specialized expensive footwear)	1.98	2.15	2.83	2.52	2.17	2.00	1.96	1.54	2.05	2.13	1.99	2.27	1.92	2.43	2.10	2.03	1.83	2.64	2.09	1.87	2.58	1.82	2.28	1.58	2.46
Sports equipment and tools	2.79	2.76	2.99	3.02	3.06	2.79	2.65	2.33	2.89	2.99	2.58	2.87	2.51	3.00	2.71	2.77	2.73	3.02	2.77	2.73	2.76	2.68	2.96	2.33	3.03
Games and toys	2.91	3.23	3.38	3.34	3.45	3.22	2.92	2.42	3.19	3.12	2.98	3.13	2.93	3.38	3.05	3.10	2.87	3.60	3.08	2.95	3.42	2.83	3.27	2.52	4.34
Furniture	2.93	3.23	3.34	3.58	3.22	3.09	3.15	2.48	3.37	3.27	2.88	2.94	2.89	3.44	3.09	3.08	2.85	3.49	3.07	3.04	3.52	3.34	3.23	2.49	3.69
Car	4.03	3.74	3.73	4.13	4.15	4.30	3.69	3.22	4.25	4.14	3.94	3.71	3.34	3.80	3.83	3.93	3.92	3.87	3.72	4.40	3.79	4.44	4.03	3.24	4.03
Sanitary ceramics	2.00	2.03	2.45	2.29	2.14	1.88	2.04	1.67	1.99	2.27	1.80	2.16	1.86	2.69	2.10	1.80	1.77	2.49	2.05	1.80	2.30	1.84	2.14	1.73	2.23
Workshop tools	3.21	2.76	3.07	2.93	3.09	2.96	3.08	2.82	3.17	3.18	2.79	3.08	2.61	3.34	3.13	2.89	2.60	3.28	3.01	2.80	3.03	3.01	3.02	2.89	2.63
Decoration and home accessories	2.64	3.00	3.55	3.06	2.81	2.77	2.83	2.52	2.81	3.09	2.60	2.97	2.69	3.20	2.91	2.79	2.50	3.34	2.89	2.52	3.24	2.63	2.93	2.58	3.43
Gifts for family	2.23	2.11	2.96	2.66	2.29	1.99	2.01	1.70	2.07	2.40	2.01	2.25	2.12	2.62	2.19	2.08	1.96	2.64	2.22	1.91	2.85	2.06	2.29	1.82	2.49
Pet supplies	2.46	2.53	3.00	2.88	2.51	2.35	2.47	2.20	2.61	2.70	2.39	2.65	2.14	2.83	2.64	2.42	2.16	2.85	2.51	2.37	2.94	2.35	2.64	2.23	2.43
Art	2.87	2.67	3.06	2.63	2.64	2.82	3.13	2.61	2.84	3.00	2.50	2.62	2.80	2.91	2.68	2.68	2.95	2.81	2.76	2.77	2.97	2.97	2.80	2.58	2.54

Note: The values are rounded to two decimal places, but calculations are based on the full figures. As a result, some identical numbers may not be labeled consistently. Values represent mean responses on a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree). Coloring is applied row-wise to highlight relative positions of the means. A green box indicates that the mean is positioned in the sector with the highest agreement percentile (≥75%) and red indicates the lower agreement percentile (≤25%).

Source: own

Tab. 6: Pearson's correlation (the reason to buy re-used items)

Question/variable	Gender	Age 18–64 and 65+	Age	Size of place of residence	Education	Income level	Economic activity
I buy used things because of							
Low prices							
The owner or seller is a acquaintance					x	x	
The shop is close to my home	x	x		x			
I meet other people there			x		x		
No one else owns this item							
I like to collect "treasures" that I can only find in this type of shop							
I am interested in the environment	x						
I will help the disadvantaged	x						

Note: The "x" represents significance found at 0.01 level.

Source: own

Tab. 7: Barriers preventing the purchase of secondhand products

Question/variable	Gender	Age 18–64 and 65+	Age	Size of place of residence	Education	Income level	Economic activity
Buying used goods, it bothers me							
Obsolescence		x	x				
Lower product performance		x	x				
Lower product lifetime							
Lack of information about product features		x	x		x		x
Lack of information about the origin of the product		x	x				x
Lack of warranty		x	x				x
Lack of service and spare parts		x	x				x
Dirt		x	x				x
Limited range of products							x

Note: The "x" represents significance found at 0.01 level.

Source: own

RQ2.3: Can differences be identified in the added value between the observed variables (contributing to a good cause/environment)?

Data about the environment and "good cause" were already interpreted however in different context. Fig. 1 shows that the environmental appeal generally scores higher across most demographic segments compared to the appeal of helping disadvantaged persons, though the difference is marginal.

Environmental concerns and aiding disadvantaged individuals generally hold greater significance for women compared to men. The environmental appeal scores higher than the concern for helping the disadvantaged, with the largest difference observed in the 18–24 age group, students, and respondents with low income. Environmental considerations seem most important for women, individuals with incomes up to EUR 642, students, and parents on maternity leave, while being least significant for those with incomes over EUR 1,604.

Regarding the importance of helping disadvantaged individuals, it resonates most with women, people with basic or incomplete education, pensioners, and aged 65+, and parents on maternity leave. Interestingly, it is slightly less significant for residents of towns with populations up to 1,000. On the other end of the spectrum stand men, younger respondents aged 18–24, and those with the highest incomes.

RO3: Identify the suitability of different types of products for trading in the second-hand market and the shortcomings of used items as perceived by potential customers. The research objective starts with research question 3.1:

RQ3.1: Which types of used goods are considered most suitable for trading?

RQ3.1 is addressed by analyzing the mean scores assigned to different categories of goods. These scores reflect the perceived suitability of these items for trading in the secondhand market. Fig. 2 provides ranks of various types of used goods based on their mean scores, which indicate how suitable respondents perceive these items for trading.

Cars rank the highest with a mean score of 5.5 (the most suitable score was 7),

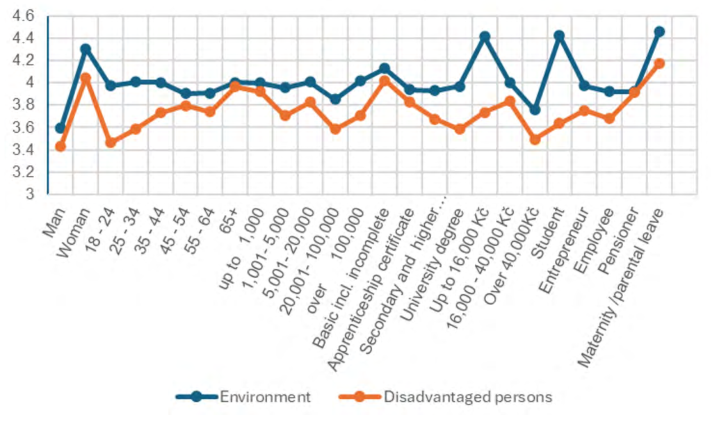

Fig. 1: Comparation environment vs. disadvantaged persons preference

Note: The x-axis represents the average mean of the responses (categories: gender, age – years, size of place of residence – number of inhabitants, education, monthly income, economic activity); Kč = CZK, exchange rate according to the Czech National Bank as of May 29, 2025: CZK 24.94 per EUR.

Source: own

Car	Art	Books, cd's, dvd's	Children's clothing	Workshop tools	Games and toys	Furniture	Children's equipment	Sports equipment and tools
5.482	5.365	5.32	4.966	4.873	4.819	4.801	4.799	4.739

Decoration and home accessories	Car	Pet supplies	Clothing (casual)	Household appliances	Specialised expensive clothing (e.g. sports, special occasion clothing)	Home textiles	Household supplies
4.452	4.441	4.319	4.275	4.204	4.137	3.814	3.742

Sanitary ceramics	Specialised expensive footwear (e.g. sports)	Gifts for family	Footwear Causual
3.398	3.316	3.014	2.804

Fig. 2: Perceived suitability of used product to trade

Note: The number in each box represents the average mean of the responses.

Source: own

suggesting they are considered the most suitable for trading in the used goods market. This could be due to the significant cost savings involved and the general acceptance of buying used cars as a practical option. Art and books, CDs, and DVDs score highly (5.3), indicating strong suitability. These items often have enduring value and can be appreciated by new owners without significant deterioration in quality. On the other hand, casual footwear has the lowest perceived suitability with a mean score of 2.8. This may reflect concerns about hygiene, fit, and wear specific to this category, making them less desirable as traded goods.

Respondents suggested, in an open question, a wide variety of other goods as suitable for trading: i) small electronics, though not specified, likely due to their practical utility and high demand; ii) items such as cosmetics, drugstore products, perfumes or wigs that might not suit one person but could still be desirable to others; iii) garden furniture, fishing gear, and collectibles (coins, stamps, knives) highlight niche markets where specific interests drive trading; iv) building materials and homemade products indicate a market for DIY (do it yourselves) enthusiasts and hobbyists, probably meant produced from old materials. This implies that the customer does not distinguish between re-use, recycle or rebuilt options but recognize them; and v) an interesting suggestion is medical supplies like crutches. Antiques and jewelry which were meant to be included in art prove that the market is segmented and almost any item can find a niche and a suitable buyer.

RQ3.2: What shortcomings do respondents perceive in used goods?

The analysis focuses on the shortcomings identified by consumers when purchasing used items. It looks like within the categories are not identified high deviation in answer distribution except one related to gender, two to broader age category, one to more segmented age category and last to place of residence (Tab. 8).

Age appears to be a significant factor in the experience of odors or the lack of information about a product's origin when shopping. Additionally, a notable gender difference is observed in responses regarding insufficient photos and descriptions on e-shops, which may reflect differing online shopping patterns between men and women. An interesting correlation exists between the size of the place of residence and the perception of products being unpleasant to touch. This correlation warrants further investigation based on the population structure of each region in Czechia.

Tab. 8: Experienced shortcomings when purchasing secondhand goods

Question/variable	Gender	Age	Size of place of residence	Education	Income level	Economic activity
I experience the following shortcomings when buying used items						
Low product quality						
Defects in the appearance of the product (e.g. paint, un-ironed or unwashed products)						
Product has an odor		x	x			
The product is unpleasant to the touch			x			
The product cannot be returned						
Short selection of used products						
The price does not correspond to the risk of buying second-hand						
Little information about where the product comes from			x			
Cannot pay by card						
The layout and general appearance of the shop						
Quality of service						
Insufficient information about the shop (opening hours, contacts, terms and conditions)		x				
Insufficient photos and descriptions on the e-shop	x					

Note: The “x” represents significance found at 0.01 level.

Source: own

3.2 Discussion

The results of the analysis on Czech consumers emphasize that consumer behavior is shaped by interactions between societal structures and individual actions (Mylan et al., 2016) and acceptance of re-used products is influenced by broader economic, cultural, and social factors (e.g., Hazen et al., 2017). The purchase of the re-used products at different levels and by different sociodemographic groups of Czech citizens points at variety reasons for or against the purchase and highlight the necessity to understand customers values and norms like the market with new products.

When promoting consumers active role in this process of building CE, the findings suggest that while consumers generally find some secondhand products suitable for sale, there are notable differences in the perception and preferences for products across demographic groups and periodicity in purchase. But the results revealed that each product has the potential to find an appropriate market and consumers.

This study further underscores the importance of understanding the barriers in consumer acceptance of re-used products. Concerns about product quality, hygiene, and insufficient information about the origin and warranties differ based on age and education level, in some cases by gender in purchases. Addressing these concerns through enhanced transparency, quality certifications, and awareness campaigns, as advocated by Mugge et al. (2017) and Watson et al. (2017), could reshape consumer perceptions and increase the adoption of secondhand goods. The lack of consistent product information highlights the critical role of transparency in the digital environment. Mostly men, but not exclusively, search for information at e-shop webpages, looking for complete data and pictures of the product for purchase decision.

Notably, the study revealed that specific categories (namely 65+ and seniors) are more resistant to secondhand shopping than other groups. The students and younger consumers up to 34 represent a new wave of market behavior. It was found that the older the customers are, the less inclined they are to buy secondhand products. However, the younger generation entering the markets may bring about change.

Age and education were shown as important factors in the societal role of re-used centers, which may help in promoting the center itself and support the purchase in the point of sale. The significance of social and personal connections in motivating secondhand purchases was evident and it aligns with the findings of Ertz et al. (2021) and Camacho-Otero et al. (2017), who emphasized the importance of trust and personal relationships in the adoption of re-used products. This suggests potential strategies to engage demographics such as university-educated individuals and seniors, who typically purchase less in secondhand markets.

The research approved that environmental concerns motivate re-used purchases (Edbring et al., 2016) because the respondents showed higher levels of environmental engagement, although not equally across all consumer categories. A positive discovery is that distance does not deter the willingness of certain consumers to purchase secondhand items for a good cause. Categories such as women and parents on maternity leave claimed willingness to travel over 30 km for such purchases significantly more than others. On the other hand, men were more inclined to provide support by donating money, highlighting different opportunities for engagement across consumer groups.

Similarly, helping disadvantaged individuals, often employed in re-use centers, also influences consumer intention to buy. However, it was observed that in Czech culture, individuals with the highest incomes show the least interest in good cause motives, which presents an opportunity for improvement. Interestingly, environmental benefits were perceived as more important than helping disadvantaged individuals, particularly among younger respondents, students, and low-income groups. Helping disadvantaged individuals, however, remains a significant motivator for older consumers, parents on maternity leave, and those with lower education levels.

The secondhand purchase product matrix identified specific target groups more likely to purchase certain types of products. Based on the results it may be said that each product, at a certain performance level may find the appropriate consumer for purchase.

The study aimed to explore whether consumers in the Czech Republic are willing to adopt secondhand products within the CE, and to identify the barriers that hinder their acceptance. Additionally, the research sought to investigate strategies to increase consumer openness to re-used products to support the broader objectives of the CE. Addressing these issues, this study supports the CE's goal of promoting sustainability through extended product lifecycles and greater consumer participation in re-use.

The findings suggest that age and education level play a crucial role in segmenting the target group. In some cases, it is productive to focus on residents in towns with populations up to 5,000, as this group has shown potential as prospective consumers. These areas may include satellite communities of larger cities, where residents tend to be more environmentally conscious and choose to live closer to nature.

To overcome these challenges, strategies such as improved transparency (including "storytelling" about the product's history), quality assurances, and awareness campaigns are vital in reshaping perceptions. By engaging the citizens within walking distance or close to the re-used centers into different community events with focus on different values of the target group will help promote the re-use shop together with products offered.

The results highlight the need to professionalize the market for re-used products, with a focus on education, social inclusion, and providing alternatives to existing products, rather than solely emphasizing environmental benefits. The range of appeals should be varied and tailored to different segments based on their knowledge and preferences. There is also an opportunity for the involvement of local and state authorities and local and national businesses.

Conclusions

The CE offers a vital framework for addressing environmental challenges by promoting the re-use, recycling, and extended lifecycles of products. This study underscores the significant potential of the secondhand market as a significant component of the CE, capable of fostering sustainability and reducing waste.

The findings reveal that Czech consumers possess both the capacity and willingness to engage in the circular economy through the purchase of secondhand goods. However, a key barrier lies in the approach adopted by re-use centers. For the circular economy to evolve effectively, the re-use market should be treated with the same strategic mindset as markets for new goods. This includes recognizing the active role of consumers in selecting and purchasing re-used items and ensuring that these items are positioned as viable, desirable alternatives to new products.

Despite its potential, the secondhand market remains largely underestimated. Barriers such as concerns about product quality, hygiene, and insufficient information persist on one hand, while inadequate promotion and lack of professionalization of re-use centers hinder consumer engagement on the other. Addressing these challenges requires a shift in focus from assuming that re-used goods appeal to limited groups of customers to actively identifying and targeting specific customer segments for each product group. The study highlights that even items perceived as "least desirable" can find a potential market if strategies align with consumer preferences and needs. Providing clear and detailed product information such as its origin, prior use, and condition, alongside quality assurance measures like warranties or post-purchase services, can build consumer trust. Maintaining clean, organized environments and ensuring the hygiene of products are critical for overcoming psychological barriers.

To foster broader acceptance, re-use centers should offer tailored products and services that resonate with specific target groups, such as affordable children's items for families or sustainability workshops for younger consumers. The centers need to engage in transparency initiatives, including sharing the product's history or guarantees, to reshape consumer perceptions and encourage trust. And finally, involve local and national institutions to provide certifications, and quality standards, addressing consumer concerns and enhancing credibility.

The professionalization of the re-use market requires active support from local and national authorities. Targeted interventions, supported by law, can significantly reduce quality uncertainty, as originally proposed by Akerlof (1978). Legal frameworks that promote consistency in seller claims, offer quality assurances, and ensure consumer protection rights as emphasized by Guiot and Roux (2010) and Watson et al. (2017) are essential steps. Incorporating such measures, alongside consumer education and community engagement, will strengthen trust and sustainability within the secondhand economy.

By implementing these strategies, re-use centers and policymakers can transform the secondhand market into a fully integrated and professionalized component of the CE, unlocking its potential to drive sustainable consumption and reduce waste.

Together with practical implementation of CE objectives, this research contributes to the growing body of literature in the re-use field, providing valuable insights into consumer behavior and the specific motivators and barriers that shape purchasing decisions. It highlights the need for further research on strategies to engage diverse consumer segments and offers a foundation for future discussions on how to better integrate re-used goods into mainstream markets. Ultimately, fostering an inclusive approach that recognizes the diverse motivations and concerns of different customer groups will be crucial in achieving the full potential of the CE and driving meaningful progress toward a more sustainable future.

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Leadership role in sustainable future of circular economy: Climate, economy, and environment interplay

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Abstract: *The issue of climate change is a significant concern in contemporary society characterized by a volatile, uncertain, complex, and ambiguous (VUCA) environment. Asian nations are also dealing with issues related to climate change. The objective of this study is to ascertain the relationship between climate change and its impact on both the economy and the environment. This research examines the moderating influence of leadership skills on the variables of climate change, the economy, and the environment. The study employed a time lag research design to gather data in Pakistan. The analysis was based on a structural equation modelling approach with a sample size of 4,243 participants. The results suggest that leadership skills have a significant moderating impact on the relationship between climate change and the economy, and between climate change and the environment. The research highlights the impact of climate change on the economy and environment of a developing nation. The findings indicate that effective leadership abilities are necessary to manage environmental and economic conditions for long-term sustainability. The study holds significant implications for both theoretical and practical domains, particularly in enhancing climate control by incorporating leadership competencies. This research contributes to the concept of circular economy by showcasing the complex relationship between climate change, environment, economy, and leadership. The research extends noteworthy avenues for future exploration, laying the foundation for further contributions to the existing body of literature related to circular economy.*

Keywords: *Leadership skills, climate change, environment, global warming, circular economy.*

JEL Classification: *Q01, M2, M10, O1, O15.*

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Introduction

In the modern world, climate change has emerged as a major problem. It has led to different kinds of issues that are directly influencing the environment (Gura et al., 2023; Iqbal et al., 2021). The sustainability of the environment is possible when the government and other supporting agencies are working together to protect the environment. Rich countries have launched different kinds of initiatives to improve sustainability in the environment (Sheller, 2021; Stoian et al., 2023). The world leaders, including the former prime minister of Pakistan, who initiated the Billion Trees Tsunami program, strive to save the environment with natural and green weather. The sustainability of the environment can be reached through large-scale initiatives for the benefit of the public. The reliability of public attitude towards the advancement of climate sustainability can motivate the government further to take direct steps for improvement in government facilities (Mohsin et al., 2021). The developed nations are advanced in their environment protection attitude that is reliable for a better and more productive approach.

The role of leadership is critical in the working administration of any country. Countries without leaders fail to achieve prosperity (Bradley et al., 2020). In this way, the economic conditions require to demonstrate leadership for the environment. The success of the government performance can be a useful way to achieve sustainability in the environment (Jeswani et al., 2021). The better working approach of leaders in the world provides a way to the sustainability of the environment. The success of the government in terms of sustainable development is possible when the role of leadership is advanced to protect the environment (Howarth et al., 2020). Many nations have paid less attention to improving their environment, and the natural hazards damaged a lot of their property. The success of the government working for the protection of the environment is possible with long-term strategic planning to get better results in the way of sustainable performance (Maja & Ayano, 2021).

The escalating environmental challenges facing our planet, from global climate change to local pollution, have prompted responses at all levels of society (Hart & Pomponi, 2021). The circular economy, with its focus on reducing waste, reusing resources, and regenerating natural systems, has emerged as a promising strategy to address these pressing concerns (Kaur et al., 2024). Previous research highlighted the significant potential of circular economy approaches to contribute to climate change mitigation. Pham et al. (2020) highlighted that climate change is a fundamental problem for successful development. Environmental problems emerge when the government of a country is not serious about solving environmental issues (Shahzad, 2020). Furthermore, the problem of environmental issues is not limited to the climate only, economic issues have also emerged from it. Indeed, Asian countries are also facing environmental issues (Balsalobre-Lorente et al., 2020). Pakistan being an atomic power in Asia is facing environmental issues that are not properly managed by the community. Economic and environmental issues are raised in Pakistan as it faced floods every year for a decade (Tariq et al., 2020). A lot of community is disturbed by floods including the agriculture sector because of this issue. There is less focus on the government to develop long-term policies for climate control in the country (Hussain et al., 2020). These little initiatives to control the climate are dangerous for the community that is suffering from such kinds of hazards.

Recent research has emphasized the role of leadership in achieving environmental sustainability and environmental performance (Yousaf et al., 2023). Moreover, leaders can raise awareness about the circular economy and its benefits. Effective leadership is crucial for driving the transition towards circularity, for the practical implementation of circular economy and its widespread adoption. Leaders educate employees, customers, and the wider public about the importance of sustainable practices and empower them to make informed choices (Ma et al., 2024). The circular economy is seen as a viable solution for climate change management.

The purpose of this research is to determine the direct effect of climate change on the economy and environment in Pakistan. This study also aims to test the moderating impact of leadership skills on climate change, the economy, and the environment. The research has novelty since a few studies were conducted to explore the abovementioned relationship, particularly in the context of Pakistan. The research has remarkable implications for theory and practice as well as for improving climate control by considering leadership skills. Furthermore, the study has significant future directions that are necessary to be taken by scholars in their future research to contribute to the literature. This paper is divided into an introduction, literature review, methodology, data analysis, discussion and conclusion, limitations, and future directions.

1 Theoretical background

Markkanen and Anger-Kraavi (2019) argued that the economies of modern countries are disturbed due to the issues related to climate change. Furthermore, Nasir et al. (2019) highlighted that climate change is a factor that must be considered to improve the economic situation of any country. In this vein, the circular economy concept is closely associated with tackling climate change (Leal Filho et al., 2023). The role of climate change is critical for the economy as hazards caused by it and other climate-related consequences significantly impact economic activities. The relationship of climate change is direct with the economic downsizing in the country due to its dangerous effect on progress and prosperity. Streletskiy et al. (2019) highlighted that developed countries are focusing on the issues related to climate change to ensure that the effect of climate change should not damage the economic growth in the country. The less focus on climate change can affect businesses, and the interest of investors is also down due to it. Enterprises are not achieving their import and export targets, which is an obstacle to progress on sustainable development due to climate change (Nawaz et al., 2021). Slow progress towards improving the environment and reducing the impact of climate change may result in a less productive approach to the environment and sustainability (Ehsanullah et al., 2021). Conversely, focusing on climate change can contribute to sustainable development goals (SDGs). The fundamental way to combat climate change can be to improve the environment and achieve sustainability. Therefore, while working on economic growth, the government must also address the negative effect of climate change.

H1: There is a relationship between climate change and the economy.

The impact of climate change on the environment is negative because many businesses are closed due to a threatening environment. Previous studies illustrated adverse impact of climate change on the business (Dogru et al., 2019). Natural disasters caused by climate change are dangerous for the environment and ecosystem that is not acceptable for sustainability (Confetto & Covucci, 2021; Norouzi et al., 2020). To achieve sustainability goals, the environment should be appropriately managed by the policies of the government. For example, the carbon emissions in the environment should be reduced over time. Environmental sustainability can be achieved by taking reasonable actions. The damaged environment is problematic for the economic growth of a country (Hoang et al., 2023; Khan et al., 2019). In this regard, the circular economy is increasingly recognized as a potential solution to mitigate climate change. Circular economy practices, such as such as material reuse and recycling, can significantly reduce greenhouse gas emissions in various sectors (Leal Filho et al., 2023). Furthermore, government policies for long-term implications can provide a better way forward to improve the environment. The leadership is required to take strategic actions to protect the environment and to avoid detrimental economic conditions (Dale et al., 2020). Sustainable development is possible with the long-term policies of the government that is the fundamental source to get advancement in the environment. The understanding and responsibility of the citizens for better environmental conditions can be helpful to save the environment that is necessary to improve the sustainability of the country (Srivastava et al., 2023; Żuk & Szulecki, 2020). However, for the protection of the environment and to reduce the impacts of climate change relevant actions are required.

H2: There is a relationship between climate change and the environment.

Leadership in any country plays a critical role in the advancement of the environment. Leaders shape policies to meet social, economic, and environmental goals, achieve sustainability, and build a circular economy (Covucci et al., 2024). The circular economy thrives on collaboration. Leaders facilitate partnerships across different sectors, organizations, and stakeholders to create circular systems and share resources effectively. The policies developed and implemented by the leadership play a critical role in the way of successful performance

(Balogun et al., 2020). The qualities of leaders are considered appropriate for the development of the economy. Leaders should develop long-term plans for improved economic conditions and for achieving sustainability (Pettorelli et al., 2021). In this regard, leadership skills need to be demonstrated. Generating knowledge through leadership skills can improve economic and environmental conditions (Bos & Gupta, 2019). Countries affected by climate change in particular require leaders with the appropriate skills to manage their economies and the environment. The available facilities for economic growth are useless when the economic environment of a country is not stable for working (Zheng et al., 2019). Access to management policies and initiatives can be useful in monitoring the environment and improving conditions. The leaders of developed nations are more concerned with advancing the economic situation of the country. Access to usable information can be a step forward in developing leadership skills (Rehman et al., 2021). Leadership with experience can play a significant role in ameliorating economic condition and boost climate change mitigation efforts.

H3: There is a moderating role of leadership skills between climate change and the economy.

Climate change is considered a critical factor for the environment. The relationship between climate change and the environment requires that leaders work on mitigation of the problem (Skovgaard & van Asselt, 2019). For this reason, leadership skills should be improved to take collective action. When the leaders are sincere in working for the advancement of climate change, they are deliberately working to improve the environment (Sovacool, 2021; Srivastava et al., 2023). Leaders are expected to drive innovation, improve organizational effectiveness, and implement changes to address current complex environmental challenges (Gigauri & Khan, 2025). Working on climate is required by the leaders as they are policymakers and decision-makers. Leaders can gain public support while implementing the initiatives aiming at dealing with climate change (Prideaux et al., 2020). Better leadership with strategic planning can facilitate the government to solve the critical problems related to the environment (Iqbal et al., 2021). Furthermore, the real-time monitoring of the actions by leaders can provide a way to reduce the emission of carbon and protect the environment in a reliable way (Bradley et al., 2020). The majority of people are willing to support their leadership in dealing with climate change-related issues.

H4: There is a moderating role of leadership skills between climate change and the environment.

The theoretical model of this research is based on four variables, including the moderating role of leadership skills, shown in Fig. 1.

