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Article

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INTEGRATING DIGITAL TECHNOLOGIES TO ENHANCE ESG PERFORMANCE: A FOCUS ON CENTRAL AND EASTERN EUROPEAN COUNTRIES

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Abstract

Grasping the complex interplay between digital innovation and Environmental, Social, and Governance (ESG) practices is vital for policymakers and businesses seeking to promote sustainable economic growth while complying with global sustainability standards. In this context, our paper analysed the impact of integrating digital technologies – quantified through a component of the Digital Economy and Society Index – on the ESG performance of Central and Eastern European (CEE) countries over the last 11 years. The aim of the research was to emphasise how the demands for sustainability reporting have influenced non-financial performance, generating national and organisational changes in CEE countries. Drawing on empirical studies and using panel data modelling techniques, we demonstrated that technological advancements foster operational efficiencies, green innovation, ultimately contributing to enhanced carbon emission efficiency and energy performance. In light of ongoing challenges related to varying regulatory frameworks and capacities, our findings underscored the imperative for cohesive strategies that leverage digital tools to meet sustainability goals. This research enriched the theoretical comprehension of the link between digitalisation and ESG performance while offering practical insights to strengthen the sustainability of CEE countries.

Keywords: ESG reporting; digital technologies; performance; CEE countries.

JEL Classification: C33, O33, Q01, Q56

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Introduction

The integration of digital technologies has emerged as a transformative force in various sectors, providing significant opportunities to improve environmental, social, and governance performance, particularly for Central and Eastern European countries. In light of the ongoing pressures generated by sustainability regulations and increasing consumer awareness, the adoption of innovative digital solutions has become a pivotal tool for meeting reporting obligations and improving corporate accountability.

The transformations brought about by emerging technologies – such as digitalisation and automation – have also profoundly changed the way companies operate, both internally and externally. These innovations generate challenges and opportunities, requiring rapid adaptation and integration of technologies to ensure long-term sustainability and competitiveness. In this context, operational efficiency, defined as the optimal use of resources to achieve maximum results while reducing waste and costs without compromising quality, becomes a priority. To improve operational efficiency, companies implement various strategies tailored to their industry and specific characteristics. Gomstyn and Jonker (2024) highlight several frequently used initiatives: process automation; predictive maintenance; process mapping; inventory optimisation; outsourcing of certain activities; efficient energy management; and investments in employee training. These measures contribute to increased productivity, cost reduction, and better valorisation of human resources.

This paper explores the mechanisms through which digital technologies can enhance ESG performance across CEE countries amidst the process of implementing sustainability regulations. Recent evidence underscores the importance of digital transformation in contributing to higher ESG-related practices. For instance, research has shown that companies leveraging digital technologies can enhance their operational efficiency and improve their stakeholder engagement, critical areas of ESG performance (Zhang et al., 2024). Furthermore, the ability to rapidly access and analyse data enhances transparency and accountability, thus aligning corporate operations with sustainability goals (Wu, 2024).

CEE countries, mainly characterised by transitional economies and regulatory challenges, present a unique landscape where these technologies can facilitate more effective ESG reporting and compliance with international sustainability standards. Comparative studies suggest notable variations in digital integration across different regions, with CEE countries still striving for technological adoption (Kołoszycz et al., 2024). As highlighted, the historical socio-economic context, including the legacy of post-communist structures, is pivotal in shaping the digital capabilities and legislative frameworks necessary for ESG excellence (Batrancea, 2023). Many CEE companies have not yet harnessed the potential of digital tools for sustainability, which represents an opportunity for improvement as well as a necessity for future competitiveness in the global market (Wang, He and Wu, 2024).

Tapping into digital transformation can also drive innovation and organisational change, enabling CEE nations to actively participate in achieving Sustainable Development Goals (SDGs). By strategically aligning digital advancements with environmental and social objectives, companies can cultivate more sustainable practices that generate long-term economic benefits (Camodeca and Almici, 2021).