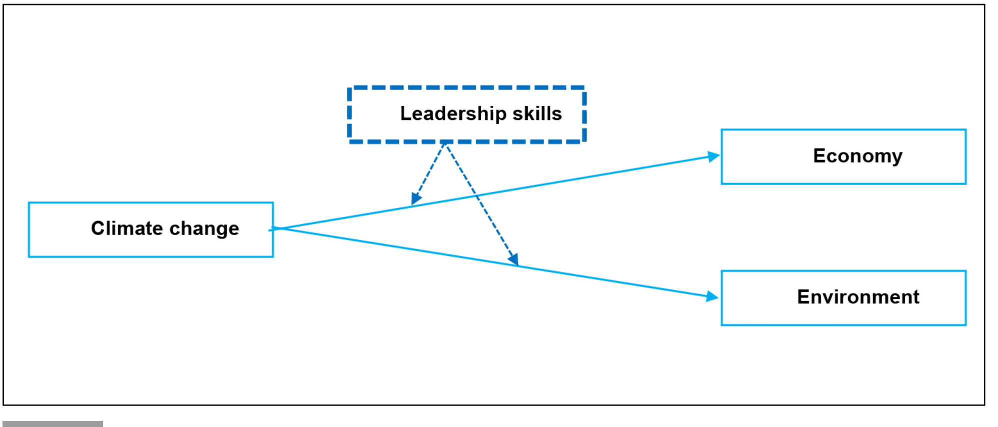

Fig. 1: Theoretical model

Source: own

2 Research methodology

The selection of a quantitative research design and survey-based methodology in this study is informed by several factors. Firstly, the research aims to investigate the relationships between climate change, leadership, the economy, and the environment, which are all complex and multifaceted phenomena that can be challenging to capture through qualitative research alone. A quantitative approach uses statistical techniques to analyze large sets of data, allowing for a more comprehensive understanding of the relationships between the variables of interest (Suieubayeva et al., 2025). Finally, the use of existing studies and measures from the literature ensures that the study is grounded in established theoretical and empirical frameworks, thereby enhancing the reliability and validity of the data collected. Overall, the choice of a quantitative research design and survey-based methodology is appropriate for this study given the complexity of the research questions, the need to collect data on a large scale, and the desire to ensure the reliability and validity of the results.

The items for climate change are taken from the study of Christensen and Knezek (2015) after determining the Cronbach alpha > 0.78 and composite reliability 0.73. Also, the items for leadership skills are taken from the study of Gilfoyle et al. (2007) after determining the Cronbach alpha > 0.72 and composite reliability 0.77. On the other hand, the items for the economy are taken from the study of Taiwo et al. (2012) after determining the Cronbach alpha > 0.71 and composite reliability 0.79. Finally, the items for the environment are taken from the study of Noordin and Sulaiman (2010) after determining the Cronbach alpha > 0.83 and composite reliability 0.81.

Pakistan was chosen for data collection because in the previous years the country's leadership, namely Imran Khan, the former prime minister, has taken a number of initiatives to mitigate environmental problems. He also raised his voice in several international forums for a collective effort to combat climate change (Rahman et al., 2022). The population for this research was the general public in Pakistan, who were asked to provide their views on the role of leadership in relation to green initiatives and climate change, and how these initiatives impact the country's environment and economy. In April 2023, the respondents from major cities across different provinces of Pakistan, including Lahore, Karachi, Faisalabad, Islamabad, Multan, and Peshawar, were surveyed to collect data. This study has shown no bias in data collection because people from every walk of life are targeted for data collection. The respondents to this research were asked to fill out a hard copy of the questionnaire, and an introductory note regarding the purpose of the study was given on the questionnaire. Their consent was taken on the questionnaire, and it was ensured that the information would not be used for commercial purposes. A total of 5,044 questionnaires were distributed in two waves using time lag approach, and data was collected successfully on 4,299 questionnaires. After conducting initial screening, the final sample size of this research was based on 4,243 responses. This research has used the structural equation modelling to analyze the data since many recent relevant studies have utilized the same method (Khan et al., 2022).

3 Results and discussion

3.1 Results

The normality of data is checked at the initial stage of data analysis. This normality is tested to determine the skewness, kurtosis, and missing values. These findings help to determine the usability of data for further analysis. In this way, the skewness values must be less than +1 which is acceptable. Furthermore, the kurtosis values must be less than −1 which is also acceptable (Royston, 1992). Moreover, the missing values are tested, and the analysis revealed that there are no missing values in this data. Thus, the data collected for this study is considered normal for further data analysis tests (Tab. 1).

Furthermore, the factor loadings of the study's measurements are tested to determine whether the study's measurements are fit for data analysis or not. The data factor loadings for significance should be above 0.60 (Shevlin & Miles, 1998). Thus, this research has appropriate validity (Tab. 2).

In addition, the test for convergent validity is used to determine the reliability and validity of data. The Cronbach's alpha, composite reliability and average variance extracted are tested in this stage. The Cronbach alpha > 0.70 is acceptable (Tavakol & Dennick, 2011), the composite reliability > 0.70 (Alarcón et al.,

Tab. 1: Data normality

Items	No.	Missing	Mean	Median	Min	Max	Standard deviation	Excess kurtosis	Skewness
CC1	1	0	4.072	4	1	5	1.072	0.816	−1.169
CC2	2	0	3.578	4	1	5	1.149	−0.333	−0.572
CC3	3	0	3.960	4	1	5	1.055	−0.078	−0.791
CC4	4	0	3.957	4	1	5	1.022	0.173	−0.830
CC5	5	0	3.448	3	1	5	1.150	−0.464	−0.422
LS1	6	0	3.574	4	1	5	1.130	−0.466	−0.494
LS2	7	0	3.610	4	1	5	1.183	−0.473	−0.574
LS3	8	0	4.448	5	1	5	0.955	2.897	−1.852
LS4	9	0	4.231	5	1	5	1.046	1.132	−1.349
LS5	10	0	4.007	4	1	5	1.177	0.439	−1.135
LS6	11	0	4.083	4	1	5	1.157	0.634	−1.216
EN1	12	0	3.928	4	1	5	1.157	0.149	−0.970
EN2	13	0	4.072	4	1	5	1.122	0.684	−1.192
EN3	14	0	4.119	4	1	5	1.090	0.877	−1.248
EN4	15	0	3.787	4	1	5	1.261	−0.401	−0.787
EN5	16	0	3.668	4	1	5	1.183	−0.475	−0.610
EC1	17	0	3.986	4	1	5	1.048	0.334	−0.918
EC2	18	0	4.065	4	1	5	0.996	0.519	−0.990
EC3	19	0	4.025	4	1	5	1.035	0.629	−1.032
EC4	20	0	4.054	4	1	5	1.051	0.628	−1.083
EC5	21	0	3.978	4	1	5	1.108	0.296	−0.983
EC6	22	0	3.783	4	1	5	1.116	−0.125	−0.739

Note: CC – climate change; LS – leadership skills; EN – environment; EC – economy.

Source: own

Tab. 2: Factor loadings – Part 1

Items	Climate change	Economy	Environment	Leadership skills
CC1	0.681			
CC2	0.692			
CC3	0.833			
CC4	0.859			
CC5	0.755			
EC1		0.872		
EC2		0.851		

Tab. 2: Factor loadings – Part 2

Items	Climate change	Economy	Environment	Leadership skills
EC3		0.856		
EC4		0.905		
EC5		0.867		
EC6		0.839		
EN1			0.873	
EN2			0.872	
EN3			0.837	
EN4			0.859	
EN5			0.640	
LS1				0.609
LS2				0.693
LS3				0.663
LS4				0.845
LS5				0.843
LS6				0.823

Note: CC – climate change; LS – leadership skills; EN – environment; EC – economy.

Source: own

Tab. 3: Cronbach alpha, composite reliability, and average variance extracted

Constructs	Cronbach's alpha	Composite reliability	Average variance extracted
Climate change	0.823	0.877	0.589
Economy	0.933	0.947	0.749
Environment	0.876	0.911	0.674
Leadership skills	0.843	0.885	0.566

Source: own

2015), and the average variance extracted > 0.50 (Alarcón et al., 2015) is accepted. The findings available in Tab. 3 demonstrate that the study has achieved a reliability test, and the data used in this study is valid. Thus, the findings are appropriate, and data can be used for further tests.

The discriminant validity of this research data is tested with the heterotrait-monotrait method. This method is recommended when the model of the study is complex. The values in the matrix must be less than 0.90 for significant reliability and validity (Gold et al., 2001). Thus, the findings available in Tab. 4 demonstrated that the study has achieved discriminant validity.

Furthermore, the cross-loadings are also tested to determine the validity of the study data. This method is used to check whether the items used for different variables are the same or different. Barlat et al. (2013) recommended that the values of cross-loadings for the items representing one construct should

Tab. 4: Heterotrait-monotrait

	Climate change	Economy	Environment	Leadership skills
Climate change				
Economy	0.650			
Environment	0.811	0.766		
Leadership skills	0.867	0.644	0.694	

Source: own

Tab. 5: Cross-loadings

Items	Climate change	Economy	Environment	Leadership skills
CC1	0.681	0.298	0.478	0.511
CC2	0.692	0.388	0.455	0.449
CC3	0.833	0.475	0.579	0.594
CC4	0.859	0.495	0.616	0.630
CC5	0.755	0.531	0.495	0.548
EC1	0.447	0.872	0.578	0.452
EC2	0.500	0.851	0.616	0.527
EC3	0.482	0.856	0.564	0.473
EC4	0.527	0.905	0.590	0.505
EC5	0.527	0.867	0.569	0.523
EC6	0.512	0.839	0.572	0.519
EN1	0.619	0.566	0.873	0.745
EN2	0.576	0.543	0.872	0.728
EN3	0.517	0.427	0.837	0.707
EN4	0.601	0.561	0.859	0.687
EN5	0.512	0.633	0.640	0.475
LS1	0.608	0.433	0.452	0.609
LS2	0.615	0.566	0.543	0.693
LS3	0.417	0.229	0.496	0.663
LS4	0.505	0.416	0.711	0.845
LS5	0.509	0.447	0.709	0.843
LS6	0.496	0.481	0.738	0.823

Note: CC – climate change; LS – leadership skills; EN – environment; EC – economy.

Source: own

be greater than the items of other constructs that are in correlation with it. Thus, the data analyzed and reported in Tab. 5 disclosed that the study data has discriminant validity.

The data for this research is quantitative in nature, and *t*-statistics are used to determine the findings. The findings are tested with the structural equation modeling method. The *t*-values > 1.96 are acceptable for significant path (Hair et al., 2020). The study has checked the *t*-values for the first path, and it is determined that climate change has a significant and positive impact on the economy (β = 0.334, $t = 4.630$, and $p = 0.000$). Similarly, the study has checked the *t*-values for the second path, and it is determined that climate change has a significant and positive impact on the environment (β = 0.199, $t = 2.931$, and $p = 0.004$). The results are described in Fig. 2 and Tab. 6.

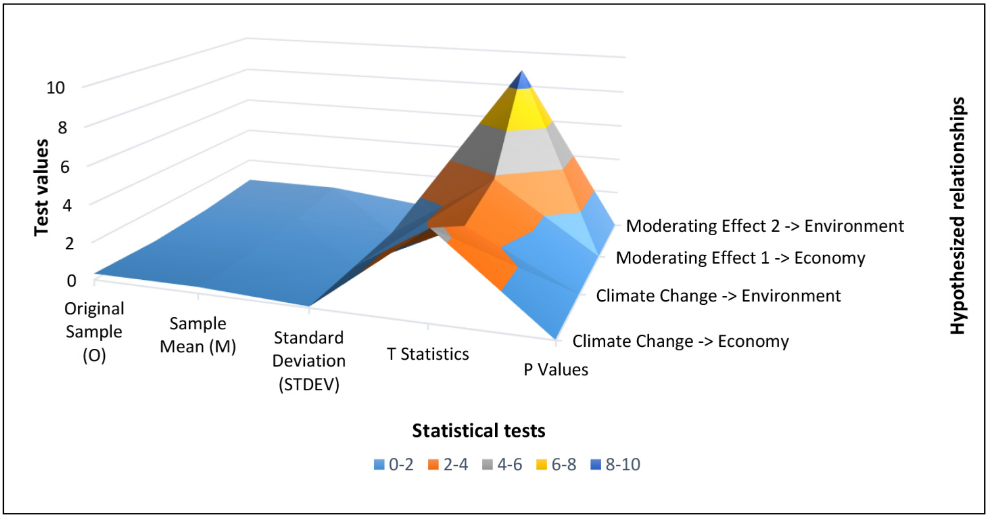

Fig. 2: Path findings

Source: own

Tab. 6: Path findings

Relationships	Original sample	Sample mean	Standard deviation	*T*-statistics	*p*-values
Climate change → economy	0.334	0.338	0.072	4.630	0.000
Climate change → environment	0.199	0.199	0.068	2.931	0.004
Moderating effect 1 → economy	0.336	0.335	0.088	3.835	0.000
Moderating effect 2 → environment	0.671	0.673	0.075	8.944	0.000

Source: own

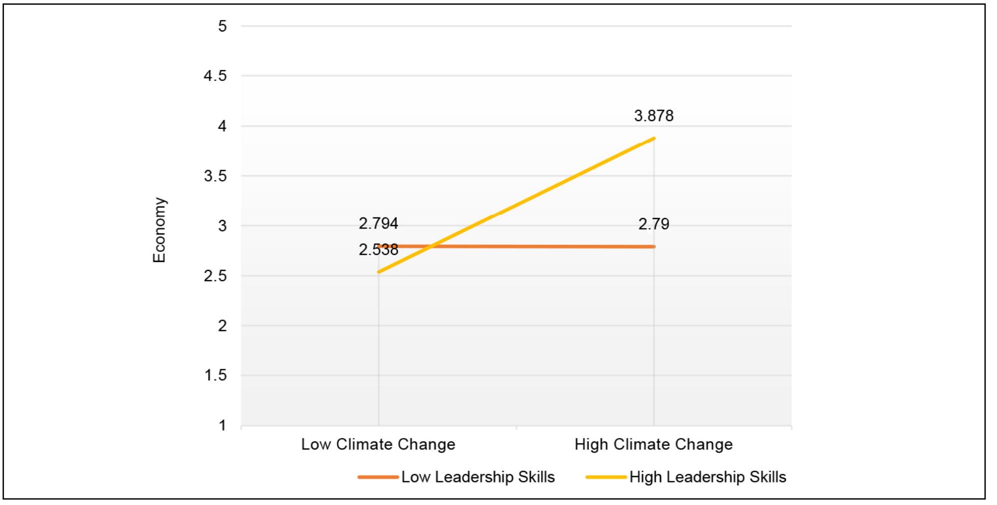

Fig. 3: Moderating effect of leadership skills between climate change and economy

Source: own

On the other hand, the *t*-values for the third path are checked, and it is determined that leadership skills have a significant and positive moderating impact between climate change and the economy (β = 0.336, *t* = 3.835, and *p* = 0.000). This moderation is strengthening the relationship between climate change and the economy (Fig. 3).

Finally, the *t*-values for the final path are checked, and it is determined that leadership

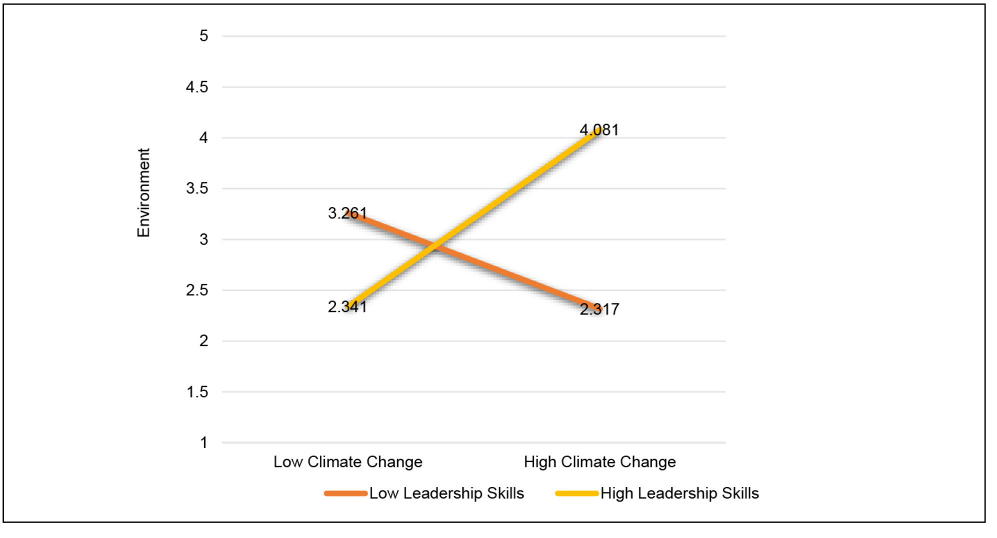

Fig. 4: Moderating effect of leadership skills between climate change and environment

Source: own

skills have a significant and positive moderating impact between climate change and the environment ($\beta = 0.671$, $t = 8.944$, and $p = 0.000$). This moderation is strengthening the relationship between climate change and the environment (Fig. 4).

3.2 Discussion

This research has used the findings of structural equation modeling to determine the paths. This model helps to find the *t*-values. The *t*-values above 1.96 are accepted for any relationship to become significant reported by Żuk and Szulecki (2020). In this way, hypothesis *H1* statistics show that there is a positive relationship between climate change and the economy. These findings are seen in light of the findings of existing studies. Balogun et al. (2020) reported that the more attention given to environmental issues, the more measures that everyone involved will take to alter it for the better. The essential solution to combating global warming can lead to a healthier environment and a sustainable future. Authorities must reduce the adverse effects of global warming while focusing on the growth of the economy. As a result of the unfavorable economic climate, global warming has a negative effect on the surroundings. Pettorelli et al. (2021) reported that poor environmental conditions can have a detrimental effect on a country's ability to support itself. To develop managerial skills properly, information availability is essential. Norouzi et al. (2020) reported that skills for leadership are needed to manage affairs and develop the economy as well as protect the environment. When the economic climate in a country is unstable, the resources available for economic expansion are useless. Nasir et al. (2019) reported that the ability to positively influence the environment may be made possible through access to the plans and efforts of the leadership. Leaders of industrialized countries are more focused on improving the economic situation. Leadership traits are seen to be suitable for economic growth.

Furthermore, hypothesis *H2* statistics show that there is a positive relationship between climate change and the environment. These findings are seen in light of the findings of existing studies. Sustainable leadership emerges as a promising model for effectively mitigating climate change impacts (Fragouli, 2020). Additionally, environmentally-specific transformational leadership and leader's pro-environmental behaviors significantly influence employees' environmental passion and behaviors (Robertson & Barling, 2013). Environmentally-specific leadership and workplace pro-environmental behaviors affect employees' environmental passion and pro-environmental behaviors. Furthermore, leadership with environmental concerns can advocate for climate and environmental protection. Our findings underscore the importance of leadership in fostering organizational environmental responsibility and adapting to climate change. Improved management and tactical preparation can help the authorities address the pressing issues that must be resolved to enhance the state of the natural environment (Felix et al., 2022; Zheng et al., 2019). The effects of rising temperatures are disrupting the financial structures of developed nations. The aspect that must be taken into account to boost financial position is warming temperatures (Rehman et al., 2021). Both developed and developing countries are considered to be critically affected by the warming climate. The complex connection between environmental degradation and climate change poses significant threats, which needs to be addressed. Since the policies for climate change and the environment do not apply to only one country, the world's leaders must cooperate (Prideaux et al., 2020).

Thirdly, the *t*-values identified for hypothesis *H3* revealed that there is a positive moderating role of leadership skills between climate change and the economy. This relationship is new in the literature and at the infancy stage, but the findings of this relationship are supported by the existing study results. Leadership plays a crucial role in addressing climate change and its economic implications. Additionally, leadership's in-the-moment oversight of the activities execution can offer a technique to effectively reduce carbon emissions and protect the environment (Khan et al., 2019). Many citizens are ready to back initiatives to address challenges connected to global warming. The consequences of climate change on the world economy are considerable as there is a direct link between rising temperatures and the economy. To prevent the effects of climate change from harming the economy and companies, developed countries are concentrating on concerns associated with warming temperatures (Streletskiy et al., 2019). To protect the environment, greenhouse gases in the atmosphere should be decreased over time. When acceptable measures are adopted, a sustainable environment is feasible. Regulations with a lasting impact may offer a better path forward for enhancing the natural environment and free it from unfavorable conditions (Nawaz et al., 2021). Focusing on reducing climate change can be a meaningful strategy for achieving sustainable development objectives. Slow environmental improvement and climate change mitigation measures may prove to be a less effective strategy for ensuring environmental sustainability (Sovacool, 2021). Natural hazards brought on by environmental disasters and other climate change-related catastrophes are intolerable for survival (Ehsanullah et al., 2021). Today's leaders are actively striving to enhance sustainability when they are genuine about advancing the fight against global warming.

Finally, the *t*-values identified for hypothesis *H4* revealed that there is a positive moderating role of leadership skills between climate change and the environment. This relationship is new in the literature and still at the infancy stage. However, some existing studies support the findings. The progress in the resolution of environmental problems depends on the sustainability of the climate. Leaders must address climate issues since they are responsible for policymaking (Markkanen & Anger-Kraavi, 2019). A step in the right direction for developing efforts to combat climate change is the support of the general public. Corporations may suffer due to the diminished attention given to world warming, and the interest of investors may also decline as a result (Dogru et al., 2019). The government's long-term policies, which are the main driver of environmental advancement, make it feasible for the environment to be sustained. A nation can increase its long-term viability by preserving its natural assets with the support of its residents' awareness of and commitment to better environmental conditions (Skovgaard & van Asselt, 2019). Therefore, improving and addressing climate change requires actions to maintain the ecosystem. In this respect, circular economy has strong potential to address environmental sustainability. However, it requires integration of environmental innovation, organizational learning, and stakeholder orientation. Leaders are needed to drive the adoption of circular economy principles in organizations. They can create sustainable value for customers, investors, and the environment in order for the successful implementation of circular economy. Thus, leadership abilities positively influence the transition towards sustainability practices. Managerial decisions and actions play a crucial role in the path to sustainable performance. From the standpoint of leadership attributes to advance human behavior for the sake of management and leadership, the role of everyone involved cannot be ignored (Dale et al., 2020; Todorovic et al., 2024).

Conclusions

Theoretical and practical implications. This research is theoretically important as the literature is extended by it. The study has introduced a newly developed relationship that had not been reported in existing studies. The relationship between climate change and the economy and environment as a whole has not been discussed in previous studies. Hence, this study has theoretical importance, as it has highlighted that climate change has a significant impact on the economy and environment. The direction of this relationship is positive, which has not been observed in existing studies. Therefore, the study has novel findings that are significant in the literature based on its critical outcomes.

Furthermore, this study also introduced two significant moderating relationships in the literature. First, the research suggested that leadership skills have a significant moderating impact on the relationship between climate change and the economy. The direction of this relationship is positive, and it is also statistically proven that the moderating impact of leadership skills is strengthening the relationship between climate change and the economy. Second, the research has shown that leadership skills have a significant moderating impact on the relationship between climate change and the environment. Furthermore, the direction of this relationship is positive, and it is also statistically proven that the moderating impact of leadership skills is strengthening the relationship between climate change and the environment.

Moreover, the research contributes to the concept of circular economy by enriching the literature with the findings displaying the complex relationship between climate change, environment, economy, and leadership. The circular economy is highly relevant for climate actions and environmental issues as circular economy strategies can reduce greenhouse gas emissions, mitigate climate change, improve waste management, use resources efficiency, implement renewable energy, and achieve sustainable development. Leaders engage with a wide range of stakeholders, including employees, customers, suppliers, and communities, to build consensus and drive collective action towards circularity. Leadership, by setting the vision for a circular future within organizations and across industries, should develop strategies and roadmaps to guide the transition, outlining specific goals, targets, and timeline.

In addition, this research has significant practical implications that can be used to improve the economy. Climate has a significant impact on the business activities that contribute to the economy. Therefore, the leadership in each country are required to adopt the sustainable development goals to promote environmental protection and economic growth. Leadership performance can be improved by access to policy information. Furthermore, successful policy implementation with a reliable leadership strategy is the way forward to augment environmental stewardship. Effective leadership can become a supportive team for improving the environment.

The findings contribute to the practice of circular economy showcasing the important relationship between climate change, environment and economy, as well as the role of leadership in mitigating climate change and protecting the environment. By fostering sustainable practices and collaborative approaches, leaders can encourage circularity. The transition to a circular economy may require different leadership approaches with transformational and pro-environmental styles. This, in turn, will lead to improved economic results. In particular, the circular economy can contribute to climate change mitigation by reducing greenhouse gas emissions through more efficient resource utilization, promoting the use of renewable and recyclable materials, and minimizing waste generation. The transition to a circular economy requires a fundamental shift in mindsets, policies, and business practices, presenting an opportunity for visionary leadership at all levels of society. Leaders who embrace the principles of the circular economy and spearhead its implementation can serve as role models, inspiring others to follow suit and accelerate the transition towards a more sustainable future.

Research limitations and future directions. This research has used quantitative data and structural equation modeling. Despite its contribution, the research has some limitations that can be addressed by future studies. This study has collected cross-sectional data; however, data obtained using a longitudinal design may be valuable in determining the moderating impact of leadership skills on climate change, the economy, and the environment. Therefore, future studies can be based on longitudinal data to compare with the results of this study. This research has used a structural equation model for path findings, and future studies should be based on regression analysis to determine the findings. Although this study is based on the quantitative method that is appropriate for the research model, it has discussed only limited variables. Thus, future research can identify new factors that may contribute to economic and climate challenges. Furthermore, the transition to a circular economy requires research from different contexts in terms of countries, cultures, and industries.

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Back to the future of fashion: Circularity and consumer ethics

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Abstract: *This paper examines the primary drivers behind the adoption of circular economy practices in the fashion industry, focusing on sustainable and ethical consumer behaviours in the digital era and future trends in young adults' engagement. Following an extensive literature review, primary data were used to develop a cross-sectional empirical model, analysed through multiple linear regression. The model focused on the four main variables identified by the academic literature as being linked to circular fashion, which focuses on consumers' information about prices, expected future trends in sustainable fashion, ethical consumption and technological developments. The results indicate strong support among young consumers for circularity in the fashion industry and highlight the potential for circularity in fashion to grow because sustainability is part of consumers' values. This research provides valuable insights into the complex interplay of economic, ethical and technological factors driving the fashion industry's shift towards circularity while highlighting the need for public policies that encourage corporate strategies aligned with ethical, responsible and technologically advanced consumption in the context of sustainable circular fashion.*

Keywords: *Sustainable fashion, circular fashion, ethical fashion consumption, consumer behaviour consumption, e-commerce.*

JEL Classification: *Q01, Q59, L67, M31, D12.*

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Introduction

The circular economy has received significant attention as an alternative to traditional linear production models, especially within the context of sustainable development. The European Parliament (2023) defines circularity as a model that prioritises recycling, reuse, and reduction, challenging traditional economic paradigms rooted in disposable consumerism. The global fashion industry, valued at USD 1.68 trillion, exemplifies both environmental and social challenges and accounts for approximately 10% of global carbon emissions (Oizom, 2024; Tab. A1). Research indicates that consumer behavior within this sector is shaped by an interplay of economic, ethical, and technological factors, particularly among younger generations. Recognizing these factors provides a more nuanced understanding of how young consumers perceive the circular economy in fashion, highlighting their attitudes toward sustainable and ethical consumption.

Tab. 1: **Research hypotheses for explaining factors influencing young consumers' assessment of the importance of the circular economy in the fashion industry**

Specific objective	Research hypotheses
To identify the relationship between concern for competitive pricing and the valuation of the circular economy in fashion	Hypothesis 1 (*H1*): Concern for competitive prices (X_1) is positively associated with the valuation of the circular economy in fashion (Y).
To evaluate the impact of projected trends toward sustainable fashion consumption among younger generation on perceptions of the circular economy	Hypothesis 2 (*H2*): The perception of a trend toward increased sustainable fashion consumption among younger generations (X_2) has a positive relationship with the importance assigned to the circular economy (Y).
To determine whether e-commerce and social commerce are perceived as drivers of sustainability in the fashion industry	Hypothesis 3 (*H3*): The belief that e-commerce and social commerce will enhance sustainability in fashion (X_3) is positively associated with the valuation of the circular economy (Y).
To explore the relationship between interest in ethical fashion and the valuation of the circular economy in the sector	Hypothesis 4 (*H4*): Interest in ethical fashion (X_4) is positively related to the valuation of the circular economy (Y).

Source: own

The main objective of this research is to evaluate the factors influencing young consumers' assessment of the importance of the circular economy in the fashion industry, among young people, with a focus on the impact of attitudes towards price, sustainable consumption, e-commerce and ethical fashion. The specific objectives, and their corresponding working hypotheses are shown in Tab. 1.

1 Theoretical background

In recent years, the circular economy has gained prominence in academic and social discourse. In the Scopus database, publications on the topic grew from 121 in 2010 to 8,036 by 2024, highlighting its relevance in various fields (Scopus, 2024; Tab. A1). Concepts of circularity permeate corporate strategies, policy initiatives, and civil society agendas, influencing consumer behavior and market trends (De Pascale et al., 2023; Ho et al., 2021). At its core, the circular economy emphasizes sustainability, focusing on reusing, recycling, and minimizing waste. According to the European Parliament, it encourages a shift from traditional linear models to a system that maximizes resource utility (European Parliament, 2023). Similarly, the Ellen MacArthur Foundation defines it as a framework addressing global issues like climate change through principles of waste elimination, material reuse, and ecosystem regeneration (Ellen MacArthur Foundation, 2024; Tab. A1).

Although often framed as a modern approach, the circular economy builds on longstanding concepts from ecological economics and industrial ecology, which emphasize cyclical resource flows to promote sustainability (Ghisellini et al., 2015; Pearce & Turner, 1989). It also incorporates general systems theory, highlighting interconnected systems that foster resource regeneration and environmental stability (Bertalanffy, 1968; Geisendorf & Pietrulla, 2018). However, some scholars argue that definitions of the circular economy remain overly broad, creating potential ambiguity in practical applications (Corvellec et al., 2022; Rödl et al., 2022). These critiques underscore the need for more precise conceptual frameworks (Kirchherr et al., 2023), as theoretical clarity is crucial for applying circular principles across various industries.

The circular economy model seeks to overcome the limitations of the traditional linear economy, which follows a take-use-dispose pattern and depends on consuming finite resources (Stahel, 2019). Rooted in neoclassical economics, this linear model views consumer preferences as fixed and endlessly insatiable (Ghisellini et al., 2015; Sen, 2002). It assumes natural and manufactured resources are interchangeable, often overlooking the finite nature of our planet's resources, making "strong sustainability" harder to achieve (Ornelas Martins, 2016). Additionally, by equating happiness with utility, the neoclassical view reduces well-being to material accumulation, overlooking deeper aspects of human fulfilment (Bruni, 2007; Pena-López & Membiela-Pollán, 2025). This "homo economicus" perspective promotes self-interest and economic gain, frequently at the expense of environmental and social health (Etzioni, 2010; Granovetter, 1985).

From a socioeconomics perspective, the shortcomings of the linear model are further intensified by their influence on lifestyle and societal values (Pérez Adán, 1997). The neoclassical paradigm leads to a "hedonic treadmill" of consumption, where material accumulation has minimal impact on subjective well-being, contributing to social and environmental degradation (Membiela-Pollán et al., 2019; Sacco et al., 2006). The pursuit of material wealth results in waste and devalues resources, ultimately undermining long-term well-being (Bartolini, 2007; Membiela-Pollán et al., 2019).

In contrast, the circular economy promotes a sustainable, regenerative approach that aligns with environmental, economic, and social goals (Ghisellini et al., 2015; Temesgen et al., 2021). This model emphasizes durable design and resource efficiency, extending product lifespans to keep materials in use and reduce resource extraction (Pearce & Turner, 1989; Webster, 2015). Circular practices have been shown to generate environmental, economic, and employment benefits, reducing waste, alleviating ecosystem stress, and lowering production costs (Schroeder et al., 2018; Schulze, 2016). The circular economy repositions waste as a resource, fostering economic opportunities in recycling, remanufacturing, and product innovation (Melece, 2016; Stahel, 2010). Such virtuous cycles are increasingly observed across various sectors as industries adopt strategies that minimize raw material use (De Pascale et al., 2023).

Nonetheless, challenges persist. Adopting circular models requires technological, regulatory, and cultural transformations, which involve coordination among government entities, corporations, and consumers (Corvellec et al., 2022). The shift from linear to circular models also demands substantial changes in supply chains, as well as investments in recycling infrastructure that may be economically unfeasible in the short term (Risteska & Gveroski, 2022). Certain circular processes can even be costlier than producing new materials, particularly when commodity prices are low. Moreover, circular practices can lead to unintended consequences, such as the "rebound effect," where improved efficiencies drive up overall consumption, diminishing environmental gains (Zink & Geyer, 2017). Circular processes also consume energy and generate waste, demonstrating that they are not entirely free of environmental costs (Korhonen et al., 2018). The regulatory framework supporting circularity remains complex and varies across regions, complicating large-scale adoption (De Römph & Cramer, 2020).

The circular economy's potential to replace unsustainable linear models hinges on overcoming these barriers. While the circular approach has clear advantages for sustainable development, achieving widespread implementation will require addressing regulatory inconsistencies, enhancing technological infrastructure, and fostering consumer and business alignment with circular values.

1.1 Circular economy and fashion industry

The emphasis on sustainability and the circular economy encompasses both industry operations (supply) and consumer behavior (demand) (De Pascale et al., 2023). One of the most visible sectors in this transition is the fashion industry, given its deep integration into daily life. This industry is composed by clothing, textiles, footwear, and fashion accessories, encompassing production, distribution, sales, promotion, and consumption (Kawamura, 2018).

Global data on this sector highlights its significance as a target for circular initiatives. The fashion industry, valued at USD 1.68 trillion annually (Euromonitor, 2024; Tab. A1), ranks as the third most polluting industry worldwide, contributing approximately 10% of total carbon emissions (Oizom, 2024; Tab. A1). Textile production alone is responsible for nearly 20% of industrial water pollution, largely due to dyeing and finishing processes, and generates 92 million tonnes of waste annually. Only about 1% of garments are recycled into new clothing (European Parliament, 2023; Ellen MacArthur Foundation, 2017 – Tab. A1).

In this context, circularity within the fashion industry operates through multiple interrelated strategies. Design-phase decisions, which account for up to 80% of a product's environmental impact, are crucial (Dan & Østergaard, 2021). These choices affect resource efficiency, material selection (favoring sustainable, recycled, recyclable, or compostable options), and product durability (Dissanayake & Weerasinghe, 2021). Circular practices extend through reuse, repair, refurbishment, remanufacturing, and ultimately recycling and waste transformation.

This model proposes a closed, "virtuous" circular system in contrast to the linear "take-make-dispose" approach, whereby resources are reused and kept within a production-use loop, generating value over a longer period (Urbinati et al., 2017).

However, the circular economy in fashion faces significant challenges on both the supply and demand sides. The fashion market has grown steadily, with production doubling since 2000 (Ellen MacArthur Foundation, 2017; Tab. A1), while contemporary lifestyles are heavily influenced by fast fashion's low-cost solutions (De Aguiar, 2021; Dissanayake & Weerasinghe, 2021). Fast fashion alone, valued at USD 68 billion in 2020, is projected to exceed USD 200 billion by 2030 (Research and Markets, 2020; Tab. A1). On the supply side, the fashion industry's long and complex supply chain (including raw material production, processing, manufacturing, distribution, and transportation) complicates the adoption of circular models and reverse logistics (Dissanayake & Weerasinghe, 2021). Furthermore, these processes require costly, specialized infrastructure and technology (Jacometti, 2019). Shifting to new business models on the supply side demands significant resources (financial, temporal, and intellectual), as well as a supportive institutional framework (Grafström & Aasma, 2021). Promoting a culture of sustainable consumption and durability over "buy-and-dispose" habits also requires awareness-raising initiatives (Papamichael et al., 2022).

Progress toward circularity and sustainability in fashion is nonetheless evident, impacting both producers and consumers. However, this shift is somewhat ambivalent, as it conflicts with the industry's rapid growth (Ritch et al., 2023). Today, brand marketing campaigns emphasize green, sustainable, ethical, and eco-conscious values through initiatives like slow fashion (Kusá & Unínová, 2020). Some brands, like Patagonia and Ecoalf, were founded on corporate sustainability principles. From a production standpoint, sustainability in fashion includes the use of sustainable, recycled, and recyclable materials; manufacturing processes that conserve water and energy; and the minimization of harmful chemicals. Brands, especially those positioned in medium-high and high markets, now promote durability as a key purchasing factor, exemplified by Levi's slogan, "Buy better, wear longer" (Levi Strauss & Co., 2021; Tab. A1). Additionally, reuse-focused initiatives are growing, such as Zara's pre-owned platform, where users can buy secondhand Zara items uploaded by other customers (Zara, 2024; Tab. A1). In recycling and remanufacturing, projects like H&M's Loop, a store-based recycling system that transforms old garments into new ones through a process of cleaning, shredding, and spinning textiles into new yarn, illustrate innovative circular practices (H&M, n.d.; Tab. A1). Brands also seek partnerships and certifications to validate their sustainable and circular commitments (Jastram & Schneider, 2015).

On the demand side, consumer behavior reflects this shift, with high percentages of consumers, differentiated by generation, indicating a preference for sustainably labeled products (Gazzola et al., 2020). Purchase decisions are influenced by eco-labeling and certifications across the supply chain (De Aguiar et al., 2021). However, consumer choices are also affected by the price of sustainable products and concerns over greenwashing (Kusá & Unínová, 2020). In terms of reuse, collaborative consumption (Ghisellini et al., 2016) and the secondhand fashion market have grown significantly, with the market value rising from USD 141 billion in 2021 to USD 230 billion in 2024 (Statista, 2023; Tab. A1). Recently, there has been a growing interest in "slow fashion," which emphasizes buying fewer items while prioritizing sustainability, quality, and durability (Domingos et al., 2022).

1.2 Consumer behaviour towards the circular economy. The case of young adults

The prevailing approach in economic science, embodied by the neoclassical paradigm, demonstrates its limitations by oversimplifying human nature, thus excluding elements that are valuable for descriptive, predictive, and evaluative economics (Sen, 1997). This reductionism not only constrains economic analysis but also impedes the generation of subjective well-being and the promotion of harmonious socio-economic and environmental growth (Membiela-Pollán et al., 2019).

Within this context, the circular economy emerges as a viable alternative to the linear, neoclassical “take-use-dispose” model, offering a framework that fosters positive externalities beneficial to both the environment and society.

The limitations of the traditional approach are particularly evident in analyses of consumer behavior, as it excludes numerous intrinsic motivations that influence individual preferences and decision-making. In the neoclassical utility function, consumer utility is derived solely from the goods and services consumed, represented in Equation (1) as follows:

$$U = f(x_1, x_2, \dots \dots \dots, x_n) \quad (1)$$

And subject to budgetary constraint, in Equation (2):

$$\sum_{i=1}^{n} p_i, x_i = Y \quad (2)$$

However, borrowing from the paradigm of socioeconomics, the utility function posited by Amitai Etzioni (2010), a more realistic view would be as appears in Equation (3):

$$U = f(x,y) \quad (3)$$

In this context, individuals are motivated by a combination of instrumental (self-serving, rational, and profit-maximizing) (*x*) and expressive (moral, altruistic, and oriented toward social welfare) (*y*) motivations, meaning they are driven both by “pleasure,” as understood in neoclassical terms, and by “moral commitments” (Etzioni, 2010).

Thus, the socio-economic utility function is represented as follows:

$$U = \alpha \cdot Ux + \beta \cdot Uy \quad (4)$$

where: *Ux* – utility derived from individual material benefits; *Uy* – the utility derived from fulfilling ethical and social values; α and β – parameters that reflect the importance the individual assigns to instrumental versus expressive benefits. These parameters vary according to personal context and the social environment.

Returning to sustainability and the circular economy, a parallel function to Etzioni’s proposal (one that integrates preferences for sustainability and circularity) can be formulated as follows in Equation (5):

$$U = \alpha \cdot f(x_1, x_2, \dots, x_n) + \beta \cdot S \quad (5)$$

where: α and β – parameters that capture the relative importance that the consumer assigns to traditional consumption satisfaction and sustainability, respectively.

If β is high, the consumer gives significant weight to sustainability, and utility is maximised when the good consumed meets sustainable criteria. If β is low or zero, the consumer acts under a traditional utility function, prioritising price and quantity over sustainability.

The utility function is directly linked to consumer behavior, as individuals aim to maximize their welfare or satisfaction through a series of choices in the consumption of goods and services (Coto-Millán, 1999). However, the traditional utility function within mainstream economics is both simplistic and reductionist, assuming that individuals act solely to maximize their satisfaction, constrained by a fixed budget. Within this framework, individuals are portrayed as perfectly rational, consistently selecting the alternative that optimizes their utility. Additionally, their preferences are assumed to remain constant over time, unaffected by social influences.

A more realistic model of consumer behavior, however, must incorporate motivational and psychosocial factors. Individuals are influenced by a range of internal variables (such as personal characteristics, values, interests, attitudes, perception, knowledge, and learning) and external variables (including culture, social norms, social class, income, social groups, and information), all of which are interrelated (Kotler & Armstrong, 2023).

In this holistic view, the consumer behavior function can be expressed as Equation (6):

$$C = f(In, Ex) \quad (6)$$

As consumers, individuals are influenced by internal psychological variables (*In*) and external social factors (*Ex*). A review of the literature on consumer behavior concerning sustainability and the circular economy identifies several pertinent variables that shape this role. Prominent among these are personal values and attitudes (Lundblad & Davies, 2015), subjective beliefs, ethical concerns, and the impact of social norms and influences (Saricam & Okur, 2018). Additional factors include knowledge, information accessibility, and availability of sustainable products (Okur & Saricam, 2018). Demographic elements such as age and generational differences (Musova et al., 2021), cultural diversity (Khan et al., 2024), and economic considerations like pricing and transparency (Ronda, 2024) are also crucial to understanding consumer behavior within this context.

1.3 Four significant variables in sustainable consumption behaviour of young adults

This paper examines four main variables of significant influence on young adults' consumer behaviour concerning sustainability and circularity: digital technology, socio-cultural and market trends, ethical considerations, and price consciousness. These variables were selected based on their theoretical relevance, topicality within the study's context, capacity to consolidate the explanatory power of related factors, and alignment with established consumer behaviour theories and models, such as Ajzen's (1991) theory of planned behaviour. Together, they encompass both internal and external influences, providing a comprehensive, multidimensional approach.

Digital technology (internet, e-commerce, s-commerce)

Technology functions as a key driver and enabler of sustainable and circular practices among both producers and consumers. Focusing on the demand side, the Internet plays a crucial role as a vast source of information and knowledge, particularly regarding sustainable products, transparency, and related movements (Charnley et al., 2022). Additionally, it supports platforms for the resale and redistribution of goods and services, aligning with the principles of the collaborative economy.

Globally, young people spend an average of more than six hours daily online, whether through mobile devices or other technologies (DataReportal, 2024; Tab. A1). From a consumer behavior perspective, individuals actively engage with information, seek out comparative product details, receive recommendations, complete transactions, and participate in post-purchase activities. E-commerce, social commerce (i.e., buying and selling via social networks), and peer-to-peer collaborative platforms (e.g., Depop, Vinted, Vestiaire Collective, Grailed) have significantly facilitated the exchange of used, repaired, or refurbished goods. These platforms reduce geographical and economic barriers, thereby enhancing accessibility and convenience (Ek Styvén & Mariani, 2022). Furthermore, these digital innovations are instrumental in fostering a mindset oriented toward reuse, repair, and recycling; central pillars of the circular economy (Hansmann & Binder, 2023).

The secondhand market for clothing and accessories has experienced exponential growth in recent years, with projections suggesting it will reach USD 350 billion globally by 2028 (Statista, 2023; Tab. A1). In the United States, for example, two out of three consumers who purchased secondhand clothing and accessories in 2023 made at least one online purchase, a trend more pronounced among younger adults (Gen Z and Millennials). For these demographics, 65% favor digital platforms over physical stores, which continue to grow at an annual rate of 17% (ThredUp, 2024; Tab. A1).

Socio-cultural and market trends

Individuals are not isolated entities; rather, both individuals and organizations are influenced by their micro-environment and the broader macro-environment (Kotler & Armstrong, 2023). Individuals are shaped by prevailing cultural and social norms and are influenced by primary and secondary groups, whether these are belonging, reference, or aspirational groups. Added to these are the messages from endorsers and influencers (Schäfer, 2021).

In recent years, sustainability-related trends have become deeply embedded, affecting cultural values that emphasize intergenerational responsibility, the notion that resources should be preserved for future generations (Peattie & Collins, 2009). These trends not only influence but also apply considerable pressure on consumers and businesses alike. From a sociological perspective, the rising significance of sustainability can be explained by normative conformity theory (Cialdini & Goldstein, 2004), which posits that individuals tend to act in accordance with social norms to gain social acceptance and recognition. Likewise, the theory of planned behavior highlights the role of subjective norms in shaping individual actions, understood as the perceived social pressure to perform or avoid a behavior (Ajzen, 1991). Within this context, sustainability serves as a form of social identity, enabling consumers to define and project themselves as responsible, environmentally conscious individuals.

In the fashion industry, the impact of the sustainability and circularity trend is especially pronounced. Fashion is deeply integrated into individuals' lives, with clothing serving as a medium of personal identity, self-expression, and social representation (Davis, 1994). Furthermore, it is heavily influenced by media and fulfills a fundamental individual need. Trends in this sector have the potential to significantly shape consumption patterns, particularly among Millennials and Generation Z. These cohorts, which engage in high volumes of fashion purchases, are also anthropologically more aligned with sustainable values. Both generations express a strong willingness to invest more in sustainable and circular practices; indeed, four out of five young consumers report interest in sustainable products and secondhand goods (PwC, 2024; Tab. A1).

Ethics

According to Encyclopaedia Britannica, ethics is defined as the "discipline concerned with what is morally good and bad and morally right and wrong" (Encyclopaedia Britannica, 2024; Tab. A1). Complementarily, the Real Academia Española de la Lengua (RAE) defines ethics as the "set of moral rules that govern a person's conduct in any sphere of life" (Real Academia Española, n.d.; Tab. A1).

It is essential to distinguish ethics from social and cultural norms, which often drive trends such as sustainability. Although interrelated, ethics is primarily internal and endogenous to the individual, whereas social norms are external and shaped by cultural context. According to Schwartz (2012), ethics influences behavior by establishing a normative framework that guides individual decisions and actions.

Such decisions impact the environment and generate externalities, both positive and negative (Smith, 1997). While individuals may be variably aware of these externalities, the concept of "warm glow" from altruism theory describes the positive feelings or emotional satisfaction that individuals experience when engaging in acts of kindness, altruism, or ethical behavior (Andreoni, 1990). This sense of satisfaction can be a powerful motivator for ethical actions.

Today, commitment to sustainability, authenticity, transparency, and social justice has become integral to the context of supply chains, particularly among younger generations who are drawn to movements like ethical and green fashion (Gazzolla et al., 2020). Generations X and Millennials, in particular, seek brands that not only offer aesthetically pleasing products but also embody genuine commitments to sustainable, ethical, and circular practices (Thredup, 2024; Tab. A1).

Ethics thus emerges as a crucial variable in analyzing consumer motivations, perceptions, and attitudes (internal variables) toward consumption in the fashion industry. Illustratively, a search on Google Scholar reveals 24 documents linking "consumer ethics" and "fashion" in 2000, increasing to 792 by 2023.

Price-consciousness

Price is a widely discussed factor in the literature on consumer behavior and sustainability. Individuals often face budgetary constraints that influence their decisions as they seek to maximize utility. Sustainable products, often perceived as costly, may therefore experience limited demand (De Aguiar et al., 2021).

However, consumers value not only price but also product attributes. From a socio-economic perspective, the dual utility paradigm formulated by Etzioni (2010) posits that consumer satisfaction derives from both pleasure and moral commitments. This framework helps explain the growth of the secondhand market within the fashion sector, where consumers maximize utility by purchasing items at lower prices that they perceive as sustainable choices, contributing to social and environmental well-being (El Observatorio Cetelem, 2024; Tab. A1). Additionally, a significant proportion of young adults report a willingness to pay more for fashion products deemed sustainable (Musova et al., 2021).

Within the price-sustainability choice dynamic, research suggests that consumers who spend more time comparing products and prices tend to exhibit greater concern for the sustainability and ethical impact of their choices. A correlation thus emerges between prudent financial resource allocation and green consumption values (Haws et al., 2014). This relationship may be attributed to these consumers' exposure to information regarding sustainable production practices, material sourcing, and the environmental impact of their purchases.

These consumers carefully assess not only the price but also the product's overall perceived value, which includes its social and environmental implications (Sheth et al., 2011). Furthermore, studies indicate that this price-conscious and ethically oriented consumer segment actively shapes the market, driving companies to adopt sustainable practices and enhance transparency in their supply chains (White et al., 2019). By exerting their influence, these consumers stimulate demand for ethical products and incentivize companies to provide sustainable options at competitive prices.

2 Research methodology

This paper's empirical analysis is based on a cross-sectional analysis using multiple linear regression to investigate young consumers' perceptions of the circular economy in the fashion industry, with data from 107 responses on a 5-point Likert scale survey (Sedgwick, 2014). The model captures relationships between circular economy valuation and core sustainable consumption factors, including price sensitivity, ethical concerns, and the influence of digital commerce. Assumptions about linear relationships between variables and the continuous approximation of the Likert scale allow us to interpret shifts in attitudes towards the circular economy (Harrell, 2015; Norman, 2010).

The questionnaire's validity was rigorously established through a panel of eight experts, comprising four professionals from the fashion sector and four with expertise in research methodology. Each expert reviewed all items for clarity, relevance, and suitability. Based on their feedback, ambiguous statements were removed, and some items were revised to enhance accuracy and alignment with the study objectives. The finalized questionnaire included five key items assessing opinions on price importance, sustainable consumption trends, e-commerce influence, and ethical dimensions, with respondents indicating agreement on a 5-point scale from total agreement to total disagreement. Sociodemographic data were also incorporated for context.

Multiple linear regression in this context has two main advantages. First, it identifies the significant impact of each variable, such as price consciousness or ethical interest, tested through the p-values of each coefficient. Second, it enables a nuanced analysis of combined variables, allowing for the examination of individual impacts within a controlled model. This is particularly valuable for studies of perception and behavior, as it provides insights into how factors like pricing, ethics, and digital access collectively influence attitudes towards sustainability, supporting a clearer understanding of circularity promotion within the fashion industry.

The first refined version of the questionnaire was subjected to a pilot test, where the questionnaire was administered to a group of 10 people between 15 and 65 years old, as representatives of the target public, and the Cronbach's alpha (coefficient that measures the internal consistency of the items on the Likert scale) was calculated among the responses obtained, reaching a value of 0.752 for 5 items (including the independent variable) and 0.714 for the 4 items of the explanatory variables, for this pilot test. In general, for a preliminary analysis of the reliability of the questionnaire with the Cronbach's alpha coefficient, it is considered that a Cronbach's alpha value greater than 0.7 usually indicates good internal consistency (George & Mallery, 2019). For the statistical and econometric calculations, the IBM SPSS-26 statistical package was used.

According to the theoretical background, the proposed model to examine whether attitudes towards sustainable consumption, interest in ethical fashion, and perceptions of e-commerce have a significant effect on the valuation of the circular economy in fashion, as shown in Equation (7):

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \epsilon \quad (7)$$

where: Y – importance of circular economy ("I think that circular economy is very important for fashion industry"); X_1 – relative price ("I check the price of the competitors before buying a product"); X_2 – future trends on sustainable consumption ("The trend of the sustainable fashion consumption increase in the future for the youngers"); X_3 – e-commerce and s-commerce influence ("The e-commerce and s-commerce will make fashion industry more sustainable"); X_1 – ethical consumption ("I express my interest in ethical fashion"); β_0 – model intercept, representing the score when all independent variables are zero; β_1, β_2, β_3, β_4 – regression coefficients for each independent variable, interpreting the expected change in Y for a unitary change in each X_i keeping the other variables constant; ε – error term, which captures the variability in Y not explained by the X_i variables.

The variables used in this model have conceptual linkages that may lead to multicollinearity, which could, in turn, impact the accuracy of coefficient estimates and hinder precise interpretation of the model. Therefore, multicollinearity was thoroughly evaluated to mitigate any potential influence on result interpretation. Two primary indicators were used for this assessment: the variance inflation factor (VIF) and the variance proportions derived from the collinearity diagnostics. The VIF quantifies the degree to which the variance of a regression coefficient is "inflated" due to collinearity with other independent variables. Conventionally,

Tab. 2: Coefficients for multicollinearity analysis

Variable	Unstandardized coefficient (B)	Standard error	VIF
X_1 – I check the price of the competitors before buying a product	0.289	0.074	1.119
X_2 – The trend of the sustainable fashion consumption increase in the future for the youngers	0.256	0.097	1.256
X_3 – The e-commerce and s-commerce will make fashion industry more sustainable	0.206	0.080	1.148
X_4 – I express my interest in ethical fashion	0.174	0.078	1.213

Note: Dependent variable: I think that circular economy is very important for fashion industry.

Source: own

Tab. 3: Coefficients for multicollinearity analysis

Dimension	Eigenvalue	Condition index	Variance proportion of constant	Variance proportion of independent variables
1	4.832	1.000	0.000	All < 0.30
2	0.058	9.092	0.000	X_1 11% X_2 1% X_3 24% X_4 72%
3	0.052	9.631	0.00	X_1 72% X_2 56% X_3 0% X_4 1%
4	0.036	11.557	10%	X_1 23% X_2 50% X_3 16% X_4 26%
5	0.021	15.009	90%	X_1 9% X_2 49% X_3 3% X_4 0%

Source: own

a VIF exceeding 5 indicates moderate multicollinearity, while values above 10 suggest significant multicollinearity (Montgomery et al., 2021).

The results, presented in Tab. 2, show that all VIF values range between 1.119 and 1.256, remaining well below the critical threshold of 5. This finding indicates minimal multicollinearity, with no substantial correlations among the variables that might compromise the stability of the coefficient estimates.

The condition index and variance proportions provide further insights into the model's stability and potential collinearity issues. A condition index above 15 indicates potential collinearity, while values above 30 suggest a severe problem (Belsley et al., 1980).