This paradigm shift emphasises the need for a cohesive regulatory approach that encourages greater investment in digital technologies in order to valorise their potential in enhancing ESG performance. Thus, for CEE countries, integrating these technologies presents a critical

avenue for improving non-financial performance, particularly when considering the increasing regulatory demands for sustainability reporting. Understanding the intricate relationship between digital advancement and ESG practices will be essential for policymakers and businesses that aim to drive sustainable economic growth while adhering to global sustainability frameworks.

In this context, our paper examines how the integration of digital technologies (measured through a component of the Digital Economy and Society Index) has influenced the ESG performance (measured through CO2 emissions and renewable energy consumption; the ratio of female to male labour force participation rate and unemployment; regulatory quality and government effectiveness) of CEE countries over the last 11 years. The aim is to assess the relationship between digitalisation and ESG performance in the context of evolving reporting regulations, with a focus on the potential differentiated implications depending on the specific ESG component analysed.

We organised the paper as follows. A literature review that thoroughly examines the current state of knowledge and research in the area addressed, followed by a section that presents the research methodology employed and data sources. The subsequent section presents and discusses our findings. Finally, we conclude with the contributions of our study, acknowledging its limitations, and underlining avenues for future research.

1. Review of the scientific literature

The move toward sustainability reporting in the CEE countries has been continuously aligned with the European Union (EU) directives aimed at promoting transparency and accountability in corporate governance. While implementations have varied by country, the overall trend indicates a significant shift toward embracing ESG principles at the national legislative level, as present in studies documenting and analysing this transformation.

Singhania and Saini (2022) conducted a benchmarking analysis for these nations, discussing how the transition from voluntary to mandatory ESG reporting has accelerated the adoption of sustainable practices across various fields. Foltynowicz and Kaps (2022) discussed how ESG considerations have become significant in business decision-making, through examples from countries like Poland and Romania, highlighting the impact of mandatory sustainability policies on corporate behaviour and investor preferences. Petelczyc (2022) examined the readiness of CEE retail companies regarding sustainability practices, illustrating how mandatory reporting influences market dynamics and investor behaviours in the region.

The interplay between national governance structures and ESG performance has been a focal point in recent studies. Mooneepen, Abhayawansa and Mamode Khan (2022) provided valuable insights into how country-level governance impacts corporate ESG performance and disclosure. Jiang et al. (2024), who revealed that varying governance factors could differently affect both ESG performance and the transparency of reporting, confirmed their findings.

Horváth et al. (2017) provided empirical data on sustainability reporting across several CEE countries, emphasising the heterogeneous landscape of sustainability practices in this region. Their research revealed the inconsistent adoption and use of various formats of sustainability reports among countries, underscoring the necessity for tailored approaches to improve the quality and effectiveness of ESG reporting. Barjaktarović Rakočević and Benković (2023)

further examined the adoption of ESG practices specifically within the banking sector of Albania, Bosnia and Herzegovina, North Macedonia, Montenegro and Serbia. They noted that integrating ESG aspects into banking strategies has begun to transform customer perceptions and behaviours, while failure to address ESG concerns could damage banks' reputations, affecting their operational viability and customer loyalty.

Meanwhile, Zumente and Lāce (2022) explored the lagging impact of ESG practices on corporate financial performance in CEE countries, suggesting that the emerging market context may delay the benefits of ESG adoption observed in more developed markets. Such insights reveal the need for evolving internal controls and committed governance to enhance both reporting and performance synergies.

A growing body of literature notes the changing dynamics of ESG practices in the post-COVID context. Gonzaga et al. (2024) argued that crises could induce shifts in corporate behaviours regarding ESG practices, particularly within emerging markets where adaptation to global standards becomes critical. Chung, Nguyen and Nguyen (2024) confirmed that applying ESG standards improves operational efficiency, making ESG investments advisable not only during normal periods but also as a strategy for managing and overcoming the effects of potential future crises.

This finding emphasises the ongoing need for continuous evaluation of ESG reporting standards, especially in the CEE, where economic and political transitions can accelerate or hinder progress. Research also highlights the increasing importance of digital transformation in enhancing sustainability reporting by improving data transparency and operational efficiency. Thus, Aroul, Sabherwal, and Villupuram (2022) highlight the existence of a positive relationship between ESG performance and operational efficiency, and this connection is stronger in companies that already exhibit a high level of operational efficiency.