As Tab. 3 shows, the highest condition index is 15.009 (moderate multicollinearity in the last dimension). However, none of the individual variance proportions exceed the 50% threshold across multiple dimensions, so the independent variables seem not to be highly correlated to the extent that it compromises the model. The distribution of variance across dimensions confirms that the model structure is suitable for multiple regression analysis (Kutner et al., 2005). Since VIF values are low and the maximum condition index is below 30, multicollinearity should not significantly impact the accuracy of coefficients or the model's stability. This finding allows a reliable interpretation of each independent variable's effects on the valuation of the circular economy without inflated standard errors or distorted coefficient estimates. In view of these results, the VIF and collinearity component diagnostics indicate that multicollinearity in the proposed model is minimal and does not compromise the validity of the analysis. Therefore, the multiple regression model can be reliably used to interpret the relationships between ethical and sustainable behavior variables and the valuation of the circular economy in fashion, with stable and credible coefficient estimates.

3 Results and discussion

3.1 Results

The R^2 score is 0.404, indicating that 40.4% of the variability in Y is explained by the X_i independent variables. Then, a moderate relationship between the independent and dependent variables is shown, which is acceptable in social studies (Cohen, 1988).

Regarding to the analysis of variance shows that the model is statistically significant, with $F(4,102) = 17.267$ and $p < 0.001$. This indicates that at least one of the independent variables has a significant effect on Y. A high F value and a low p-value indicate that the model, as a whole, is adequate to explain the variability in the dependent variable (Y), which is essential in studies investigating the relationship

Tab. 4: Results for the test of research hypotheses

Research hypotheses	Regression coefficients	Result
Hypothesis 1 (*H1*): Concern for competitive prices (X_1) is positively associated with the valuation of the circular economy in fashion (Y).	B = 0.289 $\beta_1 = 0.315$ $t = 3.890$ $p < 0.001$	Accepted
Hypothesis 2 (*H2*): The perception of a trend toward increased sustainable fashion consumption among younger generations (X_2) has a positive relationship with the importance assigned to the circular economy (Y).	B = 0.256 $\beta_2 = 0.226$ $t = 2.643$ $p < 0.010$	Accepted
Hypothesis 3 (*H3*): The belief that e-commerce and social commerce will enhance sustainability in fashion (X_3) is positively associated with the valuation of the circular economy (Y).	B = 0.289 $\beta_3 = 0.211$ $t = 2.571$ $p < 0.012$	Accepted
Hypothesis 4 (*H4*): Interest in ethical fashion (X_4) is positively related to the valuation of the circular economy (Y).	B = 0.174 $\beta_4 = 0.188$ $t = 2.237$ $p < 0.027$	Accepted

Source: own

between multiple predictors and a continuous response (Kutner et al., 2005).

The regression model coefficients are shown in Tab. 4 by schematic summary of the results and its relationship with the hypotheses. The model results are also shown in Equation (8). Results for intercept are $\beta_0 = 0.469$ ($p = 0.269$).

$$Y = 0.315X_1 + 0.226X_2 + 0.211X_3 + + 0.188X_4 + \epsilon \quad (8)$$

The acceptance of the four research hypotheses means that consumers who tend to check competitive prices assign greater importance to the circular economy in fashion (*H1*), that an expectation of increased sustainable consumption correlates with a positive view of the circular economy (*H2*), that consumers perceive digital commerce as a relevant factor in sustainability and, therefore, in the circular economy (*H3*), and that a stronger interest in ethical fashion aligns with a higher valuation of the circular economy.

3.2 Discussion

The analysis of the results suggests that all independent variables positively relate to the importance young people attach to the circular economy in fashion. The model highlights the role of economic and ethical factors in the perception of sustainability, which is consistent with previous studies on sustainable consumer behavior (Gupta & Ogden, 2009; Haws et al., 2014).

The findings emphasize that promoting circularity in fashion among young consumers requires multifaceted strategies that address economic accessibility, leverage digital channels, and foster ethical engagement. By aligning sustainable practices with these diverse motivations, brands and policymakers can effectively support the integration of circular economy models within the fashion industry (De Pascale et al., 2023).

The analysis of results underscores that each independent variable (price sensitivity, trends in sustainable consumption, e-commerce and social commerce, and interest in ethical fashion) has a significant positive relationship with the importance young consumers place on the circular economy in the fashion sector. This finding reinforces the notion that young consumers adopt a holistic approach to sustainability, balancing economic, ethical, and technological considerations. This holistic perspective aligns with findings by White et al. (2019), who proposed the SHIFT framework to explain how sustainability can become part of consumer routines when practical, moral, and identity-based appeals are combined.

In particular, the positive association with price sensitivity indicates that young consumers view responsible consumption and affordability as integral to supporting circular economy practices. However, unlike the traditional model, young consumers' preferences demonstrate an awareness of sustainability, indicating an evolution toward "ethical rationality" (Etzioni, 2010) that combines self-interest with collective environmental responsibility (Sheth et al., 2011).

The significance of trends in sustainable consumption highlights a forward-looking orientation among young people, who perceive the growing momentum of sustainability as a norm rather than an exception. This indicates a generational shift in values, suggesting that younger consumers may be catalysts for embedding circular practices in mainstream markets, driven by a collective vision of sustainability (PwC, 2024; Tab. A1).

The strong relationship between e-commerce and the circular economy demonstrates how digital platforms facilitate sustainable practices, lowering barriers to access through the resale and redistribution of goods. This finding is aligned with the current technological landscape, where online and peer-to-peer platforms are central to the adoption of circular practices (Charnley et al., 2022). The results imply that digital accessibility reinforces young consumers' engagement with circularity, making sustainable options more visible, convenient, and socially acceptable.

Finally, the positive relationship with interest in ethical fashion underscores a value-driven component in young consumers' attitudes, where ethical concerns and environmental consciousness are key factors influencing their support for circular models. This suggests a departure from purely hedonic consumption patterns toward a value-laden form of consumerism, where sustainable and ethical attributes are seen as essential product characteristics (Lundblad & Davies, 2016).

Although the sample size is limited, and linked to a specifc place in the North West of Spain, it contains responses of people of different nationalities, so this work provides valuable insights by exploring the emerging topic of circular economy practices in the fashion industry, focusing on young consumers (a key demographic for the adoption of sustainable behaviour). The depth of the analysis and the robustness of the empirical model enable the identification of relevant trends and relationships, which can serve as a foundation for future research with larger samples. Furthermore, this work contributes essential initial knowledge in a field where primary data collection is often challenging, thus strengthening its significance within the existing literature.

Additionally, it should be noted that the scalability of circular models in the fashion industry is highly dependent on the socio-economic context in which they are implemented. In developed regions, factors such as advanced infrastructure, technological capabilities, and supportive regulatory frameworks facilitate the adoption of circular practices (Papamichael et al., 2023). However, in emerging markets, barriers such as limited financial resources, inadequate technology, and lower consumer awareness often hinder scalability (Risteska & Gveroski, 2022). Policy frameworks should consider these contextual differences by providing targeted incentives, such as financial subsidies, tax reductions, and capacity-building initiatives, to promote both company and consumer engagement with circularity. Such tailored strategies can significantly improve the feasibility and expansion of circular models across diverse regions.

Conclusions

This work directly relates the circular economy in the fashion sector with consumer behaviour, placing responsible individual consumption at the centre of the analysis, in which the comparison of prices between different options is a good indicator of consumers' concern for understanding the intrinsic qualities of what they buy and how ethics in consumption drives the commitment to circular fashion. In addition, technological advances and their various applications in the fashion sector have highlighted the growing commitment to the circular economy. Thus, digital platforms and social commerce have shown themselves to be emerging and increasingly influential factors in promoting circularity, and secondhand or reconditioned products are an example of the commitment to circular behaviours.

Fashion companies seeking to adopt the circular economy should focus on strategies that optimise the use of resources and manage waste throughout the product life cycle. This includes sustainable design with recyclable or biodegradable materials, and the implementation of business models such as resale, rental and return programmes. Investment in technology for recycling and traceability in the supply chain is crucial to meet sustainable standards and improve brand reputation. Eco-certifications reinforce consumer confidence, especially among young people, whose behaviour in the digital age drives the adoption of circular practices.

Large companies, with greater investment capacity, can develop their own infrastructures and adopt extended producer responsibility (EPR) programmes. On the other hand, SMEs must resort to strategic collaborations in circular economy networks and focus on niche markets with high added value, such as ethical or personalised fashion, to differentiate themselves.

Factors such as price awareness, perception of sustainable trends, ethical consumption practices and technological advances particularly influence the decisions of younger consumers who are more likely to support circular economy initiatives in the fashion sector. This reinforces the need for business strategies and policies aligned with sustainable values. For this reason, among others, companies in the fashion sector seeking to adopt the circular economy must focus on strategies that optimise the use of resources and manage waste throughout the product life cycle, for example, through sustainable design with recyclable or biodegradable materials, and the implementation of business models such as resale, rental and return programmes. On the other hand, investment in technology for recycling and traceability in the supply chain could be an interesting avenue to explore, in order to comply with sustainable standards and improve brand reputation, as ecological certifications reinforce consumer confidence, especially among young people, whose behaviour in the digital age is the main driver for the adoption of circular practices.

In this sense, regulatory measures, such as mandatory recycled content quotas and extended producer responsibility (EPR) schemes, can drive companies to integrate circularity into their operations. Financial incentives, including tax reductions on sustainable products and subsidies for innovation in recycling technology, can alleviate the costs associated with transitioning to circular practices. Additionally, public awareness campaigns and consumer education programs can enhance demand for circular fashion, particularly among young consumers. Implementing certification and eco-labelling standards can also incentivize businesses to maintain transparency and sustainability, fostering greater trust and engagement from consumers. These combined measures strengthen both the supply and demand sides, accelerating the shift towards a circular economy in the fashion sector.

Policy makers can therefore use technology to promote circularity in fashion, with digital platforms and social commerce as essential enablers of circular economy practices, in particular with secondhand and ethically sourced products, thus providing a practical way for young consumers to engage with sustainable fashion, effectively bridging the gap between sustainable aspirations and achievable behaviours, so that emerging behaviours at the individual level are extended to broad societal groups and become mainstream. Through individual behaviours, a shift towards collective responsibility can be achieved and circular patterns are fostered, which can thus become mainstream in the fashion industry. The sustainability goals outlined by national and supranational bodies are in line with individual desires, and this commitment is expected to be reinforced for younger generations in the future.

The role of digital platforms as amplifiers of sustainable choices in fashion consumption is another area that requires the attention of public managers, due to its implications for aligning consumer behaviour with sustainable development goals.

The results obtained with this work open the door to further research on informed responsible consumption choices and underlying ethical values, which function as drivers of the circular economy in the context of the information society.

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Appendix

Tab. A1: Referenced institutions

Institution	Information
DataReportal. (2024)	Digital 2024: Global overview report. https://datareportal.com/reports/digital-2024-global-overview
El Observatorio Cetelem. (2024)	Sostenibilidad y consumo 2024 [Sustainability and consumption 2024]. BNP Paribas Personal Finance. https://elobservatoriocetelem.es/sostenibilidad/sostenibilidad-y-consumo-2024/
Ellen MacArthur Foundation. (2017)	A new textiles economy: Redesigning fashion's future. Ellen MacArthur Foundation. https://ellenmacarthurfoundation.org/a-new-textiles-economy
Ellen MacArthur Foundation. (2024)	The circular economy in detail. https://www.ellenmacarthurfoundation.org/the-circular-economy-in-detail-deep-dive
Encyclopaedia Britannica. (2024)	https://www.britannica.com
Euromonitor. (2024)	https://www.euromonitor.com/fashion-industry-half-year-update-2024/report
H&M. (n.d.)	Let's close the loop: Repair & recycle. https://www2.hm.com/en_us/sustainability-at-hm/our-work/close-the-loop.html
Levi Strauss & Co. (2021)	Levi's® launches "Buy better, wear longer" campaign. https://www.levistrauss.com/2021/04/22/levis-launches-buy-better-wear-longer-campaign/
Oizom. (2024)	Top 10 most polluting industries in the world. https://oizom.com/most-polluting-industries/
PwC. (2024)	Voice of the consumer survey 2024. https://www.pwc.com/gx/en/issues/c-suite-insights/voice-of-the-consumer-survey.html
Real Academia Española. (n.d.)	Ético [Ethical]. Diccionario de la lengua española [Dictionary of the Spanish language]. https://dle.rae.es/ético
Research and Markets. (2020)	Global ethical fashion market report 2020: Opportunities, strategies, COVID-19 impacts, growth and change 2019–2030. https://www.businesswire.com/news/home/20210111005582/en/
Scopus. (2024)	Database search. https://www.scopus.com/term/analyzer.uri?sort=plf-f&src=s&sid=e8a8283239581138a78c3152ef789ea2&sot=a&sdt=a&sl=71&s=TITLE-ABS-KEY%28%22circular+economy%22%29+AND+PUBYEAR+%3e+2009+AND+PUBYEAR+%3c+2026&origin=resultslist&count=10&analyzeResults=Analyze+results
Statista. (2023)	Value of the secondhand appaerel market worldwide from 2021 to 2029. https://www.statista.com/statistics/826162/apparel-resale-market-value-worldwide/
ThredUp. (2024)	2024 resale report. https://cf-assets-tup.thredup.com/resale_report/2024/ThredUp_2024_Resale%20Report.pdf
Zara. (2024)	https://www.zara.com/es/es/preowned-about-mkt5795.html

Source: own

Big data analytics and brand reputation: Catalysts for circular economy and sustainable performance

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Abstract: *The circular economy concept is popular because it encourages resource efficiency, sustainable production, a shift in economic thinking, and the creation of higher-skilled jobs. We are unavoidably used to the traditional linear economy cradle-to-cradle model of production and consumption in our contemporary life. This study aims to determine the elements that support and impede Malaysian manufacturing enterprises' adoption of the big data analytics and circular economy business model, given the discrepancy in developing countries in Southeast Asia. The circular economy business model is used to analyze the impacts of sustainable performance. Using the lenses of dynamic capability theory (DCT) and covariance-based structural equation modeling (CB-SEM), this study assesses the responses of 241 respondents from various sectors of the manufacturing sector having environmental management systems (EMS) within Malaysia. Therefore, survey-based primary data was gathered to understand the effect of big data analytics on sustainable performance via moderate mediation of circular economy practices, brand reputation, and environmental dynamics. Findings of distal mediation revealed that big data analytics have a significant positive effect on the sustainable performance of manufacturing firms. Furthermore, it is revealed that environment dynamics at each level of mediation moderate the relationship significantly; hence, it is important for the firms to understand the dynamics of the environment, either internal or external, where the firms are operating to effectively implement the big data analytics (BDA), circular economy practices (CEP) to achieve sustainable performance.*

Keywords: *Big data analytics, circular economy practices, brand reputation, environmental dynamics, sustainable performance.*

JEL Classification: *C88, D83, M00, Q01.*

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Introduction

Those seeking sustainable performance need big data analytics (BDA). As a result, BDA provides actionable insights that enable firms to make strategic decisions (Sahoo et al., 2023). The sustainability outcomes of sustainable organizations remain unknown despite well-documented organizational performance. By recycling, remanufacturing, and reducing waste, the circular economy practices

(CEP) promote sustainability (Le & Vu, 2024). BDA plays a crucial role in CEP and brand reputation (BR) by catalyzing them. Since environmental dynamics are dynamic and volatile, their impact on sustainability objectives may be adverse. Big data analytics (BDA) has been shown to enhance or mitigate environmental dynamics as they develop (Sahoo et al., 2023). Also, BDA processes and analyses large data sets for strategic planning. Sustainability performance varies with BDA but does not follow a linear or straightforward path. This means that intermediary variables heavily influence sustainability discourse. ED (environmental dynamics) could also have an effect. The circular economy promotes resource utilization, reduces waste, and balances the environment while promoting sustainability (Arsawan et al., 2024). Companies must put sustainability first.

As a result, CE practices are not linked to firm performance, according to Bag and Pretorius (2022). A CE practice did not increase Chinese industrial firms' profits, as CE practices were in their infancy, which led to higher investment costs affecting operating costs. With these intangible assets, brand reputation (BR) enhances consumer perceptions and legitimacy (Mitra & Datta, 2014). Intangible assets like reputation reflect stakeholder expectations about a firm's capabilities. A company's reputation can also indicate how it meets stakeholder expectations (Pérez-Cornejo et al., 2020). Further, Sangpetch and Ueasangkomsate (2023) say big data analytics can benefit from sustainability initiatives. The BDA moderates CEP, BR, and sustainable performance. A vast dataset can help businesses identify inefficiencies, predict future trends, and identify inefficiencies. Environmental dynamics (ED) moderate sustainability outcomes. Climate change, regulatory changes, and market disruptions impact sustainability. Using sustainability outcomes as a mediator, we developed an integrated BDA model.

Literature examines BDA's impact on organizational outcomes; however, the BDA-SP relationship provides nuanced insights into indirect pathways through which BDA influences sustainable performance by introducing circular economy practices and brand reputation. With context dimensions, organizations can now adapt to environmental volatility. When environmental dynamics are incorporated into the model, it becomes much more complicated. Using BDA to boost firm performance becomes a strategic priority rather than just a regulatory requirement in this study. Sustainability practices and brand positioning can complement each other. BDA can boost brand reputation and enhance sustainability by optimizing circular economy practices. By leveraging this insight, companies can develop data-driven, sustainable strategies. BR and CEP play a crucial role in mediating sustainability in BDA initiatives. A circular economy improves reputation, competitiveness, and carbon footprint (Halog et al., 2021). Data-driven approaches are essential to profitability and sustainability. Understanding environmental dynamics can improve business moderation. The study filled several literature gaps, allowing researchers, companies, and policymakers to evaluate how BDA interacts with CEP, BR, and SP as a first step toward sustainable performance. Research into BDA's moderating role is discussed. The objective of this research is to use BDA to outperform competitors sustainably.

1 Theoretical background

This study draws upon dynamic capability theory (DCT) as its theoretical foundation, emphasizing firms' ability to adapt and reconfigure internal resources, processes, and competencies in response to dynamic environments. DCT posits that firms can achieve sustained competitive advantage by fostering capabilities that enable them to sense opportunities, seize them effectively, and transform operations to align with environmental changes (Alsawafi et al., 2021). DCT focuses on how internal competencies and organizational culture facilitate the alignment of business models with sustainable performance goals (Prieto-Sandoval et al., 2019). As a result, firms are required to reorganize their operations to reduce waste, reuse materials, and regenerate resources (Khan et al., 2020). Additionally, Scarpellini et al. (2020) emphasize the importance of addressing internal challenges to implement CE effectively. By using this theoretical lens, key relationships in this study can be conceptualized: big data analytics (BDA) as an internal capability, CE practices as a transformational process, and brand reputation (BR) as a strategic outcome. Sustainable performance (SP) is the result of a combination of these elements. This study applies DCT to contemporary sustainability challenges by integrating these dynamics.

1.1 Big data analytics (BDA), circular economy (CE), brand reputation (BR) and sustainable performance (SP)

Big data analytics (BDA) has emerged as a transformative capability, enabling firms to analyse vast and complex datasets to inform strategic decision-making. Leveraging digital technologies for data analysis provides insights that help organizations identify inefficiencies, optimize operations, and minimize environmental impacts, particularly within circular economies (Yuan & Pan, 2023). The heterogeneity of technologies and the difficulty of integrating into circular business models make it challenging for firms to adopt the right digital tools (Nobre & Tavares, 2017). BDA plays an important role in increasing sustainability. For instance, Frisk and Bannister (2017) argue that BDA improves supply chain operations by providing actionable insights into waste reduction, customer behaviour, and resource optimization. Furthermore, BDA enables firms to align business operations with CE goals by identifying market trends and environmental risks (Dubey et al., 2019). A practical application of BDA for CE practices is, however, not widely accepted, requiring further study. Data analysis allows BDA to build brand reputation (BR) by creating transparency and showcasing companies' sustainability commitment in real-time. Using BDA to communicate CE initiatives effectively increases trust and loyalty among consumers (Ferraris et al., 2020). For firms to achieve sustainable performance (SP), these capabilities must be integrated together. Therefore, the hypotheses are as follows:

H1: There is a significant relationship between BDA and sustainable performance.

H2: There is a significant relationship between BDA and circular economy practices.

H3: There is a significant relationship between BDA and brand reputation.

H4: There is a significant relationship between CEP and brand reputation.

H5: There is a significant relationship between CEP and sustainable performance.

1.2 Brand reputation (BR)

Brand reputation (BR) plays a pivotal role in shaping consumer perceptions, particularly in sustainable practices. Companies that actively pursue environmental and social goals often experience spillover effects that enhance their brand reputation and increase demand for their products. By using circular economy (CE) practices, firms can communicate directly with customers about sustainability initiatives (Tura et al., 2019). A powerful tool that can be used to showcase real-time CE efforts is digital and social technologies (Belabbes et al., 2020). Sustainability-oriented initiatives and market competitiveness are linked by brand reputation. In turn, a company's CE practices can increase its consumer's goodwill and preference. Thus, environmental responsibility and financial performance are inextricably linked. Ferraris et al. (2020) highlight how customers relate a brand's ethical and responsible values to its alignment with CE goals. In this study, BR is conceptualized as an important driver of sustainable performance (SP) and part of effective CE practices. A strong reputation not only helps firms attract environmentally conscious customers but also improves their market positioning.

H6: There is a significant relationship between brand reputation and sustainable performance.

1.3 Environmental dynamics (ED)

Environment dynamics (ED) refers to the forces outside a firm that influence its strategic decision-making and ability to adapt. As markets change and technology advances, firms operating in dynamic environments must enhance their competitiveness. These dynamics compel firms to adopt circular economy (CE) practices to improve resource efficiency, mitigate risks, and address environmental concerns (Permatasari et al., 2022). Research highlights that environmental dynamism acts as a critical driver for promoting CE practices, yet empirical evidence exploring its direct and moderating roles remains scarce, especially in emerging economies (Bag et al., 2021; Santa-Maria et al., 2022). Firms must adopt strategic approaches to manage the complexities of transitioning toward CE, including addressing internal barriers and aligning operational systems with sustainability goals (Castro-Lopez et al., 2023). For instance, organizations that understand and respond effectively to environmental dynamics can better rank sustainability projects and prioritize actions such as waste reduction and resource reutilization (Gupta et al., 2019). Illustrative examples further underscore ED's relevance. For example, Pirelli, a global tire manufacturer, utilized big data analytics to enhance inventory management, reduce tire landfill disposals, and lower greenhouse gas emissions. Keeping CE principles in mind.

The case illustrates how market pressure for sustainable products can drive innovation and achieve sustainability objectives (Koseleva & Ropaite, 2017; Song et al., 2017). As a moderating variable, ED factors into the relationships between big data analytics (BDA), CE practices, brand reputation, and sustainable performance. ED is accounted for in this research to provide a nuanced understanding of how firms can optimize their sustainability strategies. Fig. 1 shows the conceptual model illustrating the relationships and hypotheses tested in this study. Therefore, the hypotheses are as follows:

H7: The effect of big data analytics on sustainable performance significantly moderate by environmental dynamics.

H8: The effect of big data analytics on circular economy practices significantly moderate by environmental dynamics.

H9: The effect of big data analytics on brand reputation significantly moderate by environmental dynamics.

H10: The effect of circular economy practices on brand reputation was significantly moderate by environmental dynamics.

H11: The effect of circular economy practices on sustainable performance was significantly moderate by environmental dynamics.

H12: The effect of brand reputation on sustainable performance was significantly moderate by environmental dynamics.

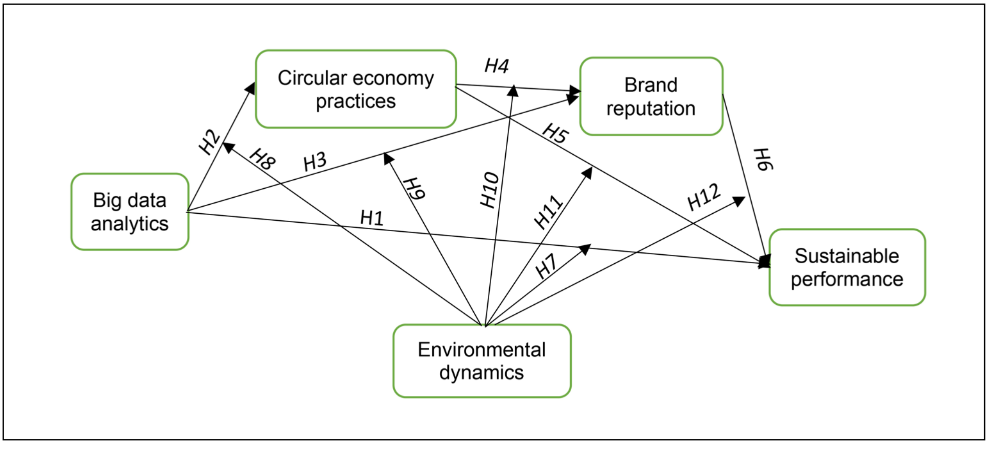

Fig. 1: Conceptual framework

Source: own

2 Research methodology

We used explanatory and descriptive research design, requiring minimum researcher interference to avoid biases. The study is cross-sectional, but the data collection was completed at intervals of two months for the same survey. Participants were asked to respond for sustainable performance to avoid the common method biases. We target firms that have environmental management systems (EMS). The participants are supply chain managers, employees who are part of production lines, and employees who play critical roles and have authority to instrument the circular economy's implementation decisions. Based on knowledge and interest in sustainable performance, manufacturing firms have chosen to have EMS since these firms have an understanding related to sustainable production to attain the EMS certification. MITI (Malaysian International Trade and Industry) has 975 manufacturing firms with EMS, and 276 firms were selected from 16 manufacturing sectors as targeted participants (Ting et al., 2024). We used a cluster random sampling technique to collect data from participants. In the first stage, the 16 manufacturing sectors

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were considered clusters, and 18 questionnaires were distributed randomly in each sector. According to Hair et al. (2014), for multivariate data analysis, select sample size based on a rule of thumb number of items × 5; here, this study has 46 items × 5 = 236. However, we increased the sample size by 20% to handle outliers and missing responses, which total 46. Hence, the study distributed 276 questionnaires and received 241 valid responses after missing values and outliers. Data was collected via a questionnaire; we used a five-point Likert scale to measure participants' responses. 9-items were adapted loaded on single factor to measure the BDA as variable (Bag et al., 2021). The circular economy practices were measured with four items adapted from (Kucharska, 2020). At the same time, the environmental dynamics variable was measured with five items loaded on a single construct adopted (Kumar & Bhatia, 2021). The brand reputation scale with four items was also adopted from (Kucharska, 2020). Lastly, sustainable performance was measured with 4 dimensions, i.e., environmental performance (7 loaded items), economic performance (7 loaded items), social performance (5 loaded items), all adapted from Shoaib et al. (2022), but human development (5 loaded items) adapted from Mueller and Parcel (1981).

2.1 Analytical approach

This study used the CB-SEM technique via the AMOS 26 process to measure the model developed based on a theory (Hair et al., 2019). Further, this study used the MLE method in data analysis to robust the parameter estimates more than other required estimations, like generalized least squares, because the observed constructs did not attain the multivariate normality distribution. Moreover, this study follows four steps of analysis: PCFA was conducted to confirm the validity of the survey and reliability of data, and path analysis was performed to assess the effect of exogenous constructs on endogenous constructs. In the third step, we performed mediation by applying bootstrapping techniques. Lastly, we apply moderate mediation with a subgroup approach and bootstrapping technique by applying 5,000 bootstrapped samples as suggested by Hayes (2009). To evaluate the association among the constructs via the application of Pearson correlation (r) with a coefficient of multivariate data determination (R^2), the effect size was assessed via premeditated with Hedges' g (Ellis, 2010). Fig. 2 presents the measurement model used in this study, illustrating the relationships between observed variables and their corresponding latent constructs.

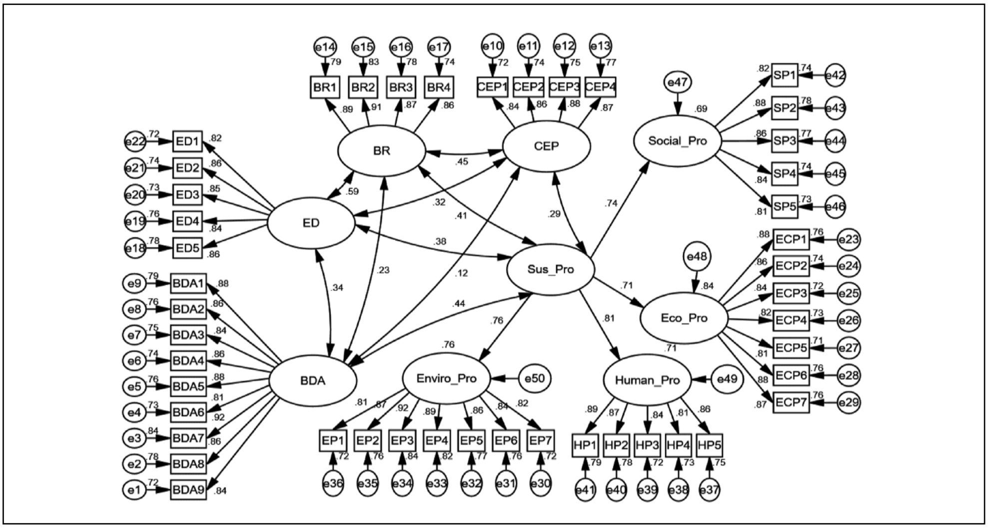

Fig. 2: Measurement model

Source: own

3 Data analysis

3.1 Confirmatory factor analysis

The study confirmed the face and content validity with experts and deleted one item from big data analytics before the process for the PCFA. Hence, 5 constructs with 45 loaded items were used to evaluate the measurement model, so it found a significant fit by achieving the threshold value required for multivariate data analysis when using CB-SEM. Once the study performed the measurement model, the results generated the Bollen-Stine value of χ^2 356.451 with 241 degrees of freedom, which assessed a relative value of chi-square 1.479, with RMSEA value of 0.051, CFI 0.979, TLI 0.977 and NFI 0.973, which are acceptable and achieved the threshold value. The construct validity was assessed via factor loading achieved above 0.70 with significance below $p < 0.001$. The results revealed that the items achieved convergent validity and confirmed the latent constructs (Hair et al., 2019), see Tab. 1.

Tab. 1: Convergent validity – Part 1

Construct	Statement	FL	AVE	CR	α
Big data analytics	Our company used BDA to improve decision-making power.	0.88	0.742	0.963	0.821
	Our company integrate information from various sources via application of BDA.	0.86			
	Our company used a visualisation technique to make complex information understandable for decision-making.	0.84			
	Our company used BDA to do root cause analysis to work for continuous improvement.	0.86			
	Our firm improves machine life cycle, reduces waste and follows an efficient process via application BDA.	0.88			
	By applying BDA, the company can optimise its resources and make processes more efficient.	0.81			
	BDA helps us to identify the more options for recycling of wastage.	0.92			
	After application BDA, our company have better demand curves, efficient use of resources and effective use of energy.	0.86			
	Our company employed experts to handle BDA, and everyone follows the given timelines to complete the task.	0.84			
Circular economy practices	Our company work closely with supplier/clients to develop environment friendly products/services.	0.84	0.744	0.921	0.887
	Our company confirm the recycling process of products at initial stage of product development.	0.86			
	Our company used recyclable material for production.	0.88			
	Our company follow design policies and process for disposal of machinery and equipment.	0.87			
Brand reputation	Customers have overall better perception for total experience of our product.	0.89	0.779	0.934	0.899
	Customers prefer our products in comparison to others.	0.91			
	Our customer believe that we are doing well for product quality.	0.87			
	Customers have positive feeling to buy products from our company in future.	0.86			

Tab. 1: Convergent validity – Part 2

Construct		Statement	FL	AVE	CR	α
Environmental dynamism		Our company focused on doing ecological transition in the market.	0.82	0.716	0.926	0.921
		Our company focus on producing new products by focus on environment.	0.86			
		Our company focus on continuous ecological transition in the market.	0.85			
		Our company focus on significantly improvement in ecological transitions in government regulations.	0.84			
		Our company prefer to being innovative product in the industry those environment friendly.	0.86			
Sustainable performance	Environmental	Lower discharge of noxious chemicals into the air and water.	0.81	0.743	0.958	0.881
		Increase in the usage of renewable energy and sustainable fuels.	0.87			
		Enhancement in the organization's environmental state.	0.92			
		Reduction in the frequency of environmental mishaps.	0.89			
		Direct and indirect toxic emissions are reduced.	0.86			
		Increase the rate of purchase of environmentally friendly goods.	0.84			
		Increase the volume of recycled materials and reduce waste.	0.82			
	Economic	The organization's profit growth is generally due to reduced energy consumption and materials.	0.88	0.726	0.949	0.843
		Rise in the enterprise's market share and improve the organization's reputation.	0.86			
		Reduction in the cost of energy usage.	0.84			
		Reduction in the processing fees and waste disposal.	0.82			
		Average growth in market share over the past two years has increased.	0.81			
		Average profit and profit growth over the past two years has increased.	0.88			
		Average growth in market share over the past two years has increased.	0.87			
	Social	Increase attention to the rules for the health and safety of employees when using hazardous materials and radiation.	0.82	0.710	0.924	0.891
		Improving community health, safety, and infection control.	0.88			
		Reducing the impact of the organization's waste on the community.	0.86			
		Improving the quality of service provided and commitment to the code of ethics.	0.84			
		We are developing economic activities in the community and providing more job opportunities.	0.81			
	Human development	Human capital has a greater sense of belongingness to an organization and its goals.	0.89	0.730	0.931	0.889
		Employees feel safe at work.	0.87			
		Organizations can practice zero tolerance for workplace harassment.	0.84			
		Employee-organizational relationships get better.	0.81			
		Employees' expectations towards success are well met.	0.86			

Source: own

All the constructs achieved an AVE value greater than 0.50 to ensure convergent validity. Composite reliability was also achieved over the threshold value of 0.70; results signify that each construct attained internal consistency (Hair et al., 2019). Further, we ensure the discriminant validity (as shown in Tab. 2) by examining the square root of each construct's AVE and comparing it with the estimated correlation between the constructs. It is revealed that bold diagonal values of the square root AVEs are above the conforming correlation coefficients, which indicates that each construct is discrete from the other. Tab. 3 shows that the specific measurement model accurately fits the sample data and supports the successive structural equation model for path analysis (Hair et al., 2019). Fig. 3 shows the final measurement model results obtained using AMOS, illustrating the standardized path coefficients and the relationships among the latent constructs in the study.

Tab. 2: Discriminant table

Construct	Mean	SD	VIF	*BDA*	*CEP*	*BD*	*ED*	*SP*
Big data analytics	4.01	0.61	1.189	***0.86***				
Circular economic practices	3.99	0.91	1.231	*0.12*	***0.86***			
Brand reputation	4.21	0.89	1.119	*0.23*	*0.45*	***0.88***		
Economic dynamics	4.14	0.88	1.146	*0.34*	*0.32*	*0.59*	***0.84***	
Sustainable performance	3.98	0.81	1.106	*0.44*	*0.29*	*0.41*	*0.38*	***0.85***

Note: Bold and italic refer to the square root of AVE values, which explained that the below values are not greater than the calculated value of AVE's square, indicating that there is no issue of multicollinearity with this study, and it achieved the discriminant validity.

Source: own

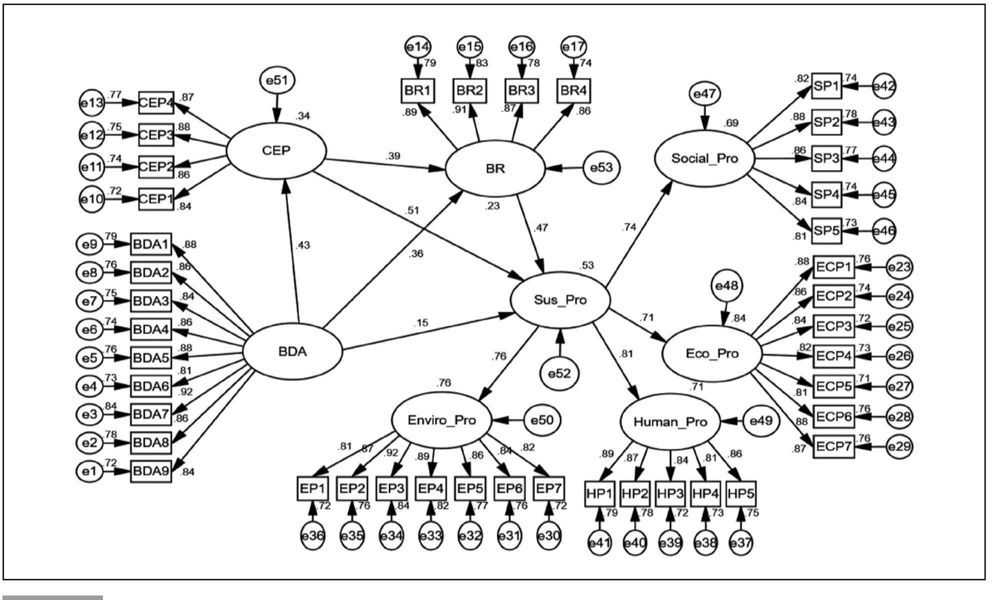

Fig. 3: Structural model

Source: own

3.2 Structural model and mediation analysis

At first, the reliability of data and validity of the survey were confirmed, further ensuring the structural path between constructs. Hence the results revealed that structural model achieved the model fitness, because the value of Bollen-Stine χ^2 356.451 with degree of freedom value 241, also study achieved the threshold level of CFI value 0.979, TLI 0.977, NFI value of 0.973 along with 0.051 value of RMSEA, all the values are above the suggested values of multivariate data analysis of measurement model (Hair et al., 2022). Furthermore, the study also assessed the standard estimation of causal path, the model achieved the 0.54 value of R^2, which refers to the total change caused by exogenous constructs in the endogenous construct of sustainable performance. Mediational analysis was conducted with 5,000 bootstrapped sample with 95% confidence interval, the study found a significant direct effect of BDA on sustainable performance. Also, the indirect effect of BDA via CEP and BR was found significant (β = 0.488; $p < 0.001$). Whereas the overall effect of direct effect + indirect effect show a significant effect (β = 0.568, $p < 0.01$). Furthermore, with bootstrapped confidence interval, it is revealed that zero did not prevail between the lower and upper bounds of each path, hence revealing that partial sequential mediation prevails between BDA and sustainable performance (Hair et al., 2019).

Tab. 3: Sequential mediational analysis

Path	β value (stand)	B value (unstand)	SE	Z	Bootstrapping sample with 95% confidence				Two-tailed significance
					Bias-corrected		Percentile		
					Lower	Upper	Lower	Upper	
Specific indirect effect									
SIE1	0.223	0.269	0.059	3.112	0.037	0.359	0.039	0.297	**
SIE2	0.021	0.027	0.041	4.141	0.006	0.269	0.004	0.229	*
SIE3	0.221	0.237	0.057	4.561	0.119	0.467	0.217	0.467	***
Total indirect effect									
BDA → CEP → BR → SP	0.488	0.521	0.087	5.554	0.298	0.647	0.419	0.647	***
Total direct effect									
BDA → SP	0.148	0.167	0.061	3.897	0.064	0.398	0.091	0.459	**
Total effect									
BDA → CEP → BR → SP + BDA → SP	0.568	0.611	0.081	7.118	0.409	0.587	0.499	0.678	***

Note: We used a 5,000 bootstrapped sample, $n = 241$, unstandardized refers to SE, SIE1 = BDA → CEP → SP, SIE2 = BDA → BR → SP and SIE3 = BDA → CEP → BR → SP; *$p < 0.05$, **$p < 0.01$ and ***$p < 0.001$.

Source: own

For distal moderate mediation results assessed, the sub-group SIE1 was found significant only at grade 3 (β = 0.221; $p < 0.001$), but SIE2 was not significant at any of the three determined grades, whereas SIE3 was found significant at each of the three grades. Furthermore, it is assessed that SIE1 and SIE2 were not significantly different at grade 3 when compared all the SIEs. Whereas the sub-group SIE1 was found significantly different from SIE3 at each stage SIEdiff = −0.268, −0.109 and 0.211 correspondingly; $p < 0.05$). Also, the sub-group SIE2 comparing with SIE3 assessed different from each other when compare at 1st grade SIEdiff = −0.399; $p < 0.001$), see Tab. 4.

After completion of sub-group comparison process at each grade, we further investigate the relationship between direct and indirect effect at each of grades. At each level of three grades, no significant difference emerged

Tab. 4: Moderation mediation analysis (point estimates and SIE comparison with each grade variable)

Grade	β-value of the indirect effect				SIE's evaluation		
	Total indirect effect	SIE1	SIE2	SIE3	SIE1–SIE2	SIE1–SIE3	SIE2–SIE3
1	0.387***	0.019	0.007	0.268***	0.011	−0.268*	−0.399***
2	0.411***	0.101	0.061	0.348***	0.019	−0.109	−0.119
3	0.589***	0.221***	0.066	0.112***	0.198	0.211*	−0.033

Note: We used 5,000 bootstrapped sample, n = 241; SIE1 = BDA → CEP → SP, SIE2 = BDA → BR → SP and SIE3 = BDA → CEP → BR → SP; *p < 0.05, **p < 0.01 and ***p < 0.001.

Source: own

Tab. 5: Comparison at direct and indirect level among the grades for moderated mediation

Grade	Estimate	Bootstrapping with 95% confidence					
		Bias-correct			Percentile		
		Lower	Upper	*p*-value	Lower	Upper	*p*-value
Total indirect effect comparison							
G1 – G2	−0.012	−0.234	0.289	0.441	−0.311	0.298	0.568
G1 – G3	−0.011	−0.447	0.121	0.289	−0.398	0.169	0.299
G3 – G2	0.176	−0.231	0.566	0.658	−0.199	0.478	0.111
SIE 1 comparison							
G1 – G2	−0.071	−0.366	0.188	0.447	−0.389	0.177	0.447
G1 – G3	−0.030	−0.457	−0.054	0.011	−0.544	0.011	0.029
G3 – G2	0.231	−0.061	0.587	0.164	−0.101	0.531	0.119
SIE 2 comparison							
G1 – G2	−0.071	−0.289	0.051	0.267	−0.321	0.049	0.269
G1 – G3	−0.088	−0.265	0.049	0.178	−0.287	0.032	0.398
G3 – G2	0.007	−0.191	0.289	0.547	−0.188	0.289	0.447
SIE 3 comparison							
G1 – G2	0.121	−0.101	0.487	0.289	−0.071	0.454	0.166
G1 – G3	0.211*	0.011	0.554	0.047	0.003	0.398	0.049
G3 – G2	−0.077	−0.431	0.129	0.478	−0.421	0.147	0.389
Direct effect comparison							
G1 – G2	−0.008	−0.289	0.457	0.687	−0.387	0.489	0.547
G1 – G3	−0.006	−0.198	0.447	0.589	−0.299	0.472	0.589
G3 – G2	0.003	−0.287	0.589	0.611	−0.347	0.399	0.597

Note: We used 5,000 bootstrapped sample, n = 241; SIE1 = BDA → CEP → SP, SIE2 = BDA → BR → SP and SIE3 = BDA → CEP → BR → SP; *p < 0.05, **p < 0.01 and ***p < 0.001.

Source: own

between sub-group for direct and indirect effect. But in the case of sub-group SIE1 and SIE3, a difference was observed (SIEdiff = 0.231 and 0.211; *p*-values < 0.05). Furthermore, the effect size was assessed at a medium level for SIE1 (Hedges' g = 0.193), whereas the effect size for SIE3 was found to be small (Hedges' g = 0.101), see Tab. 5.

Conclusions and discussion

Although the circular economy has garnered much attention in recent decades, more research is still necessary. A manufacturing company's participation in a circular economy is crucial due to the nature of its operations, which include the use of energy and raw materials, the production of goods and services, the creation of jobs, and the potential to create value to break free from linear consumption. Adopting the circular economy business model presents both technical and non-technical, internal and external problems for industrial businesses. Motivators are essential to translate the potential advantages of the circular economy into corporate strategy and business plans. Malaysia is among the countries that have committed to achieving the sustainable development goals (SDGs), which include several goals about the circular economy that must be achieved by 2030 (Ting et al., 2024). The study's findings indicate that sustainability and environmental concerns somewhat impact most industrial organizations' long-term growth strategies. When assessing the current state of big data analytics, circular economy practices, and sustainable performance issues among environment management system firms, most respondents are eager to work toward this as part of their business plan. Manufacturing firms are extremely cautious about starting costly and resource-intensive projects because they are capital and resource-intensive despite the numerous calls for them to engage in sustainable activities (Ormazabal et al., 2018). Thus, it is crucial to conduct studies that can direct their shift toward sustainability (Katz-Gerro & Lopez Sintas, 2019).

Under the lens of the theory of TRB, we investigate the effect of BDA on circular economy practices. It revealed that manufacturing firms with higher levels of involvement in BDA practices have advanced levels of involvement in CEP. Hence, findings are aligned with previous studies like Nobre and Tavares (2017), which have shown how to use IoT and big data to create circular economies. Data analytics is used in business choices to find, examine, handle, and assess data (Dubey et al., 2019). There is no consensus on how to assist BDAC. CEC's application in supply chains encourages sustainability. The BDAC is a tool that organizations can use to assess supply and demand options. Big data has a major impact on corporate operations management techniques. BDA can help supply chains and organizations. Further, we examine the influence of BDA on brand reputation, which was also found to be a significant effect of BDA and CE on the brand reputation of the firms. Businesses can benefit from the development of CE practices by integrating consumer and environmental considerations into their fundamental strategy and operations. This is because these practices assist businesses in building a strong brand reputation, which is a crucial component in assessing performance. Accordingly, this research examines how brand reputation, which influences performance, and CE practices, especially the company's internal waste treatment, reduction, and recycling, relate to one another. The study also seeks to ascertain whether and to what extent brand reputation mediates the connection between performance and the 3Rs principles (Mazzucchelli et al., 2022).

Our findings are aligned with previous studies that state that CE (i.e., reduce, reuse, and recycle) practices help manufacturing firms improve their sustainable performance (Geissdoerfer et al., 2017). But to achieve more sustainable performance, companies must adopt eco-friendly practices that will reduce their negative climatic impacts and create jobs that will boost the economy and benefit society. While recycling and trash management will offer low-skilled jobs in garbage handling, collecting, and processing, reuse techniques will create more jobs requiring higher skills than recycling (Van Loon & Van Wassenhove, 2018). Hence, CE will lead to sustainable performance in firms because it fosters economic efficiency and social and environmental well-being (Chowdhury et al., 2022). Furthermore, the study found that CEP significantly positively influenced brand reputation and sustainable performance. Large firms aggressively reduce their carbon footprints (Dey et al., 2019). The academic literature has concentrated on understanding why firms adopt CE. Additionally, they are responsible for as much as 70% of the world's pollution (Bonner, 2019). Business procedures and practices can drastically cut greenhouse gas emissions by implementing CE (Bhatia et al., 2020), improving the brand reputation and the firm's sustainable performance. Lastly, it was revealed that brand reputation mediates the relationship between CEP and sustainable performance.

Therefore, environmentally responsible enterprises may see positive knock-on effects that increase product demand and improve brand awareness. By giving customers immediate access to information about implementing CE practices in real time, companies can enhance their brand reputation while leveraging digital and social technologies as sustainability enablers (Belabbes et al., 2020). CE practices can benefit from brand reputation, which describes how customers perceive the brand's association with the cause. Positive perceptions of CE procedures are transferred to the relevant brand through brand reputation (Ferraris et al., 2020). Moreover, this study applied environmental dynamics to moderate each mediating path, and the results were significant. So, it revealed that businesses must be alert to prospects to advance and implement deliberate intends and choices to increase effectiveness and grow sustainably (Permatasari et al., 2022). Companies can moderate marketplace commotion, competitive intensity, and technical instability by organizing environmental dynamism using CE approaches (Castro-Lopez et al., 2023). According to this outlook, ecological enthusiasm is a peripheral factor supporting the CE but is little understood (Bag et al., 2021). Additionally, the strategy has to altered accordingly anticipated to the involvedness of transmuting planned and operational processes to become circular. Businesses may find it more challenging to adopt the circular economy if they encounter internal resistance (Santa-Maria et al., 2022).

Managerial and theoretical significance. A significant contribution has been made to managerial practice and theory in the areas of big data analytics (BDA), circular economy practices (CEP), brand reputation (BR), and sustainable performance (SP). Developing sustainable business performance relies heavily on BDA. This study uses data-driven strategies to show that BDA significantly influences SP directly and through the mediating effect of CEP and BR. Despite BDA's direct impact on performance, its full potential is unlocked when combined with environmentally sustainable practices and brand-building initiatives. A business that integrates BDA and the circular economy framework achieves operational excellence. In practice, managers should prioritize BDA infrastructure while simultaneously refining CEP. As a result, they will maintain a competitive edge in increasingly sustainability-focused markets. As CEP has contributed to mediating BDA's influence on SP, it illustrates how advanced data analytics can help sustainable business models improve their reputation and stakeholder trust. To achieve sustainable growth, a comprehensive strategy must include technological, operational, and reputational elements. This study examines CEP and BR as mediators of the BDA-SP relationship from a theoretical perspective. Previous research has examined how BDA improves operational efficiency, but this study demonstrates how BDA can contribute to sustainable performance through the contextualization of circular economy practices and brand reputation. Furthermore, the study explores the moderating role of environmental dynamics (ED) in shaping BDA's indirect effect on SP. Based on the findings, BDA has a dynamic effect on SP mediated by CEP and BR, depending on the environmental context. In this theoretical advancement, firms can tailor sustainability initiatives based on BDA to different environmental conditions, adding to the current discussion of contingency theory. A robust theoretical framework linking BDA, CEP, and BR to sustainable performance is developed in this study. Additionally, it provides managers with strategic insights into data analytics and sustainability. By integrating these dimensions, firms can gain and maintain competitive advantage using data-driven innovation and sustainability-focused strategies.

Limitations and future research. This study contributes significantly to theory and practice, but it has limitations. Being cross-sectional, it limits causal inferences. While the study demonstrates relationships between big data analytics (BDA), circular economy practices (CEP), brand reputation (BR), and sustainable performance (SP), a longitudinal approach is needed to understand how these constructs evolve over time and reflect cause-and-effect relationships. Future research should employ longitudinal designs to capture these dynamics, particularly in response to external changes.

The moderating role of environmental dynamics (ED) on BDA and sustainable performance was not explored. Future studies should examine dimensions of ED, such as technological turbulence, competitive intensity, and regulatory pressures, to better understand how external factors influence data analytics strategies and sustainability outcomes. This study focused on CEP and BR as mediators in the BDA-SP relationship. However, other mediating factors, like organizational learning and innovation capacity, should be explored. Additionally, firm-specific factors (size, industry, market volatility) may provide further insights into how contextual factors shape BDA's impact on sustainability. The findings, based on Malaysian manufacturing firms, are limited in generalizability to other sectors or regions. Future research could explore BDA's role in sustainability across different industries and geographical contexts, identifying patterns and the influence of cultural or institutional factors. Finally, the practical implications could be made more actionable. Future studies should explore the trade-offs between implementing CEP and the associated benefits, helping organizations develop targeted strategies. Balancing sustainability goals with financial performance metrics could provide a practical framework for decision-making. More rigorous designs, diverse datasets, and expanded theoretical frameworks will advance understanding of BDA's impact on sustainability.

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Stakeholder pressure, circular economy, and SME performance: The role of green innovation in emerging markets

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Abstract: *Addressing the factors influencing small and medium-sized enterprises (SMEs) to implement environmentally friendly manufacturing processes and how they affect their performance is essential for both researchers and practitioners. While the literature has extensively investigated the economic and environmental aspects of the circular approach, it lacks empirical evidence regarding the societal considerations of the circular economy (CE). Using 381 valid responses of SME managers in Vietnam, we employed a quantitative methodology to investigate how stakeholder pressure (STP) and the moderating effect of green innovation (GE) affect CE practices (CEP), which accordingly influence corporate social responsibility participation (CSRP) and sustainable firm performance (SFP). The results revealed a positive correlation between STP, CEP, CSRP and SFP. The findings further indicate that GE moderates the link between CEP, CSRP and SFP. This study contributes significantly to CE literature by investigating the impact of CEP on sustainable performance in developing countries. It also provides a theoretical framework utilizing RBV theory, stakeholder theory, and network theory to promote CEP. Subsequently, this study sheds light on the importance of stakeholder pressure and green innovation in promoting CE practices and achieving greater sustainable performance within SMEs in emerging markets. Furthermore, the findings of this study present several implications for managers and policymakers as these insights can be utilized to formulate strategies and public policies aimed at bolstering support and advancement for CEP.*

Keywords: *Circular economy practices, stakeholder pressure, green innovation, sustainable firm performance.*

JEL Classification: *Q56, O31, O44.*

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Introduction

Given the worsening environmental degradation and resource shortages, governments, customers and communities have increased their demands for firms to find alternatives to protect the environment (Dey et al., 2022). Circular economy (CE) is of great importance for sustainable business as it embraces restoration and regeneration (Chowdhury et al., 2022; Dey et al., 2022; Magnano et al., 2024). To achieve sustainability outcomes, the adoption of circular economy practices (CEP) offers an achievable solution to minimize resource inputs and waste generation (Baah et al., 2023). CEP includes product/service life extension, sustainable packaging and decreased energy usage could promote a regenerative approach towards sustainable and responsible production (Agyabeng-Mensah et al., 2024; Jabbour et al., 2020).

The urgency to address the stakeholder demands has made adopting CEP critical in various industries (Jabbour et al., 2020). While some companies in developed countries have exerted efforts to attain sustainability objectives, it is difficult for small and medium-sized enterprises (SMEs), often resource-constrained, to prioritize sustainability within budgetary constraints (Chowdhury et al., 2022). Additionally, global businesses are increasingly focusing on their environmental performance by enhancing socially responsible behaviors, fostering innovations, putting more pressure on CE transition in SMEs (Dey et al., 2022). However, Ghisellini et al. (2016) stated that while CE offers benefits, the increasing stakeholder pressure (STP) on SMEs to adopt these practices poses critical threats to their resources, competencies and their existence. Companies comply with stakeholder demands for many reasons, including fulfilling legal obligations and the pursuit of legitimacy. Regardless of the style, size, or objectives of a corporation, stakeholders are essential foundations of organizational success, given the interconnected societies that currently prevail. Despite calls to go beyond sustainability (linear economy/eco-efficiency) and incorporate circular economy principles (eco-effectiveness), there has not been extensive scrutiny of the role that stakeholders play. Therefore, this study focuses on the stakeholders' aspect of CE, highlighting how stakeholder influences impact the adoption of CE practices and how such adoptions affect sustainable performance in emerging markets.