Recent research (Peng, Chen and Li, 2023) underline that digital technologies are instrumental in improving the quality and efficiency of non-financial reporting, thus achieving elevated green innovation and operational efficiency. By optimising human capital structures and using data analytics, companies can capture in a more accurate manner the impact of their activities on the environment and the society. Wang et al. (2023) stress that the extensive use of disruptive technologies significantly transforms traditional operational frameworks, thereby facilitating superior ESG performance. Chen and Ge (2025) reveal that the implementation of artificial intelligence enhances ESG performance by increasing operational efficiency and optimising human capital potential.

Furthermore, Zenkina (2023) explores the prerequisites for reliable and comprehensive ESG assessments and underscores the need for robust digital frameworks. The integration of data-driven technologies within sustainability frameworks enhances information transparency and improves investors' confidence, providing a clearer picture of the companies' commitments toward sustainable practices.

In their study, Yang and Han (2023) draw attention to the fact that digital transformation alleviates financing constraints, which can obstruct a company's capability to pursue robust ESG practices. This confirms that the use of emerging technologies facilitates better access to funding, thus positively contributing to corporate ESG performance (Zhao, 2024). Specific research has found that the digital transformation phenomenon amplifies the impact of ESG practices by improving both the quality of sustainability metrics and of disclosures. Duran and Tierney (2023) note that emerging "green" Fintech solutions support compliance with ESG standards, thus

streamlining the process of generating accurate and timely sustainability reports. These innovations are particularly beneficial for small and medium-sized enterprises (SMEs) in CEE, as they frequently encounter obstacles in adopting comprehensive ESG frameworks.

El Hazbi and Mounir (2023) argue that technological innovation significantly contributes to embracing ESG practices and outcomes, which ultimately leads to superior environmental performance. This assertion is supported by Wu and Li (2023), who outline that companies engaged in digital transformations are better positioned to improve their reporting through enhanced green innovation, illustrating how digital capabilities can directly facilitate adherence to ESG metrics.

Despite the benefits, the integration of digital technologies in ESG reporting presents specific challenges. Gladilina et al. (2024) underline the need for robust evaluation mechanisms that are often lacking, which aggravates the assessment of counterparty ESG performance. SMEs may struggle with the financial and operational burdens of investing in the necessary technologies and processes. Additionally, while digitisation offers opportunities for enhancing ESG reporting, regulatory frameworks must support these advances. Di Natale and Cordella (2023) assert that flexible and inclusive ESG regulations are crucial to fostering collaboration between private sector entities and technological experts, ensuring high-quality data integration into sustainability reporting practices.

These aspects are all the more problematic for CEE countries, as they face unique challenges in establishing comprehensive digitalisation frameworks necessary for robust ESG reporting. Brodny and Tutak (2022) reveal that the level of digitisation across various enterprise sizes in the CEE directly correlates with economic performance, suggesting that increased investment in digital skills and infrastructure is necessary. Strategies that enhance enterprise digitalisation must be developed in conjunction with supportive public policies to facilitate this shift.

Moreover, Rupeika-Apoga, Bule and Petrovska (2022) highlight the role of governmental financial support, including tax incentives, as crucial elements fostering digital transformation among SMEs in the region. These public instruments not only promote innovation, but also align with ESG goals by encouraging sustainable business practices. However, the literature reveals the need for more empirical evidence on the effectiveness of such public initiatives, reinforcing the call for targeted research.

In this context, the intersection of ESG reporting, digital transformation, and government support plays a significant role, especially in CEE countries, where these factors can greatly influence sustainability practices. This research, focused on the ESG performance indicators of CEE countries, aims to provide relevant insights for corporate reporting by highlighting the specific challenges and opportunities of emerging markets. This reinforces the idea that understanding regional ESG performance, shaped by country-level indicators, can offer valuable guidance for corporate sustainability reporting policies.

2. Research methodology

In light of our research objective and based on the findings from the previous literature review, the research hypotheses were established, identifying various research methodologies used in the scientific literature.

Jóźwik, Doğan and Gürsoy (2023) examine how digitalisation and renewable energy consumption affects environmental quality, highlighting a mediating effect that supports

enhanced environmental performance in various Central European nations. Further empirical analysis by Chen and Hao (2022) asserts that digital technologies facilitate effective communication among stakeholders, which is essential for improving environmental outcomes, as proven by other relevant studies (Xie, Zhang and Zhao, 2023; Haller et al., 2024). Thus, we have formulated hypothesis 1: *H1. For CEE countries, integrating digital technologies has a direct and substantial impact on the environmental performance.*

Studies show that digital engagement positively contributes to overall social performance of companies (Kim and Lee, 2021; Rapoliene, Gedvilaite-Kordusiene and Tretjakova, 2024). Chen et al. (2024) suggest that a well-integrated digital strategy can enhance social performance in enterprises by improving their operational efficiencies and social engagement. Additionally, Nchor and Rozmáhel (2020) underline that digital technologies may not necessarily disrupt labour markets, but could strengthen social performance by creating new job opportunities and roles. Hence, the second research hypothesis is *H2. For CEE countries, integrating digital technologies has a direct and substantial impact on the social performance.*

In terms of governance performance, Xu (2024) explores how digital governance, facilitated by robust digital infrastructure, enhances social governance in CEE countries, emphasising that effective digital government initiatives promote social outcomes by improving service delivery and citizen engagement. Visković, Burnać and Herman (2021) examine the effects of political and fiscal decentralisation on governance quality in these regions, suggesting that effective management and resource allocation, often facilitated by digital technologies, can lead to improved governance outcomes. Moreover, Brodny and Tutak (2022) provide a broader perspective on the digitisation of enterprises across CEE countries, asserting that digitalisation plays a vital role in enhancing governance performance by fostering economic growth and improving institutional capacities. Consequently, the third research hypothesis is *H3. For CEE countries, integrating digital technologies has a direct and substantial impact on the governance performance.*

Based on our research objectives and findings from the literature, for an 11-year timeframe (2013-2023), for CEE countries, we categorised the data into two groups of indicators (Table no. 1).

Table no. 1. Data used in the study

Group	Category	Variable	Abbreviation	Data source
Digital Economy and Society Index (DESI)	Integration of digital technology	Integration of digital technology - component of DESI	desiintdigtech	Digital Decade DESI visualisation tool (europa.eu, European Commission, 2023)
ESG framework	Environmental	CO ₂ emissions	co2em	DataBank (worldbank.org, World Bank, 2021)
		Renewable energy consumption	renergcons	
	Social	Ratio of female to male labour force participation rate	labforfm	
		Unemployment	unempl	
	Governance	Regulatory Quality	regq	
		Government effectiveness	goveffect	

Source: Authors' contribution

The data capturing the ESG performance dimension covers the 2013–2023 timeframe; however, for the Digital Technology Integration dimension - a component of DESI (Digital Economy and Society Index) - data is available only for the 2017-2022 period.

Next, we present the summary statistics for our data (Table no. 2), that reveal moderate CO₂ emissions per capita with significant variability influenced by economic factors and energy sources, while notable differences in renewable energy consumption and ratio of female to male labour force participation rates highlight varying economic conditions and policy impacts.

Table no. 2. Summary statistics

Variable	<i>n</i>	Mean	Standard Deviation	Minimum	Maximum
co2em	110	6.0212	2.4146	3.56	14.3
renergcons	88	23.0284	8.9954	10.7	43.8
labform	121	78.6422	4.4188	66.4	86.1
unempl	121	6.8050	3.0406	2	17.3
regq	110	0.8709	0.3713	0.2	1.7
goveffect	110	0.6573	0.4167	-0.3	1.3
desiintdigtech	66	2.8057	2.0021	-1.07	6.88

Source: Authors' contribution in STATA 18

To highlight the relationship between the integration of digital technologies and ESG performance in CEE, a graphical representation of the indicators used in the research model was created (Figure no. 1).