However, the implementation of CEP alone does not suffice for business sustainability. Green innovation (De Jesus & Mendonça, 2018), corporate social responsibility (CSR) (Mazzucchelli et al., 2022; Morea et al., 2021) and CEP (Le et al., 2023) are introduced as key elements to tackle sustainable concerns. Jabbour et al. (2020) argued that embracing CEP drives organizations toward both exploitative and exploratory innovations. Furthermore, sustainability initiatives, including CEP, critically depend on innovation, and without innovation, achieving sustainability targets remains elusive. Morea et al. (2021) discovered that combining CE with CSR provides a fundamental strategy to embrace sustainability objectives in multinational cosmetic companies. Notwithstanding its significance, the existing literature lacks empirical studies assessing the interplay of CEP, CSR, and GE on sustainable performance. The body of literature currently examines these aspects individually, and empirical research on the combined effect of CEP on driving CSR and sustainable performance is notably limited.

Theoretically, the integration of CEP, green innovation (GE), and corporate social responsibility participation (CSRP) plays a pivotal role in advancing sustainable development (Magnano et al., 2024). Le (2022) connoted that CSR and GE have a positive and significant impact on sustainable firm performance (SFP) in the manufacturing sector. This study reveals the positive relationship between green strategy, CSR, and GI, although it does not explore CEP and SFP. Rodríguez-Espíndola et al. (2022) asserted that sustainability-oriented innovation has a strong relationship with firm performance in Mexican companies. From a social perspective, Mies and Gold (2021) contended that CEP, facilitated by innovative mechanisms, has the potential to yield improved social outcomes. However, previous studies did not collectively address the combined effects of CEP, CSRP, and GE, nor did they consider sustainable performance outcomes and STP. Despite the growing research on CE, an empirical examination of the linkage of CEP, CSRP, and GE in promoting SFP is missing in the current literature.

As the world population is expected to reach over 9 billion by 2050, a comprehensive worldwide strategy for CE adoption is essential to achieve sustainability objectives

(Murray et al., 2017). Despite the adoption of the CE Action Plan by Europe and other developed nations, little is known about CE efforts in emerging countries (Friant et al., 2021). Additionally, Corvellec et al. (2022) and Goyal et al. (2021) emphasized that most of CE literature has focused on economic and environmental concerns in industrialized nations and called for more research on the social implications of CE from developing economies. Furthermore, it is evident that major corporations like Philips and Adidas have demonstrated a forward-thinking commitment to CEP implementation (Yadav et al., 2020). However, there remains a notable scarcity of empirical evidence from emerging economies, especially from the views of SMEs.

As a result, the current study seeks to understand how CEP coerced by STP promotes CSRP and SFP. Furthermore, the study explores the role of GE in regulating the impact of CEP on CSRP and CEP on SFP within the framework of SMEs in developing nations. The resource-based view (RBV) theory, stakeholder theory, and network theory serve as the foundation for the proposed conceptual model. The research utilized a dataset of 381 responses from Vietnamese SME managers and owners in Ho Chi Minh City to evaluate hypotheses. The current study aims to address the following research questions (*RQ*) to achieve the above objectives.

RQ1: How does CEP coerced by STP promote SFP and CSRP in SMEs in emerging economies?

RQ2: How does GE moderate the relationship between CEP, CSRP, and SFP in emerging economies?

Our research provides theoretical and practical insights by investigating the impact of CEP coerced by STP towards CSRP and SFP. The theoretical contribution of this research is significant, as it enhances sustainable management literature by investigating the moderating role of GE in the relationship between CEP and CSRP as well as SFP. The findings emphasize the relevance of RBV theory, stakeholder theory, and network theory as predictive frameworks for understanding the CEP-SFP relationship. Additionally, the findings elucidate that this relationship is more intricate than previously understood. Furthermore, it stresses the essential role of STP in promoting CEP. Empirically, this study also enriches CE research by utilizing network theory to propose that SMEs should comply with STP regarding the adoption of CEP to access external resources for GE supporting business operations. In addition, through an examination of the moderating effects of GE, we have gained insight into SMEs' strategies to achieve higher CSRP and SFP within an emerging economy context. The findings yield practical implications for scholars and policymakers in developing nations, emphasizing the necessity of integrating CEP into strategic frameworks. This research offers valuable insights for subsequent studies on the role of CEP in fostering sustainable performance. The paper is organized in the following manner. Section 1 outlines the theoretical framework, whereas section 2 describes the methodology. The findings are outlined in section 3, followed by the discussion in section 4. Finally, the last section concludes the study with limitations and future outlook of research.

1 Theoretical background

1.1 Underlying theories

This research referenced three underpinning theories, including the RBV theory, stakeholder theory, and network theory. Levy and Powell (2005) described the RBV theory as a progressive approach to strategic thinking in terms of attaining a competitive advantage. According to Barney (1991), an organization's resources are essential for sustaining its competitive advantage. Within the context of this research, we regard GE as a crucial asset for a firm, essential for preserving its competitive advantage by facilitating the implementation of CEP and CSRP to meet the requirements of different stakeholders and achieve SFP. Additionally, the stakeholder theory highlights the significance of a business to create value for different stakeholders, both internal and external (Freeman et al., 2020). Individuals or groups known as stakeholders have the potential to impact the organization's performance or influence operational effectiveness in various ways (Freeman et al., 2020). The current literature on corporate sustainability has indicated the significant role of stakeholders in a CE transition. Therefore, STP drives firms to adopt and implement environmentally sustainable production practices. In this study, CEP, GE, and CSRP are considered firm attempts to address stakeholders' environmental and social concerns.

Companies are integrated into networks of interactions that facilitate the acquisition of knowledge and the sharing of resources to foster development (Baah et al., 2023). From traditional network theory, a network is a set of linked connections wherein a modification in one relationship influences the others (Gilbert & Behnam, 2013). A network is defined by its flexibility, decentralization and social linkages (Baker, 1992). SMEs can use their network connections to obtain resources, acquire knowledge, and access expert capabilities, thereby, it could satisfy business and societal demands (Coyte et al., 2012). By leveraging network connections, SMEs can cultivate innovation to proactively respond to stakeholder demands (Baah et al., 2023). Thus, we propose that SMEs are driven by STP to utilize external resources to sustain their operation by adopting CEP. Nevertheless, securing these external supports also relies on fulfilling the social and environmental expectations of the diverse stakeholders, ultimately leading to CSRP and SFP (Harris et al., 2021).

1.2 STP and CEP

The stakeholder theory clarifies the functions of stakeholder groups in advocating for the adoption and maintenance of sustainable practices within an industry. Policymakers, suppliers, consumers, NGOs, media and communities are putting more pressure on SMEs for the increased adoption of CEP (Jabbour et al., 2020). Although SMEs recognize the significance of CE, the obstacles associated with CEP discourage their voluntary participation (Rodríguez-Espíndola et al., 2022). However, lack of STP may hinder the implementation of CEP. Furthermore, Agyabeng-Mensah et al. (2024) have linked stakeholder participation to knowledge exchange and increased consumer satisfaction. Thus, stakeholders have an even greater obligation to exert pressure regarding CE implementation due to substantial organizational slacks in SMEs (Rodríguez-Espíndola et al., 2022). Recent studies suggest that external pressures such as government directly and robustly lead to CEP adoption in SMEs, especially in an industrial setting (Agyabeng-Mensah et al., 2022; Govindan & Hasanagic, 2018). Agyabeng-Mensah et al. (2022) emphasized that SMEs which disregard STP could be unable to develop innovation capabilities and establish collaborations due to damaging publicity, loss of reputation, and potential legal action. Hence, the benefits of addressing institutional pressures have prompted widespread incorporation of green practices, including CEP (Bag et al., 2022). Accordingly, we hypothesize that:

H1: Stakeholder pressure has a beneficial impact on circular economy practices.

1.3 CEP, CSRP and SFP

Scholars including Hong et al. (2023) and Morea et al. (2021) argued that while most CE literature suggests that CEP is primarily focused on environmental issues, it utilizes the fundamental principles of CSR to accomplish sustainable development goals (SDGs), as well as societal and environmental progress. According to Aguinis (2011), CSR involves implementing organizational actions and policies tailored to specific situations, considering stakeholder expectations and the triple bottom line of economic, social, and environmental performance. The attempt of SMEs to engage in CEP through stakeholder networks elicits a further reaction to stakeholders' environmental and social concerns or demands. SMEs that neglect the social and environmental concerns of stakeholders are unable to secure CSR, hence hindering SFP. This study, based on network theory, posits that SMEs pursuing SFP and CSRP must adapt to and fulfill stakeholders' social and environmental requirements to maintain CEP implementation. Baah et al. (2023) claimed that through the mediating effect of innovation and collaboration capabilities, CEP positively impacts CSR participation in SMEs. Walker et al. (2022) also revealed that CE is a potential approach to achieving a more sustainable society using survey data of 155 firms operating in Italy and the Netherlands. Using data from EU enterprises, Dey et al. (2022) found a correlation between CE and social performance. Therefore, the adoption of CEP will result in increased engagement in CSRP.

SFP stands for the evaluation of environmental, social, and financial performance metrics within an organization (Le et al., 2022). Le et al. (2022) suggested that SFP is characterized by a collection of performance metrics that encompass a variety of financial and non-financial factors. Contemporary academic literature widely addresses the relevance of CSR in creating value for both a firm and its stakeholders. According to Hou (2019), socially responsible enterprises could gain better financial outcomes in Taiwan. Furthermore, by implementing effective CSR strategies, firms would exhibit better social and environmental outcomes. Nureen et al. (2023) claimed that through the mediation mechanism of GE and green transformational leadership, firms adopting CSR would improve their performance. The firm SFP is therefore driven by CSRP.

The implementation of CE principles exerts a beneficial influence on a company's economic, environmental, and social outcomes (Jabbour et al., 2020). Companies implementing robust sustainable initiatives can enhance the environmental sustainability of their products, thereby differentiating themselves from rival products in the market (Agyabeng-Mensah et al., 2022). Additionally, by actively incorporating sustainable practices into their operations and supply chains, these organizations demonstrate a genuine commitment to the well-being of the planet and its resources. According to Sharma et al. (2022), the implementation of environmentally conscious practices in electronic supply chain networks significantly impacts the sustainable performance of manufacturing firms over time. In Vietnam, Chowdhury et al. (2022) revealed that organizational leadership plays a critical role in fostering the development of culture and innovative capacity necessary to embrace CEP aimed at improving long-term sustainable performance in SMEs. Drawing from these justifications, we propose the following hypotheses:

H2: Circular economy practices have a beneficial impact on CSR participation.

H3: CSR participation has a beneficial impact on sustainable firm performance.

H4: Circular economy practices have a beneficial impact on sustainable firm performance.

1.4 The moderating effect of green innovation

GE involves improving software or hardware for eco-friendly purposes, such as energy conservation, pollution prevention, waste recycling, sustainable product design, and environmental management (Novitasari & Agustia, 2023). By incorporating environmental concerns and stakeholders' interests into the organization's fundamental operations, GE contributes to sustainability (Le & Govindan, 2024). Current studies elaborate that GE is seen as a catalyst for environmental performance, thereby increasing the company's green competitive edge (Aftab et al., 2022). As concerns about environmental protection grow among stakeholders like

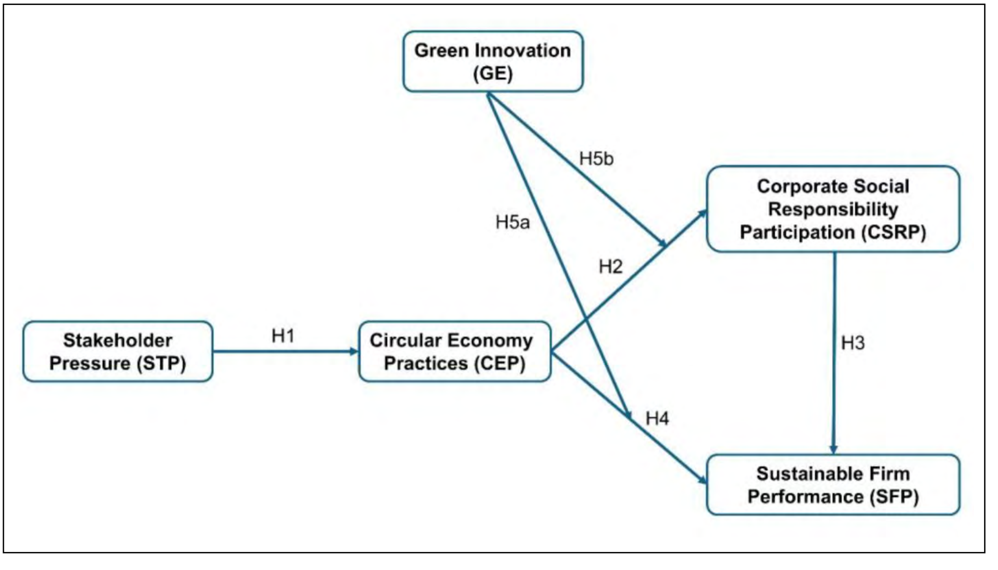

Fig. 1: Theoretical model

Source: own

governments, environmental organizations, consumers, communities, and the media, GE is gaining attention from policymakers and academics. This is due to its potential to simultaneously reduce pollution and increase profits, allowing companies to enhance resource productivity and offset environmental costs (Baah et al., 2024).

Despite extensive examination, a universal consensus on the nature of this relationship between CSR and innovation remains elusive (Marin et al., 2017). While some researchers argue that CSR has a positive impact on innovation (Bahta et al., 2021), others suggest that the relationship may be negative, contingent upon the type of innovation involved (Yuan & Cao, 2022). Tang et al. (2018) identified that technological innovation enhanced CSR performance and subsequently advocated for further investigation into this relationship. Yu et al. (2022) contended that command-and-control and market-based environmental rules moderate CSR fulfillment for GE and manufacturing SMEs. From the RBV theory point of view, GE is regarded as a strategic asset that is essential for maintaining a competitive advantage by advancing CSR efforts and implementing GE to meet the needs of diverse stakeholders and address their specific concerns. Consequently, GE will assist the business in maintaining a competitive advantage, thereby resulting in SFP.

According to the network theory, SMEs need to adopt new approaches to apply CEP (Agyabeng-Mensah et al., 2022). To enhance their ability to innovate, SMEs should actively participate and promote partnerships that facilitate the sharing of resources and insights with stakeholders (Agyabeng-Mensah et al., 2022). Despite the few studies mentioned above, a thorough empirical investigation into the moderating role of GE in the relationship between CEP and SFP and CEP and CSRP has not been conducted in the context of emerging markets. To bridge the gap, as graphically presented in Fig. 1, we hypothesize that:

H5a: Green innovation moderates the relationship between circular economy practices and sustainable firm performance.

H5b: Green innovation moderates the relationship between circular economy practices and CSR participation.

2 Research methodology

2.1 Sampling procedure and data collection

The population of this research was SMEs in Ho Chi Minh City, Vietnam. According to Vietnamese regulations, SMEs are businesses with fewer than 200 employees, a turnover of less than VND 100 billion (for the current and previous year), and registration with the state social insurance scheme (VNB, 2018). The economic significance of Ho Chi Minh City, which is home to nearly half of Vietnamese enterprises, led to its selection.

SMEs and their contacts were obtained with the support and acceptance of local unions of business associations and local authorities. Criteria for sample selection included company size and accurate contact information available. At the end of the sampling process,

Tab. 1: Description of sample – Part 1

Characteristics	Respondents (*n* = 381)	%
Gender		
Male	207	54.34
Female	174	45.66
Current position		
Owners	32	8.39
Top level-managers	23	6.03
Middle-level managers	49	12.86
Departmental heads	131	34.38
Supervisors	146	38.32

Tab. 1: **Description of sample – Part 2**

Characteristics	Respondents (*n* = 381)	%
Sector		
Construction	12	3.14
Manufacturing	92	24.14
Food and beverages	105	27.55
Retail	51	13.38
Electronics	26	6.82
Transportation	29	7.61
IT services	13	3.41
Others	53	13.91
Working seniority		
6–10 years	133	34.90
11–15 years	145	38.05
16–20 years	72	18.89
More than 20 years	31	8.13

Source: own

652 samples were collected. Next, we emailed the online survey link or sent the questionnaires in person to potential respondents for their voluntary participation in addition to a cover letter detailing the purpose of the study, which was obtained from local union of business associations. It is crucial to emphasize that the survey assured anonymity to respondents and collected data solely serves the objectives of this research. For the scope of this study, the target respondents are business owners, business executives and managers in SMEs.

This study employs quantitative analysis. We gathered the data between August 2023 and February 2024. Out of 652 questionnaires, a total of 418 responses were returned, indicating a 64.1% response rate. We scrutinized the data and excluded 37 answer sheets due to missing inputs, the presence of outliers, or uniform ratings across all items within a single construct. Thus, we collected 381 valid responses (accounting for a 59.2% response rate) to process further analysis. The collected data have been statistically categorized in Tab. 1.

2.2 Survey instrument

A survey was conducted using a self-administered questionnaire based on Elangovan and Sundaravel (2021). The questionnaire is translated into Vietnamese and sent to three researchers and two SME managers to ensure initial meanings. A pilot test with 25 SMEs' managers and researchers was conducted to evaluate the questionnaire's construct validity and wordings. We contacted local unions of business associations to seek their permission to access employees for research purposes. This pilot study evaluated the questionnaire's validity from the respondents' standpoint, focusing primarily on clarity, duplication, and the feasibility of respondents' answers. The outcomes of the pilot test indicated that it was appropriate to proceed with formal research. Subsequently, we sent out 652 questionnaires to participants by paper and e-mail. The questionnaire is divided into two sections: section 1 collects primary data and section 2 gathers respondent information.

Drawing insights from relevant literature, we adopted a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree), wherein participants are instructed to indicate their responses by selecting the point that aligns most closely with their beliefs regarding the respective items. The final questionnaire for the current study included 30 items. We adapted CEP from Chowdhury et al. (2022) and

Le et al. (2022). This study measured CSRP using 5 items adapted from Nazir et al. (2021) and Baah et al. (2023). SFP and GE were also measured using 7 and 6 items (Chowdhury et al., 2022; Dey et al., 2022; Le, 2022; Padilla-Lozano & Collazzo, 2021). STP was measured with 5 items adapted from Baah et al. (2023), as presented in Tab. 2.

Tab. 2: Reliability and validity of measurement model – Part 1

Constructs and items	Factor loading	Source
Circular economy practices (Cronbach's alpha: 0.880; CR: 0.908; AVE: 0.624)		
CEP1: My firm promotes saving energy consumption	0.834	Chowdhury et al. (2022) and Le et al. (2022)
CEP2: My firm uses recycled materials as inputs in our process	0.742	
CEP3: My firm ensures reuse, recycling, and remanufacturing initiatives	0.789	
CEP4: My firm prolongs duration of goods and their usage	0.812	
CEP5: My firm is proactive in creating valuable inputs for business partners in the supply chain	0.808	
CEP6: My firm is proactive in sharing certain resources to improve collective efficiency	0.750	
Corporate social responsibility participation (Cronbach's alpha: 0.874; CR: 0.909; AVE: 0.665)		
CSRP1: My firm develops CSR programs	0.801	Nazir et al. (2021) and Baah et al. (2023)
CSRP2: My firm participates in CSR activities	0.815	
CSRP3: My firm responds to community social concerns	0.811	
CSRP4: My firm operates within the norms consistent with society's values and expectations	0.824	
CSRP5: My firm operates and competes within socially and ethically accepted standards in society	0.828	
Green innovation (Cronbach's alpha: 0.891; CR: 0.912; AVE: 0.635)		
GE1: Production process uses energy saving technology	0.880	Le (2022) and Padilla-Lozano and Collazzo (2021)
GE2: In production activities, we apply recycling technology according to international standards	0.803	
GE3: Any packaging used is environmentally friendly	0.802	
GE4: In production activities, we apply waste treatment technology according to international standards	0.740	
GE5: Product research and development process is continuously improved towards green standards	0.799	
GE6: In production activities, we give priority to consuming renewable energy	0.748	

Tab. 2: Reliability and validity of measurement model – Part 2

Constructs and items	Factor loading	Source
Sustainable firm performance (Cronbach's alpha: 0.938; CR: 0.950; AVE: 0.729)		
SFP1: We have created jobs to support the community and thus contributed to nation's entrepreneurial growth	0.846	Chowdhury et al. (2022)
SFP2: We have improved work safety in recent years	0.872	
SFP3: We have improved compliance with environmental standards	0.861	
SFP4: We improve resource efficiency over time	0.844	
SFP5: We have commitment from employees and managers towards incorporating environmental management	0.852	
SFP6: We achieved profitable growth over time	0.857	
SFP7: We improve environmental performance over time	0.845	
Stakeholder pressure (Cronbach's alpha: 0.885; CR: 0.912; AVE: 0.634)		
STP1: My firm is under pressure from company's owners/shareholders to adopt circular economy practices	0.770	Baah et al. (2023)
STP2: My firm is under pressure from customers to adopt circular economy practices	0.806	
STP3: My firm is under pressure from community to adopt circular economy practices	0.803	
STP4: My firm is under pressure from suppliers to adopt circular economy practices	0.791	
STP5: My firm is under pressure from governments to adopt circular economy practices	0.807	
STP6: My firm is under pressure from media to adopt circular economy practices	0.801	

Source: own

2.3 Data analysis

The analysis incorporates the final data using the partial least square structural equation model (PLS-SEM) technique, which is recommended as the best fit for a complex model type such as the current one (Hair et al., 2021). The initial phase of the analysis involved the evaluation of the scales, constructs, and model. This evaluative process employed statistical techniques such as Cronbach's alpha, factor loading indices, average variance extracted (AVE), composite reliability (CR), the square root of AVE, and the Fornell-Larcker criterion (Fornell & Larcker, 1981). After that, the bootstrapping method was adopted to conduct an in-depth analysis of the structural constructs and the proposed theoretical hypotheses. The study's framework was extensively examined and validated using this sequential strategy.

3 Results

3.1 Common method bias

Regression analysis was conducted to investigate multicollinearity and common method bias (CMB) by evaluating the variance inflation factor (VIF). Following the guidelines of Hair et al. (2021), the model demonstrated no presence of multicollinearity and CMB problems as VIF was below 3.0 (ranging from 1.589 to 2.325). Therefore, the data were free from methodological bias or multicollinearity issues.

3.2 Evaluation of measurement model

We tested the measuring model by assessing reliability, convergent and discriminant values in Tab. 2. The reliability of the scales was confirmed, with both Cronbach's alpha indices and composite reliability (CR) exceeding 0.7 (Hair et al., 2021). In addition, we employed factor loading, average variance extract (AVE), and squared AVE to assess convergent validity (Hair et al., 2021). The factor loading and AVE values were all reported to exceed 0.7 and 0.5, respectively. The results revealed that convergent validity was satisfied.

Furthermore, we used the square root of AVE and correlations between latent variables to test for discriminant validity. According to Fornell and Larcker (1981), discriminant validity is satisfied when the square root of AVE surpasses the correlation coefficients below it. As shown in Tab. 3, the square root of each construct's AVE met Fornell and Larcker's requirements. Therefore, discriminant validity is satisfactory. In addition, the heterotrait-monotrait ratio of correlations (HTMT) values were all below 0.9 in Tab. 4, a recommended threshold value, thus corroborating the discriminant validity evidence.

We also examined the relevance of our proposed model by SRMR, NFI and R^2. The results were acceptable (SRMR = 0.044 < 0.08; NFI = 0.916 > 0.9). R^2 values were 0.429, 0.453, and 0.642 for CEP, CSRP, and SFP, respectively, surpassing the acceptable threshold (>0.1) recommended by Falk and Miller (1992). Furthermore, Cohen's *f*-square (f^2) is a standard metric for assessing effect size, quantifying the relative significance or impact of an independent variable on a dependent variable. The results showed that CEP has a large effect size on CSRP with f^2 = 0.665 and a medium effect size on SFP with f^2 = 0.236, while CSRP also has a medium effect size on SFP with f^2 = 0.253. Finally, STP on CEP has a large effect size with f^2 = 0.753.

Tab. 3: Fornell-Larcker criterion

	CEP	CSRP	GE	SFP	STP
CEP	**0.790**				
CSRP	0.654	**0.816**			
GE	−0.075	0.030	**0.797**		
SFP	0.704	0.714	−0.074	**0.854**	
STP	0.655	0.404	0.002	0.463	**0.796**

Source: own

Tab. 4: Heterotrait-monotrait (HTMT)

	CEP	CSRP	GE	SFP	STP
CEP					
CSRP	0.725				
GE	0.080	0.068			
SFP	0.761	0.786	0.085		
STP	0.736	0.459	0.070	0.508	

Source: own

3.3 Result of hypothesis testing

The correlations were determined by analyzing the path coefficients and *p*-values. After confirming the reliability and validity of the measurement model and verifying the overall model fit, the hypothesized routes and coefficients were assessed using bootstrapping with a resampling size of 5,000. The structural equation modeling (SEM) and bootstrapping outcomes are provided in Fig. 2 and Tab. 5.

The results show a strong positive impact of STP on CEP (*H1*: path coefficient = 0.655, p < 0.001). Similar positive relationships were found for *H2*, *H3*, and *H4* between CEP and CSRP, CSRP and SFP, and CEP and SFP,

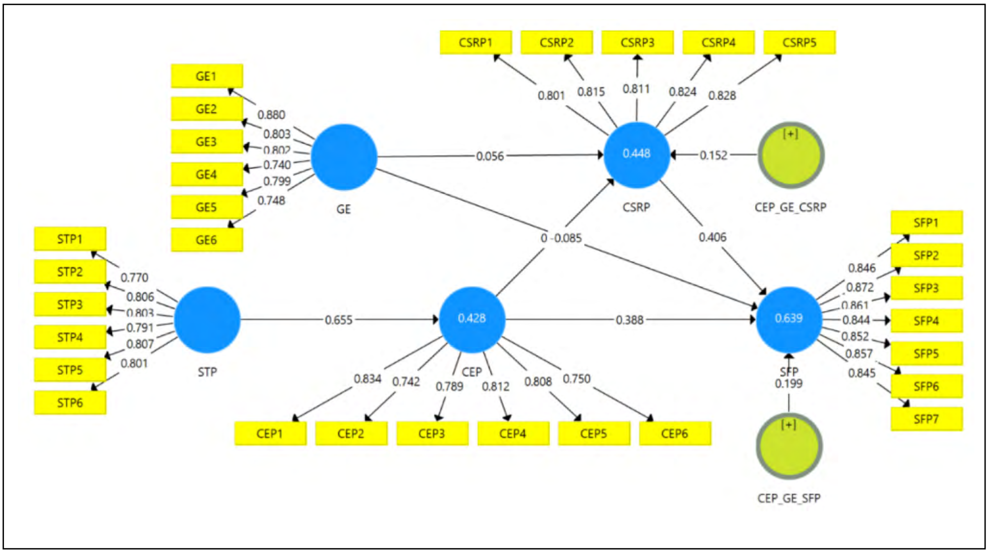

Fig. 2: **SEM testing diagram**

Source: own

Tab. 5: **Path analysis and hypothesis testing**

Hypothesis	Relationship	Path coefficient	Standard deviation	*t*-value	*p*-value	Remarks
H1	STP → CEP	0.655	0.028	23.774	0.000	Supported
H2	CEP → CSRP	0.624	0.039	16.206	0.000	Supported
H3	CSRP → SFP	0.406	0.048	8.420	0.000	Supported
H4	CEP → SFP	0.388	0.048	8.007	0.000	Supported
H5a	CEP * GE → SFP	0.199	0.056	3.553	0.000	Supported
H5b	CEP * GE → CSRP	0.152	0.053	2.879	0.004	Supported

Source: own

respectively (path coefficients: 0.624, 0.406, 0.388; all $p < 0.001$). These findings align with Baah et al. (2023). Additionally, the analytical results pinpoint that GE generally moderate relationships between GE and CEP on SFP (*H5a*: path coefficient = 0.199, $p < 0.001$) and CSRP (*H5b*: path coefficient = 0.152, $p < 0.001$).