Within the analysed dataset, CO₂ emissions (metric tons per capita) show a moderate average value, but with significant variations across countries. Latvia records the lowest emissions (3.56), while Estonia reports the highest (12.7). This pronounced variability indicates significant national disparities, likely influenced by economic factors, regulatory policies, and the structure of the energy mix. Renewable energy consumption (as a percentage of total energy consumption) also varies considerably among the analysed countries, ranging from 10.7% in Slovakia to 43.8% in Latvia. Latvia stands out with a high share of renewable energy in total consumption, significantly contributing to reducing its carbon footprint (European Environment Agency, 2021). Its commitment to expanding renewable sources aligns with the European Union's climate objectives, reinforcing the transition to a low-emission energy sector.

The labour market analysis in the studied region reveals significant differences among countries in both female versus male labour force participation and unemployment rates. The participation ratio ranges from 66.4% (for every 100 active men there are 66.4 active women) in Romania to 86.1% (for every 100 active men there are 86.1 active women) in Estonia, highlighting generally good female involvement but also disparities shaped by economic conditions and national policies. Unemployment also shows substantial variability, with the lowest rate in the Czech Republic (2%) and the highest in Croatia (17.3%). Croatia faces challenges such as youth unemployment, reliance on seasonal tourism, low investment, and structural rigidities in the labour market (David, Wang, and David, 2024).

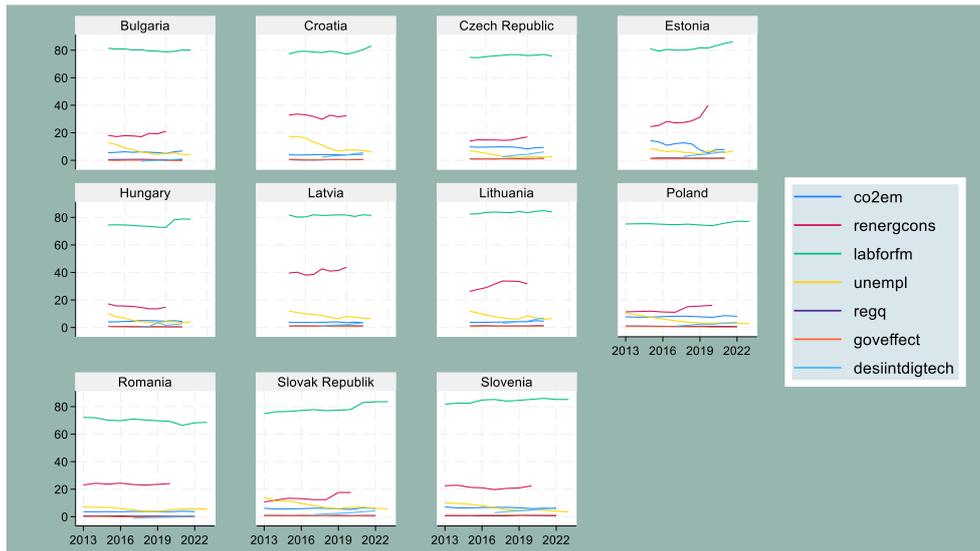


Figure no. 1. Graphical representation of the data used in the study

Source: Authors' contribution in STATA 18

Regarding regulatory quality and government effectiveness, the data analysis shows significant differences among the countries studied. Estonia stands out with the best results, while Croatia, Romania, and Bulgaria record the lowest scores. These disparities negatively influence economic performance and highlight the need to improve public policies in countries with low results. Poor performance is largely explained by the communist legacy, which led to high levels of corruption, political instability, limited institutional capacity, and low civic engagement.

The analysis of the digital integration dimension within the DESI index reveals a moderate level of variation in terms of digital readiness among CEE countries. Countries with higher scores have a more developed digital infrastructure and a deeper technological integration. Estonia stands out as the regional leader due to consistent investments in digitalisation as well as innovative initiatives such as e-Residency, digital identity, and online voting, strengthening its position as a pioneer in e-governance and digital services (Zumente and Lāce, 2022).

Considering previous empirical methodologies (Hunter and Schmidt, 2000; Bogdan, Popa and Beleneși, 2022), we used fixed effects and random effects models to address unobserved heterogeneity across different countries and time periods (equations 1 and 2).