4 Discussion

Using the RBV theory, stakeholder theory, and network theory, this study examined how SMEs can accumulate resources to enhance CSRP and achieve SFP by adopting CEP. Jabbour et al. (2020) noted that the variability in findings concerning STP and CEP highlights the importance of contextual factors, including institutional voids, in understanding the relationship between these two concepts. Our findings support the previous results that STP has a positive and significant impact on CEP (Agyabeng-Mensah et al., 2024; Jabbour et al., 2020). Consistent with the findings of Agyabeng-Mensah et al.

(2024), we further elucidate that STP from governments, suppliers, customers, and society significantly influences SMEs' adoption of CEP. The results also reinforce the findings of Dey et al. (2022) that SMEs' motivation to implement CE is affected by both internal and external stakeholders in the EU context. However, these findings challenge the claim of Govindan and Hasanagic (2018) that governments are the primary influencing factors of CEP because of their authority.

The results of this study suggest that the implementation of CEP significantly enhances SMEs' CSRP and contributes to improved SFP. The study results for the current dataset are entirely consistent with the recommendations from prior theoretical and empirical studies, supporting the assertion that CE practices will improve the sustainable performance of corporate organizations (Chowdhury et al., 2022). These findings are consistent with the research of Hong et al. (2023) and Baah et al. (2023), who also demonstrated that the implementation of CEP results in an increase in CSRP. Furthermore, the positive impact of CEP on SFP corroborates recent studies, such as those by Chen and Dagestani (2023) and Le et al. (2022), which indicate that greater emphasis on CEP correlates with higher levels of sustainable performance. However, this study challenges the perspective of Padilla-Rivera et al. (2020), who argued that CEP primarily focuses on environmental concerns while neglecting social issues.

Furthermore, the moderation results show that GE, a resource efficiency promoter, plays a crucial role in fostering the relationship between CEP and SFP, as well as CSRP in SMEs, underscoring the novelty of this study. Farza et al. (2021) highlighted that existing research on the link between biodegradable innovation and corporate performance shows mixed results. This study extends the findings of Bag et al. (2022) and Le and Govindan (2024), demonstrating that GE not only positively and significantly influences SFP, but also generally moderates the correlation between CEP and SFP in SMEs in emerging economies. Furthermore, the outcomes support findings of Yu et al. (2022) on the interrelation between GE and CSR, stating that GE moderates the association between CEP and CSRP. This study demonstrates that green innovation benefits both the environment and business by enhancing corporate social responsibility and sustainable performance. The potential explanation could be that SMEs, often resource-constrained, need to utilize GE in processes, products, energy-saving technology, and waste management to foster CEP to meet stakeholders' demands (CSR participation) and enhance SFP.

4.1 Theoretical implication

The present work makes the following contributions to the theory. First, the study enhances expanding the existing literature on CEP and its association with SFP by depicting a further understanding of how GE could strengthen SMEs' sustainable performance. Therefore, the study addresses the concerns raised by Cillo et al. (2019), who emphasize the importance of innovation for development; nevertheless, innovation aimed at sustainability remains fragmented in existing literature. Additionally, this study also extends the current literature on GE and corporate performance by introducing additional dimensions, offering a more multifaceted perspective compared to Tang et al. (2018). Thus, this study extends RBV theory and stakeholder theory by validating their applicability in a setting where CEP, CSRP, and GE are integrated as strategic resources for attaining sustainable performance.

Second, drawing insights from the network theory, SMEs need to cope with stakeholder pressures to mitigate resource constraints. This facilitates networking with stakeholders, enhancing GE and access to external resources. In contrast to the assumption that SMEs overlook environmental and social issues because of limited resources, our findings, aligning with Baah et al. (2023), demonstrate that SMEs could mitigate resource constraints and enhance CSRP and SFP through the deployment of CEP.

As a third contribution, despite criticisms that CE fails to address social concerns (Corvellec et al., 2022), empirical research addressing this gap is limited. This study heightens our understanding of the linkages between CEP, CSRP and SFP by depicting the moderating effects of GE on these relationships in emerging economies. This indicates that CE enhances responses to social issues through increased CSRP, facilitated by GE mechanisms that support CEP. By embracing CEP, SMEs can create eco-friendly products that satisfy customer demands and address social concerns.

4.2 Practical implication

This study provides some practical implications for government policy makers, SMEs' managers, and senior leadership to develop an organizational wide strategy for managing and adopting CE philosophy. First, SME managers can leverage STP to obtain essential resources in emerging markets. By addressing stakeholder demands, they can strive for improved sustainable performance, stakeholder satisfaction, and increased profitability. Through this approach, SMEs could appeal to various stakeholders and establish a positive reputation, ultimately enhancing their sustainable performance. Second, the results indicate that the adoption of CEP is essential in addressing social concerns. Therefore, we recommend that managers of SMEs should adopt CEP to improve their CSR in addition to financial and environmental gains. Third, this study also provides managers and professionals with insights by elucidating green innovation in firms' strategies. This indicates that Vietnamese SMEs require enhanced awareness of green innovation for an effective long-term strategy. Green innovation needs to be regarded as a cost-reducing element that enhances efficiency and competitiveness, rather than an expensive factor (Le & Govindan, 2024). Fourth, government policymakers should establish a framework and onboarding plan to enhance managers' and decision-makers' comprehension of CE concepts, practices, and strategies, thereby fostering the skills and competencies necessary for effective CE adoption. Policymakers can facilitate the adoption of CEP and access to sustainable technologies for SMEs through the implementation of subsidies and technology-driven sustainability supporting programs. Such policies will enhance innovation, collaboration, and environmentally and socially sustainable practices that foster clean production and CSR performance.

Conclusions

This paper aimed to explore how CEP responds to social concerns by examining the connection between STP, CEP, CSRP, SFP and GE of SMEs in Vietnam, utilizing RBV theory, stakeholder theory and network theory. The main finding of this study suggests that, contrary to the current CE literature, implementing CEP in conjunction with STP would significantly enhance CSRP and SFP in SMEs. Although resource scarcity is a significant issue for SMEs, this study demonstrates that they can address these concerns and access external resources by responding to STP. Furthermore, GE is another strategy that could enhance SMEs' sustainability. Integrating GE into production would assist companies in the adaptation of CEP, thus supporting CSRP and sustainability. Overall, this study offers insights into management and theory, highlighting its importance for business professionals, top and middle management, and legislators. Furthermore, this study contributes to addressing present social and environmental challenges in Vietnam.

Despite the relevance of the research, certain limitations must be addressed. The research primarily concentrates on developing nations, potentially limiting the generalizability of its conclusions. Additionally, the reliance on self-reported data may introduce response bias and social desirability bias, thereby potentially compromising the accuracy of the findings. Firstly, the specific focus on the Vietnamese environment limits the generalizability of the study findings. Future research endeavors should strive to include more diverse and representative samples, gathered from various geographic locations and differing circumstances, to effectively address the constraints identified. Secondly, as this research model used GE as a moderator, future research could consider incorporating green organizational factors and AI application into the proposed model to understand the relationship between CEP and SFP. This indicates a promising direction for future research to develop and validate new variables that effectively capture the distinctive aspects of the CEP landscape. Thirdly, a longitudinal approach to data collection could be considered to better understand the relationships between variables. This strategy would enable the monitoring of CEP variations over time and facilitate the analysis of the long-term implications of SFP, thereby contributing to a more comprehensive understanding of this complex field. Furthermore, future research might delve deeper into the influence of government involvement (such as government support and environmental regulations) on CEP in developing countries. Although stakeholders' pressure is often regarded as a significant factor, it is crucial to recognize how external elements, particularly governmental actions, can facilitate the implementation of sustainability initiatives.

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Analysis of circular strategies: A case study of the food processing industry

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Abstract: *This research investigates the implementation of the circular economy in the Galician canned fish and seafood sector. This sector is crucial, producing 225,000 t annually and representing 75% of Spain's total production, significantly contributing to the regional economy and employment. Moreover, this industry significantly contributes to the regional economy employing around 12,000 people. Using the PESTLE methodology, the study systematically and holistically examines the most relevant systems and actors in the sector. The analysis is complemented by a SWOT analysis, enriched through brainstorming sessions with 24 industry experts who evaluated and scored each factor's importance from 0 to 1. From the analysis of the external environment of the circular strategy that the industry is exposed to and does not control, economic uncertainty is identified as the main threat (0.8) and technological innovation as the main opportunity (0.9). The internal environment analysis, influenced by the industry's current situation, identified the main weakness of the circular strategy as high implementation costs, and the main strength is institutional and regulatory support (0.9). The results highlight significant institutional and regulatory support, availability of public subsidies, and strong technological and research capabilities as major strengths. However, the sector faces challenges such as dependence on public funding, high implementation costs, and a lack of qualified workforce. Opportunities include growing demand for sustainable products and technological innovation, while threats encompass economic uncertainty and global competition. The conclusions emphasize the need for strategic management of these factors to ensure the successful adoption of circular economy practices. Specifically, enhancing collaboration between the public and private sectors, increasing investment in innovation and workforce training, and leveraging favorable legislation are crucial for improving the sector's sustainability and competitiveness. By strategically managing these elements, the Galician canned fish and seafood sector can not only enhance its environmental sustainability but also achieve greater economic resilience and market competitiveness. This comprehensive approach ensures that the sector can effectively transition to a circular economy, benefiting both the environment and the industry's long-term viability.*

Keywords: *Processing fish industry, green strategy, strengths, weaknesses, Spain.*

JEL Classification: *O30, O40, O50, Q50.*

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Introduction

The implementation of the circular economy in the Spanish canning industry is of utmost importance. The circular economy model can generate new sources of income and improve resource efficiency in this sector (Fernández-González et al., 2024a). In the fast-growing consumer goods industry, including canned food, around 80% of the material value of EUR 3.2 million is lost annually due to the predominant linear economic approach (Teigiserova et al., 2020). Adopting circular economy principles can enable the Spanish canning industry to recover and reuse valuable resources, reducing waste and environmental impact (Fig. 1).

Several studies have highlighted the significant benefits of applying the circular economy in the food processing industry. According to a study by Cortés et al. (2021), the canned fish industry in Spain is adopting the principles of the circular economy by implementing strategies such as waste reduction, material reuse and eco-design to promote sustainable production processes. Furthermore, research by Laso et al. (2018) highlights the importance of collaboration between stakeholders in the canned fish industry to effectively implement circular economy practices. By fostering partnerships with suppliers, manufacturers and consumers, the industry can streamline its operations, optimize resource utilization and promote a closed-loop system that minimizes waste generation. In addition, other research has shown that circular economy business models can improve the resilience and competitiveness of food producers in the face of supply chain disruptions and resource scarcity (Contreras et al., 2022; Cooney et al., 2023).

This analysis focuses on the study of the implementation of the circular economy in the fish processing industry in Galicia. Galicia is a Spanish region, located in the northwest of the Iberian Peninsula, leader in the processing and preservation of seafood products in Spain. This region has the highest figures for number of companies (55%), production (75%), turnover (69%), exports (74%) and jobs (56%) in Spain (EUMOFA, 2024). The fish and seafood canning industry in Galicia is fundamental to the region's economy, representing about 3% of the Galician GDP (Fernández-González et al., 2024a).

Historically, the Galician processing fish industry is a sector with a long tradition dating back to the 19th century (Madariaga & García del Hoyo, 2019). Politically, it is a strategic sector that receives institutional support for

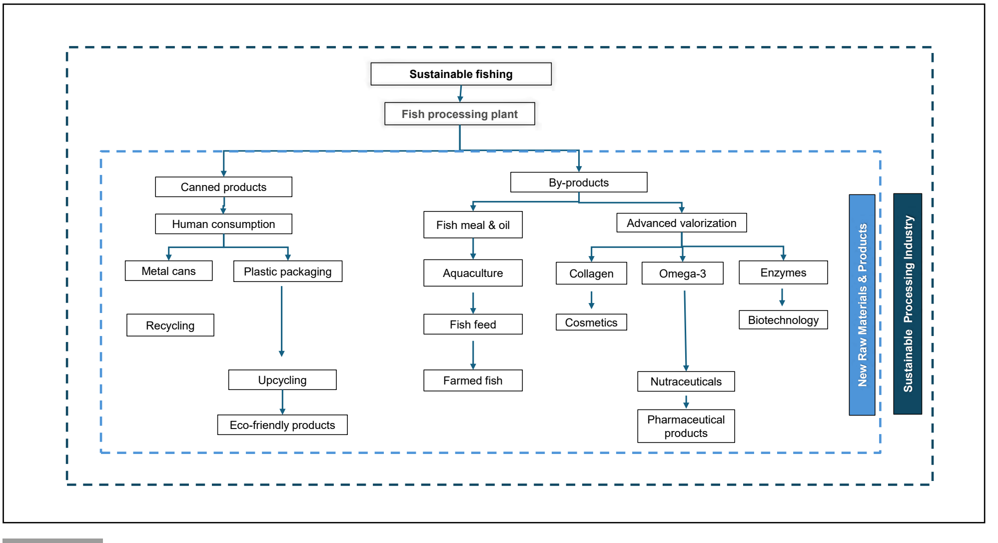

Fig. 1: Circular strategies in the fish processing sector

Source: own

its development and modernization from the central government, but, above all, from the regional government and the association of canning producers in Spain. The implementation of the circular economy in this industry is crucial, as it promotes sustainability and efficiency in the use of resources, reducing waste and improving competitiveness. Compared to other regions in Spain and Europe, Galicia stands out for its leadership in the adoption of circular practices, although it faces similar challenges, such as the need for innovation and efficient resource management (Fernández-González et al., 2024b). But what has really boosted the circular economy in this industry has been the collaboration between institutions and companies in Galicia, promoting significant advances.

The academy has carried out several studies on the fish processing industry sector focusing on its history (Carmona, 2022; Fernández-González et al., 2024a; Villasante et al., 2021), the socio-economic analysis of the implementation of the circular economy (Cortés et al., 2021; Fernández-González et al., 2024b), or the technical analysis of circular economy practices implemented in the canning sector applied to species such as anchovy, tuna or mussels (Entrena-Barbero et al., 2023; Fraga-Corral et al., 2022; García-del-Hoyo et al., 2021; Laso et al., 2016, 2018; Vázquez et al., 2024). However, there has not yet been a multidisciplinary article that holistically analyses the factors involved in the success or failure of the production model of a linear economy to a circular economy in the Galician fish processing industry. In fact, this is the objective of the article, which will use PESTLE and SWOT analyses. The latter technique will be evaluated and scored by experts to attribute different degrees of importance to the factors that make up the SWOT analysis tool.

1 Theoretical background

The fish and seafood canning industry in Galicia has a rich history characterized by resilience and adaptability. It began in the late 19th century, driven by the scarcity of sardines in France, which led to the importation of canning techniques and the utilization of Galicia's excellent raw materials. During World War I, industry flourished, with Galicia becoming a significant center for canned fish and seafood production. However, economic crises and export difficulties between 1930 and 1980 led to diversification into new products such as tropical tuna and the relocation of factories to other parts of Galicia (Carmona, 2022).

From an economic and strategic perspective, the industry is governed by the Regional Government of Galicia and the National Association of Fish and Seafood Cannery Manufacturers. Strategic plans have played a crucial role in maintaining and improving the sector's performance, even during economic crises (García-del-Hoyo et al., 2021). Studies show that larger companies in the sector have stronger financial structures and better compliance with strategic objectives compared to smaller companies. The sector's resilience during economic crises has been largely attributed to these strategic plans and the consolidation of large companies, which have seen increases in turnover, investment in fixed assets, and employment. For instance, between 2011 and 2018, large companies doubled their turnover, significantly increased investment in fixed assets, and boosted employment.

In terms of social and cultural impact, women have played a fundamental role in the industry, from shellfish gatherers to factory workers. The introduction of female can seamers in the early 20th century significantly changed the industry's dynamics. Additionally, the canning industry is deeply rooted in Galician culture, with a strong emphasis on preserving both tangible and intangible heritage. The industry has also exhibited diverse innovation patterns. A study identified four main innovation patterns in the Galician industry: conservative, dominated by large retailers, territory-oriented, and ecology-oriented. These patterns reflect the different strategies companies have adopted to remain competitive and adapt to market changes (Fernández-González et al., 2024a).

The evolutionary theory of the firm suggests that companies are not homogeneous units but differ in terms of their internal organizations, knowledge bases, and capabilities, which influence their innovation strategies. In Galicia, fewer than 70 companies produce around 85% of Spain's canned fish, and in the case of canned tuna, 50% of the total European production. Despite these figures, the sector has undergone a profound restructuring process over the past decades, with a strong concentration of production and an internal composition marked by heterogeneity (CYTMA, 2022).

2 Research methodology

The methodological approach used in this article is categorized into several study phases (Fig. 2). The different areas of study – social, technological, political, or legal – involved in the treatment of the recompiled information require the use of quantitative and qualitative methods. In this way, a holistic and integrated view of the factors involved in the implementation of the circular economy in the fish-canned sector is achieved. In the first phase of the study, a literature review was carried out and the following criteria were considered: blind peer-reviewed empirical articles published in scientific journals in the last decade (January 2014–October 2024), both in English and Spanish. The databases used for the search included Emerald, Google Scholar, and Web of Science, which cover significant research on the circular economy in the fish processing industry.

Other publications and magazines were useful, such as the annual reports of ANFACO-CECOPESCA, an organization that brings together more than 250 companies in the marine industry complex including the production of canned seafood and fish. The reports used by organization were the annual report and the CYTMA annual report. In addition, the quarterly publication Revista conservera has also been consulted. Another report used is the Economic report on the EU fish processing industry (STECF 21 14) (European Commission. Joint Research Centre, 2022).

As far as legal information related to the sector under study is concerned, the primary sources used are the Official Journal of the European Union, the Official State Gazette (Spain), and the Official Journal of Galicia. Plans, reports and strategies on the websites of public administrations have also been consulted.

In the second phase of the methodology, to holistically analyze the transition from the linear to the circular economic model, the critical influencing factors were identified. After conducting a comprehensive review of secondary literature, identifying both the critical factors and successful initiatives. In addition, we applied the PESTLE analysis models (political, economic, social, technological, environmental and legislative). Importantly, we also considered relevant case studies to enrich our analysis and relevant to the analysis were considered to provide a more comprehensive perspective. Through PESTLE analysis, we identified the most relevant positive and negative factors.

Finally, in the third phase, the most important factors in the sector for the transition to a circular production model are identified. These factors are classified into strengths, weaknesses, opportunities, and threats. In this way, a SWOT matrix is elaborated. The relevance of the different factors considered in the classification is weighted according to the ratings given by experts in the fish processing industry. The ratings ranged from 0 to 1, with 0 being the lowest value for the importance of the factor

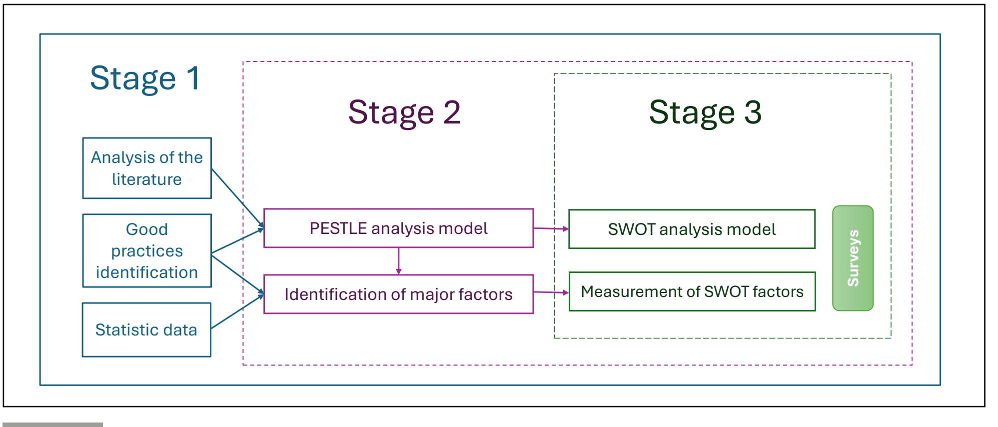

Fig. 2: Structure of the phases of methodology

Source: own

in adopting circular strategies and 1 being the highest value.

3 Results

First, a PESTLE analysis will be carried out to identify the most important factors and, finally, to assign them a degree of importance according to the assessments of the aquaculture experts consulted through the SWOT analysis.

3.1 PESTLE analysis

In this section, the elements of the PESTLE analysis will be analyzed in line with the introduction of the circular economy in the fish processing industry. PESTLE analysis, which encompasses the political, legal, economic, social, technological and ecological dimensions, will assess how these factors influence the transition towards a circular economy model. This will identify the ecosystemic and social characteristics and the actors and their interactions in which circular economy initiatives are implemented.

Political and legal challenges

The regulatory framework applied to circular economy adoption in the fish processing sector in Galicia is multilevel. Since January 1986, Spain has been a member state of the European Union, which means that regulations and decisions approved by the Council and the European Parliament are binding for Spain (Giacomarra & Bono, 2015). In addition, Spain is obliged to ensure that European directives are transposed into national legislation. Moreover, Spain has devolved part of its functions and services to its regions, including most competencies in coastal management (Rosete Verges & Sanz Larruga, 2024). Therefore, an institutional analysis from top to bottom of three public administrations, European, national and regional, is necessary (Tab. 1).

We will, therefore, begin by analyzing the European legal framework applicable to our case study. The first relevant European regulatory step was the approval of the European Bioeconomy Strategy (Tab. A1; Appendix) in 2015. Its subsequent update, in 2018, is committed to the sustainable and circular bioeconomy of land and sea, the latter being the inputs of the Galician canning industry. The Circular Economy Action Plan was also approved in 2015, establishing an initial regulatory framework that was replaced in 2020, when the European Commission (EC) presented a new Circular Economy Action Plan (Tab. A1; Appendix). This latest plan, which is still in force, includes more than 30 measures focused on the development of sustainable products, circularity of production processes and waste reduction.

In addition to this backbone plan in European circular policy, there are other regulations such as the ones presented below. One of these guidelines concerns harmful chemicals, which

Tab. 1: Legal structure designed to stimulate the circular economy in the fish processing sector – Part 1

Name*	Publisher	Level	Approval or proposition	Status
European Bioeconomy Strategy	European Commission	European	2012	In force
A new Circular Economy Action Plan for a cleaner and more competitive Europe	European Commission	European	2020	In force
Amending Annexes IV and V to Regulation (EU) 2019/1021 on persistent organic pollutants	European Parliament	European	2022	In force
Regulation of the European Parliament and of the Council on packaging and packaging waste	European Parliament	European	2023	In force
REPowerEU chapters in recovery and resilience plans and amending regulations (EU)	European Commission	European	2024	In force

Tab. 1: Legal structure designed to stimulate the circular economy in the fish processing sector – Part 2

Name*	Publisher	Level	Approval or proposition	Status
Empowering consumers for the green transition through better protection against unfair practices and better information	European Parliament	European	2024	Pending approval
Spanish Bioeconomy Strategy	Ministry of Agriculture, Fisheries and Food	Spanish	2015	In force
Spanish Circular Economy Strategy	Ministry for the Ecological Transition and the Demographic Challenge	Spanish	2020	In force
Long-term strategy for a modern, competitive and climate-neutral Spanish economy by 2050	Ministry for the Ecological Transition and the Demographic Challenge	Spanish	2020	In force
National Climate Change Adaptation Plan (2021–2030)	Ministry for the Ecological Transition and the Demographic Challenge	Spanish	2021	In force
Law 7/2022 of April 8, 2002 on waste and contaminated soils for a circular economy	Spanish Ministry for Ecological Transition and Demographic Challenge	Spanish	2022	In force
State R&D&I Program oriented to society's challenges	Ministry of Science and Innovation	Spanish	2023	In force
Food Loss and Waste Prevention Law	Spanish Ministry of Agriculture, Fisheries and Food	Spanish	2024	Pending approval
Galician Circular Economy Strategy	Government of Galicia	Galician	2020	In force
Sectorial plan for industrial waste management in Galicia (2023–2030)	Government of Galicia	Galician	2024	In force
Law 2/2024, of November 7, on the promotion of the social and economic benefits of projects that use the natural resources of Galicia	Government of Galicia	Galician	2024	In force

Source: own

can concentrate in recycled materials. Therefore, in October 2022, the European Parliament adopted revised rules on persistent organic pollutants (Tab. A1; Appendix). These new rules include: i) a reduction in the maximum levels of persistent organic pollutants; ii) the obligation to incinerate or destroy materials exceeding certain levels of contaminants; iii) the inclusion of new chemicals in the list of harmful substances, including perfluoro hexane sulphonic acid (PFHxS), used in the production of food packaging (Heuser, 2022).

Another regulation that directly affects the canning industry is the 2020 regulation on packaging reduction. The new rules focus on reducing packaging and making all packaging recyclable, banning persistent pollutants used for flame retardants or packaging sealing, and setting a minimum target for packaging recycling (Halkos & Aslanidis, 2024). Regarding energy savings, the RePowerEU regulation approved the provision of funds to member countries to save energy, produce clean energy and diversify supplies (Tab A1; Appendix). These grants are especially designed for micro and small and medium-sized enterprises, which represent 60% of the fish processing industry.

In addition to the above regulations already approved, there is also a proposal to combat greenwashing on environmental claims, neutral impact or sustainability of a product without going through strict control. These assessments, when the regulation is approved, will also affect all those companies with organic products.

At the national level, the Spanish legal framework for the circular economy is mainly based on the Spanish Circular Economy Strategy (SCES) (Tab. A1; Appendix). This strategy is implemented through three-year action plans that coordinate the measures of the General State Administration to integrate the circular economy into various sectoral policies. Among the priority sectors recognized by this plan is the fishing sector, which is closely linked to the sea-industry chain. In the canned fish and seafood sector in Galicia, this regulation is crucial for improving the efficiency of water use, reducing emissions of industrial pollutant gases, and reducing and recovering food waste.

In addition to the SCES, other initiatives promote the circular economy in the canned fish and seafood sector. The National Plan for Adaptation to Climate Change 2021–2030 (Tab. A1; Appendix) encourages the adoption of technologies that reduce waste non-efficient consumption, like water recycling systems and the use of by-products. The Long-term Strategy for a modern, competitive and climate-neutral Spanish economy by 2050, among other initiatives, promotes the development of biodegradable packaging and the improvement of production processes to reduce the carbon footprint. Finally, the State R&D&I Program (Tab. A1; Appendix), oriented towards society's challenges, supports research and development projects that seek sustainable solutions. All these initiatives are relevant to the fish processing industry.

Spain also has laws that promote the circular economy. The most important of these is Law 7/2022, on waste and contaminated soil for a circular economy, which updates waste management regulations and encourages more sustainable practices (Tab. A1; Appendix). This law introduces measures such as extended producer responsibility, which obliges manufacturers to deal with the waste generated by their products. In 2024, the Food Waste and Loss Prevention Act (Tab. A1; Appendix) is currently being discussed for approval, which obliges companies to reduce food waste at all stages of the production and distribution chain. For the canning sector, this would mean optimizing processes to make the best use of raw materials, reusing by-products and improving waste management.

At regional level, Galicia has not passed comprehensive circular economy law, as Catalonia, Castilla La-Mancha, Valencia, Andalusia or Madrid have. However, Galicia does have the Galicia Circular Economy Strategy 2020–2030 (Tab. A1; Appendix). In addition, other regulations related to the circular economy that affect the fish processing industry have been approved in Galicia. The first of these is the Galician Sectoral Plan for Industrial Waste Management 2023–2030. It establishes measures for prevention, recycling and landfill restrictions until 2035. The second regulation is the Law on the promotion of the social and economic benefits of projects that use Galicia's natural resources (Tab. A1; Appendix). This law includes all industries that require the concession of water or energy storage. This law concerns the canning industry, especially vertically integrated companies that own fish farms, and those that use renewable energy.

Tab. 2: Main public subsidies for circular economy projects – Part 1

Name	Publisher	Level	Year	Total funding
Subsidies to promote the circular economy in companies for the year 2022	Ministry for the Ecological Transition and the Demographic Challenge	Spanish	2022	EUR 192 mill.
Subsidies to promote the circular economy in companies for the year 2024	Ministry for the Ecological Transition and the Demographic Challenge	Spanish	2024	EUR 26 mill.
Subsidies for the fish processing industry and aquaculture sector	Ministry of Agriculture, Fisheries and Food	Spanish	2024	EUR 20 mill.
Subsidies for the implementation of advanced solutions for the development of the circular economy in Galicia, co-financed under the Feder Galicia 2014–2020 operational program	Government of Galicia	Galician	2022	EUR 1.5 mill.
Subsidies for the implementation of advanced solutions for the development of the circular economy in Galicia, co-financed under the Feder Galicia 2014–2020 operational program	Government of Galicia	Galician	2023	EUR 1.5 mill.
Subsidies for the implementation of advanced solutions for the development of the circular economy in Galicia, co-financed under the Feder Galicia 2014–2020 operational program	Government of Galicia	Galician	2024	EUR 1.5 mill.
Subsidies in the fishing and aquaculture product processing investments for SMEs	Government of Galicia	Galician	2016	EUR 6.8 mill.
Subsidies in the fishing and aquaculture product processing investments for SMEs	Government of Galicia	Galician	2017	EUR 18.1 mill.
Subsidies in the fishing and aquaculture product processing investments for SMEs	Government of Galicia	Galician	2018	EUR 12.7 mill.
Subsidies in the fishing and aquaculture product processing investments for SMEs	Government of Galicia	Galician	2019	EUR 14.7 mill.
Subsidies in the fishing and aquaculture product processing investments for SMEs	Government of Galicia	Galician	2020	EUR 17 mill.
Subsidies in the fishing and aquaculture product processing investments for SMEs	Government of Galicia	Galician	2021	EUR 16 mill.

Tab. 2: Main public subsidies for circular economy projects – Part 2

Name	Publisher	Level	Year	Total funding
Subsidies in the fishing and aquaculture product processing investments for SMEs	Government of Galicia	Galician	2022	EUR 19 mill.
Subsidies in the fishing and aquaculture product processing investments for SMEs	Government of Galicia	Galician	2023	EUR 9.7 mill.
Subsidies in the fishing and aquaculture product processing investments for SMEs	Government of Galicia	Galician	2024	EUR 19 mill.

Source: own

Economic challenges

Green finance is necessary for the development of the circular economy. However, uncertain outcomes and incomplete institutional frameworks can paralyze or diminish the investment, if the company can make it. There are also companies that, given their low profitability margins, cannot afford to invest. This scenario may create a two-speed growth situation where companies that are successful in adopting the circular economy and others that continue to adopt a linear production model will coexist in the same sector (Kumar et al., 2024).

Therefore, if the Galician canning sector were to depend solely on private investment, this could generate a competitive advantage for companies with greater financial resources, which are mostly large and medium-sized companies, which would lead to the strengthening of their position in the market. Therefore, there is also a flow of public funds (Dewick et al., 2020).

In 2024, the Government of Spain included the processing industry of the fishing and aquaculture sector in the agri-food PERTE for the first time. This PERTE is part of the Recovery, Transformation, and Resilience Plan. The inclusion of the fish processing industry means that it can access grants of EUR 20 million. Each company must present a project with a budget exceeding EUR 1.5 million, and the grants can cover up to 50% of the investment cost. Among the projects that can be subsidized are those that enhance the circular economy by reusing materials, reducing waste, and utilizing by-products (European Commission: Joint Research Centre, Scientific, Technical and Economic Committee for Fisheries, 2024).

The Recovery, Transformation, and Resilience Plan is also the source of funding for another state aid that the fish processing industry can apply for to subsidize circular initiatives (Tab. 2). These are the calls for subsidies to promote the circular economy in companies made in 2022 and 2024, which subsidize 50% of projects ranging from EUR 100,000 to EUR 10 million. These projects must be related to: i) reducing raw material consumption; ii) eco-design; iii) improving waste management; and iv) implementing digital transformation to promote any circular economy initiative (Perramon et al., 2024).

The public administration of Galicia has also published its own grants. There are grants for the implementation of advanced solutions for the development of the circular economy, which subsidize 60% of the value of projects ranging from EUR 75,000 to EUR 200,000. Since 2016, the regional government of Galicia has been calling for grants for investments in SMEs for the processing of fishery and aquaculture products (European Commission: Joint Research Centre, Scientific, Technical and Economic Committee for Fisheries, 2023). Although these grants have a more general objective, they also subsidize circular economy projects.

In addition to financing, the lack of qualified labor is increasingly one of the biggest problems for companies with circular initiatives (European Commission. Joint Research Centre, 2024). However, there is no noticeable increase in investment in personnel qualification for these tasks (Moreno-Mondéjar et al., 2021).

Technological challenges

The implementation of the circular economy presents market barriers, including high investment in technology. According to Araujo Galvão et al. (2018), this barrier can be overcome with support from both governmental and non-governmental entities. In the case of the Galician fish processing industry, there is a transfer of public funds from governmental entities to companies in the sector to undertake circular economy initiatives. Regarding non-governmental entities, the business association of the Spanish sea-industry complex ANFACO-CECOPESCA (A-C) is a key player in advancing and implementing circular economy processes in the canning sector. A-C is associated with 250 companies dedicated to canning, freezing, semi-preserving, and other forms of seafood processing. More than 75% of the companies in the Galician canning sector are part of this association (Carmona, 2022).

The research and technological advances in the circular economy driven by A-C have focused on redesigning production processes and circular business models, life cycle analysis, energy efficiency, and water resource management. Efforts have also been made in the eco-design of processes, products, and packaging to minimize environmental impact.

There are two distinct stages in the technological development of the Galician canning sector driven by A-C. During the first stage, between 2007 and 2015, involvement was regional, both in research projects and in many interactions between stakeholders. During this period, the value of by-products began, such as the development of alternative proteins and new bio-ingredients. In 2016, the CYTMA was inaugurated, expanding research and development capabilities, which was a milestone as it boosted A-C's research. Additionally, from 2016 to 2022, new equipment was incorporated, and the number of members increased, allowing greater collaboration with sector agents and reinforcing the implementation of the circular economy. Consequently, between 2016 and 2022, most projects were international and national, resulting in increased funding (Fig. 3).

The CYTMA Center is available to A-C partners. This allows a significant portion of the sector's companies to access technological advancements. These advancements include blue biotechnology, the implementation of emerging technologies, such as high pressure and ultrasound for food preservation, and robotics to optimize production processes.

Social challenges

The COVID-19 pandemic resulted in a year-on-year increase in retail sales of 5% in volume and

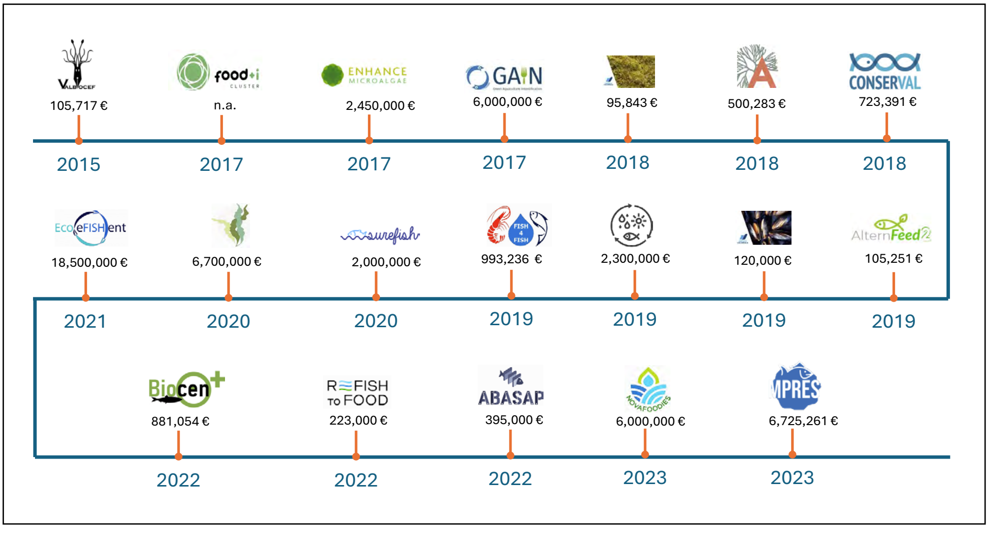

Fig. 3: **Most important circular economy projects with ANFACO-CECOPESCA as leader or partner (2015–2023)**

Source: own (based on Fernández-González et al. (2024b))

6.8% in value for the canning sector (Fernández-González et al., 2022). The reasons for this increase are home confinement and the closure of the HORECA channel. However, in 2021, the consumption index of canned goods decreased to pre-pandemic levels. This scenario marked the beginning of a downward trend that still persists in 2024, due to various factors. The first is the supply shortage and global logistical collapse, the second is the increase in industrial costs, and the third is the rise in inflation in Spain.

This trend has led to a decline in both Spanish (300,000 t) and Galician (225,000 t) canned production to levels seen 20 years ago. Additionally, due to the widespread crisis in Europe and the decline in exports within the community area, canning companies have diversified their foreign trade with transactions with countries in America and Asia (Fernández-González et al., 2022). This situation has reduced the profitability of canning companies, which have seen their profit margins decrease to minimal levels. Consequently, there is a high turnover of assets and a growing concern about cutting costs, including R&D&I expenses (European Commission. Joint Research Centre, 2022).

To be precise, R&D&I spending is a key component on the practical side of the circular economy techniques in the canned industry. Thus, progress in the comprehensive utilization of fish, the creation of by-products, the reuse of packaging, water recycling, the deployment of green energy, the optimization of energy processes, and the digitization of the supply chain is slowing down.

On the other hand, the consumption of final products derived from circular practices, which are often labeled as organic or ecological, has stagnated. This trend coincides with the increase in sales of distributor-branded canned goods to the detriment of producer-branded ones, as well as the increase in canned goods of cheaper species such as mussels, sardines, or mackerel (Ministerio de Agricultura. Pesca y Alimentación, 2024). The loss of purchasing power of Spanish households, along with the greater effort consumers must make regarding circular economy initiatives (Paparella et al., 2023), has resulted in the limited penetration of such canned products.

Environmental challenges

The activities of fish and seafood canning companies entail the potential for environmental contamination. To prevent this industrial pollution, legislative burdens have progressively increased. The Galician canning industry is subject to community laws (Directive 2010/75/EU on industrial emissions), national laws (Law 22/2011 on waste and contaminated soils; Law 29 on marine environment protection), and regional laws (Industrial Emissions Regulation – Royal Decree 815/2013); Law 7/2008 on landscape protection of Galicia; Decree 7/2019 on environmental inspection of Galicia; Galicia Industrial Waste Management Plan 2023–2030; Law 6/2021 on waste and contaminated soils of Galicia) (Tab. A1; Appendix).

This regulatory framework aims to reduce excessive water and energy consumption, decrease the pollutant load of liquid discharges, reduce the overuse of fish or seafood, excessive consumption of packaging, limit the generation of hazardous waste, and reduce the emission of polluting gases (Ortiz-Martínez et al., 2023). The Galician canning industry is implementing environmentally friendly and circular economy practices, and some have obtained certifications to this effect. These initiatives are of vital importance as most canning companies are in areas of special environmental protection, with even stricter environmental regulations (Fig. 4).

Several Galician canning companies, including Conservas Calvo, Frinsa, Jealsa, Conservas Rianxeira, Conservas Albo, Conservas Pescamar, Conservas Orbe, Conservas Antonio Pérez Lafuente, Conservas Daporta, Conservas La Brújula, Conservas Cerqueira, Conservas Selectas de Galicia, Conservas Lou, Conservas Portomar, Conservas Chanquete, Conservas Antonio Alonso, Conservas Peperetes, Conservas Cortizo, Conservas Boya, and Conservas Cuca, have obtained ISO 14001 certification. ISO 14001 ensures that these companies manage their processes sustainably, minimizing pollution and promoting environmentally responsible practices.

Another widely adopted environmental certification in the canning sector is ISO 50001, which guarantees efficient energy management. Companies such as Frinsa, Jealsa, Conservas Calvo, Conservas Antonio Alonso, Conservas Selectas de Galicia, Conservas Lou, Connorsa, Conservas Albo, Conservas Pescamar, Conservas Orbe, Conservas Antonio Pérez Lafuente, Conservas Daporta, Conservas La Brújula, Conservas Cerqueira, Conservas Portomar, Conservas Chanquete, Conservas

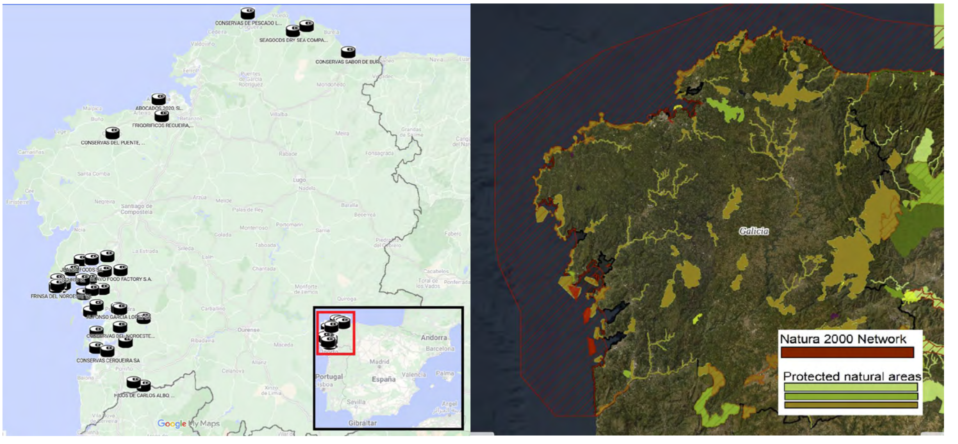

Fig. 4: Location of fish and seafood canning companies in Galicia and protected natural areas (2023)

Source: own (based on European Commission: Joint Research Centre, Scientific, Technical and Economic Committee for Fisheries (2024))

Peperetes, Conservas Cortizo, Conservas Boya, and Conservas Cuca have obtained these certifications. Additionally, Conservas Albo also holds the EMAS Certification (Eco-Management and Audit Scheme), and Conservas Calvo, Frinsa, Jealsa, Conservas Albo, Connorsa, and Conservas Antonio Alonso have obtained Integrated Environmental Authorization (AAI).

3.2 SWOT analysis

The SWOT approach was carried out considering the main characteristics of the following previous section of the research article, identifying the key factors that constitute the strengths, weaknesses, opportunities, and threats of the canning sector. This analysis was complemented by a brainstorming session with industry experts, who evaluated the importance of each factor, scoring them from 0 to 1 (Tab. 3). The weighted scores from the 24 participating experts are presented below, providing a detailed and quantified view of the critical elements affecting the sector, thereby facilitating informed strategic decision making.

Tab. 3: SWOT analysis of the circular economy in the canned fish and seafood sector in Galicia

Weaknesses	Strengths
Dependence on public funding: 0.7 Lack of qualified workforce: 0.6 High implementation costs: 0.8 Reduction in R&D spending: 0.7	Institutional and regulatory support: 0.9 Public subsidies and grants: 0.8 Technological and research capabilities: 0.8 Environmental certifications: 0.7
Threats	**Opportunities**
Economic uncertainty: 0.8 Global competition: 0.7 Supply chain disruptions: 0.7 Greenwashing: 0.6	Growing demand for sustainable products: 0.8 Technological innovation: 0.9 New markets: 0.7 Favorable legislation: 0.8

Source: own

3.3 Discussion

The results of this study on the implementation of the circular economy in the canned fish and seafood sector in Galicia align with several findings from previous research. For instance, Hossain et al. (2024) also found that the adoption of circular economy strategies, such as waste reduction, material reuse, and eco-design, promotes sustainable production processes in the canned fish industry in Spain. This study, like ours, underscores the importance of stakeholder collaboration to optimize resource utilization and minimize waste generation.

Furthermore, Barbhuiya et al. (2024) highlighted the relevance of collaboration among suppliers, manufacturers, and consumers to effectively implement circular economy practices. This collaborative approach is essential for creating a closed-loop system that minimizes waste generation, which is consistent with our findings on the need for strategic alliances in the Galician sector.

Another relevant study by Massari and Giannoccaro (2024) demonstrated that business models based on the circular economy can enhance the resilience and competitiveness of food producers in the face of supply chain disruptions and resource scarcity. Our results also indicate that technological innovation and the growing demand for sustainable products represent significant opportunities for the canned fish and seafood sector in Galicia.

Despite these similarities, there are also discrepancies between our results and those of other studies. For example, while Castro-Lopez et al. (2023) emphasize that regulatory support and technological capabilities are sufficient to drive the circular economy, our findings suggest that these factors, although important, are not sufficient on their own. Our study reveals that dependence on public funding and a lack of a qualified workforce are significant barriers that must be addressed to ensure long-term sustainability.

Additionally, Dewick et al. (2020) argue that private financing is a key driver for the circular economy. However, our results indicate that in the Galician canned fish sector, public financing remains crucial due to high implementation costs and the low profitability of many companies. This discrepancy highlights the need for a more balanced approach that combines both public and private financing.

Another notable difference is found in the study by Moreno-Mondéjar et al. (2021), which suggests that investment in personnel qualification is a growing priority in companies with circular initiatives. In contrast, our findings show that despite the recognized importance of personnel qualifications, there has not been a significant increase in investment in this area in the Galician canned fish sector.

To solve the problem of the lack of qualified labor, the solution involves developing training and qualification programs, collaborating with technical schools, universities and professional training centers to create specific courses aimed at the needs of the canning and fish processing industry, Implementing awareness campaigns to attract young people to the industry, highlighting career opportunities and the importance of the sector for the economy and sustainability, Investing in automation and advanced technologies can reduce dependence on skilled labor, while increasing efficiency and productivity.

Providing better working conditions, including competitive wages, benefits and a safe and healthy work environment, can help retain and attract qualified workers. In some cases, it may be necessary to use foreign labor to fill skills gaps. This requires favorable immigration policies and effective integration programs. The identified similarities and discrepancies in this discussion have important implications for the implementation of the circular economy in the canned fish and seafood sector in Galicia. The alignment with previous studies underscores the validity of our findings and reinforces the need for collaboration and regulatory support. However, the discrepancies highlight critical areas that require additional attention, such as dependence on public funding and the lack of a qualified workforce.

To address these barriers, we recommend a comprehensive approach that includes specific financing mechanisms for the circular economy, training and skill development programs, and policies that encourage private investment. Additionally, it is essential to promote technological innovation and stakeholder collaboration to maximize the benefits of the circular economy.

There are several technological challenges necessary to develop the circular strategy of the processed fish industry, namely, automation and robotics to increase efficiency and reduce operational costs, however the integration of these systems requires high investments and specialized training; advanced processing technologies, and quick-freezing techniques to improve fish quality and safety; artificial intelligence (AI) to optimize production processes and manage the supply chain; Non-thermal technologies for fish conservation can reduce thermal degradation and increase conservation efficiency (CYTMA, 2023).

There are several barriers to the adoption of technologies, namely the very significant cost, especially for SMEs, resistance to change, lack of qualified labor that prevents the implementation or maintenance of advanced technology, the level of adequate technological infrastructures in companies that delay its updating and evolution may also be subject to strict food safety regulations and standards that take time to implement due to the need for testing, meaning approval takes longer (CYTMA, 2023).

Conclusions

Launching the circular economy in the fish-processing industry in Spain has led to several promising initiatives. One such initiative involves the recovery and reuse of valuable resources, such as recycling metal cans and reusing by-products from the canning process. For instance, some companies have developed methods to convert fish waste into fertilizers or biofuels, helping to limit the quantity of waste sent to landfills. In addition, some Spanish canning companies have explored the use of renewable sources of energy. These circular economy strategies have enabled industry to minimize waste, increase resource efficiency, and enhance overall sustainability. Furthermore, the industry is exploring the use of innovative technologies, such as advanced sorting and processing methods, to recover and reuse a broader range of materials, maximizing the value derived from their resources. The application of the circular economy has also fostered collaboration among canning companies, as they work together to share best practices and develop new circular solutions.

However, it is important to note that private investment is influenced by structural, operational, financial, technological, and institutional barriers. To implement circular strategies, companies must rethink all their production processes. This includes designing products with their end-of-life in mind, using renewable materials, and creating systems for collecting and recycling items after use. Adopting business models that prioritize service over ownership can also help reduce consumption and promote a more sustainable approach. Nevertheless, getting to circularity is not without challenges. Companies must overcome obstacles such as the high costs of new technologies, the need for extensive collaboration across supply chains, and resistance to change from stakeholders accustomed to traditional practices. As organizations work to adopt circular strategies, they must overcome these obstacles to fully reap the benefits of sustainability and business transformation.

The adoption of circular economy principles in the Spanish canning industry can enable the recovery and reuse of valuable resources, significantly reducing waste and environmental impact. This aligns with the EU's Circular Economy Action Plan, which aims to make sustainable products the norm and boost the reuse of materials in the economy. By adopting circular practices, the Spanish canning sector can contribute to the EU's climate goals and support the changeover to a more sustainable future.

The implementation of the circular economy in the Galician canned fish and seafood sector presents a complex and multifaceted landscape, characterized by a series of strengths, weaknesses, opportunities, and threats that must be carefully managed to ensure success. The sector benefits from strong institutional and regulatory support at the European, national, and regional levels, providing a favorable framework for the adoption of circular practices. The availability of public subsidies and grants is another key factor facilitating the transition to a circular economy. Additionally, technological and research capabilities, driven by centers like CYTMA and associations like ANFACO-CECOPESCA, are fundamental for developing and implementing sustainable innovations. The attainment of environmental certifications by many companies in the sector also highlights their commitment to sustainability.

However, dependence on public funding can limit the long-term sustainability of these initiatives if funds decrease. The lack of qualified labor and high implementation costs are significant barriers that can slow progress. Additionally, the reduction in R&D spending due to the economic crisis and the need to cut costs is a concern that could negatively impact innovation in the sector. However, technological advances and market diversification towards America and Asia open new possibilities for the adoption of the circular economy.

There are several possible future lines of research that result from the analysis of the circular strategy of the processed fish industry, which could lead to the development of advanced waste recycling and reuse technologies that allow the identification of methods to convert fish waste into fertilizers or biofuels, for example, or even the transformation of by-products into new value-added resources. Study the integration of circular economy practices across the supply chain, identify strategies, collaboration measures and blocking measures between industries as they work together to share best practices and develop new circular solutions that prioritize service over property.

At the macro level, future research could focus on the Spanish canning sector, positions, and contributions by countries to the EU's climate objectives in supporting transition and sustainability. Or even investigate the relationship between technological advances and the diversification of markets towards America and Asia in the new possibilities for adopting the circular economy.

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Appendix

Tab. A1: Overview of legal documents – Part 1

Name	Publisher	Level	Date of Publication
European Bioeconomy Strategy	European Commission	European	2012
A new Circular Economy Action Plan For a cleaner and more competitive Europe	European Commission	European	2020
Amending Annexes IV and V to Regulation (EU) 2019/1021 on persistent organic pollutants	European Parliament	European	2022
Regulation of the European Parliament and of the Council on packaging and packaging waste	European Parliament	European	2023
REPowerEU chapters in recovery and resilience plans and amending Regulations (EU)	European Parliament	European	2024
Empowering consumers for the green transition through better protection against unfair practices and better information	European Parliament	European	2024
Spanish Bioeconomy Strategy	Spanish Ministry of Economy and Competitiveness	National	2015
Spanish Circular Economy Strategy	Spanish Ministry for Ecological Transition and Demographic Challenge	National	2020
Long-term strategy for a modern, competitive and climate-neutral Spanish economy by 2050	Spanish Ministry for Ecological Transition and Demographic Challenge	National	2020
National Climate Change Adaptation Plan (2021–2030)	Spanish Ministry for Ecological Transition and Demographic Challenge	National	2021
Law 7/2022 of April 8, 2002 on waste and contaminated soils for a circular economy	Spanish Ministry for Ecological Transition and Demographic Challenge	National	2022
State R&D&I Program oriented to society's challenges	Spanish Ministry of Science, Innovation and Universities	National	2023

Tab. A1: Overview of legal documents – Part 2

Name	Publisher	Level	Date of Publication
Food Loss and Waste Prevention Law	Spanish Ministry of Agriculture, Fisheries and Food	National	2024
Galician Circular Economy Strategy	Government of Galicia	Regional	2020
Sectorial plan for industrial waste management in Galicia (2023–2030)	Government of Galicia	Regional	2024
Law 2/2024, of November 7, on the promotion of the social and economic benefits of projects that use the natural resources of Galicia	Government of Galicia	Regional	2024
Directive 2010/75/EU on Industrial Emissions	European Union	European	2010
Law 22/2011 on waste and contaminated soils	Ministry of the Environment, Rural and Marine Environment, Spain	National	2011
Law 41/2010, of December 29, 2010, for the protection of the marine environment	Ministry of the Environment, Rural and Marine Environment, Spain	National	2010
Industrial Emissions Regulation (Royal Decree 815/2013)	Ministry of Agriculture, Food and Environment, Spain	National	2013
Law 7/2008 on landscape protection of Galicia	Government of Galicia	Regional	2008
Decree 7/2019 on environmental inspection of Galicia	Government of Galicia	Regional	2019
Galicia Industrial Waste Management Plan (2023–2030)	Government of Galicia	Regional	2023
Law 6/2021 on waste and contaminated soils of Galicia	Government of Galicia	Regional	2021
Catalonia Circular Bioeconomy Strategy	Government of Generalitat de Catalunya	Regional	2021
Castilla-La Mancha Circular Economy Strategy	Government of Castilla-La Mancha	Regional	2021
Valencia Circular Economy Strategy	Government of Generalitat Valenciana	Regional	2020
Andalusia Circular Bioeconomy Strategy	Government of Andalucia	Regional	2018
Madrid Circular Economy Strategy	Government of Madrid	Regional	2022

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