- **Fixed effects model:**

$$Y_{it} = \alpha + \beta \text{desiintdigtech}_{it} + \mu_i + \varepsilon_{it} \tag{1}$$

where:

Y_{it} – the dependent variable (co2em, renergcons, labform, unempl, regq, goveffect) for country i at time t ;

$\text{desiintdigtech}_{it}$ – the independent variable (the integration of digital technology) for country i at time t ;

α – the intercept;

β – the vector of coefficients for the independent variable;

μ_i – the unobserved individual-specific effect (fixed effect);

ε_{it} – the idiosyncratic error term.

- **Random effects model:**

$$Y_{it} = \alpha + \beta \text{desiintdigtech}_{it} + u_i + \varepsilon_{it} \quad (2)$$

where:

Y_{it} – the dependent variable (co2em, renergcons, labform, unempl, regq, goveffect) for country i at time t ;

$\text{desiintdigtech}_{it}$ – the independent variable (the integration of digital technology) for country i at time t ;

α – the intercept;

β – the vector of coefficients for the independent variable;

μ_i – the unobserved individual-specific effect (random effect), assumed to be a random variable that is independent of the regressor $\text{desiintdigtech}_{it}$;

ε_{it} – the idiosyncratic error term.

Our analysis involved four steps. First, we performed a panel unit root test (Levin – Lin – Chu test) in order to evaluate the stationarity of panel variables within the dataset, followed by a multicollinearity test (correlation matrix) aimed at understanding the correlation coefficients between independent variables. Then, we run both a fixed effects model and a random effects model (with a Hausman test used to decide which model is more appropriate), succeeded by a Wooldridge test with the purpose of examining first-order autocorrelation. These regression models can control some of the unobserved heterogeneity specific to each country (through fixed or random effects), which may also include inherent methodological differences, allowing for a more robust estimation of the relationships between the variables considered. Additionally, these methods are designed to manage the panel data structure, enabling valid inferences even with a smaller number of observations per entity (country) over the years, as long as there is sufficient variation over time (Hunter and Schmidt, 2000).

3. Results and discussion

For the Panel unit test (table no. 3), results show that the null hypothesis of non-stationarity for the relevant variables is mainly rejected at standard significance levels, implying that, in general, the panel variables exhibit stationary characteristics.

Table no. 3. Panel unit root test

Variable	Adjusted t - stat	p - value
	Levin-Lin-Chu	Levin-Lin-Chu
co2em	-2.3175	0.0102
renergcons	-0.9193	0.0790
labform	-0.6657	0.0528
unempl	-5.9977	0.0000

Variable	Adjusted <i>t</i> - stat	<i>p</i> - value
	Levin-Lin-Chu	Levin-Lin-Chu
regq	-1.1220	0.1309
goveffect	-3.5944	0.0002
desiintdigtech	1.2648	0.0977

Source: Authors' contribution in STATA 18

Next, in order to verify the multicollinearity among the exogenous variables, the correlation matrix was generated (Table no. 4). Results showed no multicollinearity problems in the models (as the coefficient of the variables is < 0.8).

Table no. 4. Correlation matrix

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) co2em	1.000						
(2) renergcons	-0.366***	1.000					
(3) labform	0.049	0.483***	1.000				
(4) unempl	-0.320***	0.308***	0.179**	1.000			
(5) regq	0.534***	0.177*	0.371***	-0.155*	1.000		
(6) goveffect	0.346***	0.268**	0.581***	0.073	0.722***	1.000	
(7)desiintdigtech	0.259**	0.212	0.616***	0.018	0.557***	0.746***	1.000

Source: Authors' contribution in STATA 18

The subsequent step involved the development of fixed and random effects models. These models were systematically estimated on three distinct panels. Panel 1 tested the dependency between integration of digital technology (desiintdigtech) and the environmental metrics (co2em and renergcons) (Table no. 5.a). Panel 2 tested the dependency between integration of digital technology (desiintdigtech) and the social metrics (labform and unempl) (Table no. 5.b). Panel 3 tested the dependency between integration of digital technology (desiintdigtech) and the governance metrics (regq and goveffect) (table no. 5.c). To evaluate the suitability of the methods, a Hausman Test was conducted (Tables no. 5.a, 5.b, and 5.c).

Given the p-value for the different dependent variables (0.0327; 0.8785; 0.0198; 0.1368, 0.0175, 0.1637), for the dependent variables co2em, labform, and regq, as the p-value is lower than 0.05, the null hypothesis can be rejected. For renergcons, unempl and goveffect as dependent variables, the p-value is greater than 0.05, therefore, the null hypothesis cannot be rejected. Thus, based on the Hausman Test results, for those regressions where the dependent variables are co2em, labform, and regq, the fixed effects model is preferable over the random effects model, while for the regressions where the dependent variables are renergcons, unempl and goveffect the random effects model is preferable over the fixed effects model.

After establishing the panel regressions, in order to check for first-order autocorrelation in the residuals, a Wooldridge test was conducted (Table no. 5.a, 5.b, and 5.c). The results indicated that there is generally no serial correlation, with only a few indicators showing limited first-order autocorrelation.

Overall, results showed that the estimations are accurate and robust; therefore, they can be used within an economic framework, ensuring a reliable foundation for decision-making and policy formulation. In addition, these results strengthen the research's validity and credibility, ensuring that the conclusions are methodologically robust. However, the analysis of the

results must also consider potential uncontrolled external factors – such as public policies and cultural differences – that may also influence these relationships.

Table no. 5. Results

a. ENVIRONMENTAL DIMENSION				
	co2em		renergcons	
	(1) LSDV (Fixed effects model)	(2) GLS (Random effects model)	(1) LSDV (Fixed effects model)	(2) GLS (Random effects model)
desiintdigtech	-0.197 (0.111)	-0.137 (0.107)	0.324** (0.102)	0.155*** (0.0362)
_cons	6.492*** (0.331)	6.324*** (0.668)	59.44*** (3.095)	2.937* (1.096)
	Hausman Test (RE vs FE) Chi2(5) = 4.56; p = 0.0327		Hausman Test (RE vs FE) Chi2(5) = 0.02; p = 0.8785	
R ²	0.417		0.241	
Woolridge test	F(1,10) = 4.524 Prob > F = 0.071		F(1,10) = 1.507 Prob > F = 0.81	

b. SOCIAL DIMENSION				
	labform		unempl	
	(1) LSDV (Fixed effects model)	(2) GLS (Random effects model)	(1) LSDV (Fixed effects model)	(2) GLS (Random effects model)
desiintdigtech	0.579** (0.173)	0.660*** (0.170)	-0.320** (0.0960)	-0.282** (0.0926)
_cons	77.12*** (0.517)	76.89*** (1.194)	6.319*** (0.287)	6.212*** (0.606)
	Hausman Test (RE vs FE) Chi2(5) = 5.43; p = 0.0198		Hausman Test (RE vs FE) Chi2(5) = 2.21; p = 0.1368	
R ²	0.371		0.371	
Woolridge test	F(1,10) = 4.115 Prob>F = 0.08		F(1,10) = 5.53 Prob>F = 0.67	

c. GOVERNANCE DIMENSION				
	regq		goveffect	
	(1) LSDV (Fixed effects model)	(2) GLS (Random effects model)	(1) LSDV (Fixed effects model)	(2) GLS (Random effects model)
desiintdigtech	0.0163 (0.0119)	0.0217 (0.0119)	-0.00749 (0.0135)	0.0208 (0.0158)
_cons	0.818*** (0.0354)	0.803*** (0.102)	0.650*** (0.0402)	0.570*** (0.0895)
	Hausman Test (RE vs FE) Chi2(5) = 6.73; p = 0.0175		Hausman Test (RE vs FE) Chi2(5) = 3.21; p = 0.1637	
R ²	0.134		0.106	
Woolridge test	F(1,10) = 8.375 Prob>F = 0.045		F(1,10) = 5.53 Prob>F = 0.57	

Standard errors in parentheses *p < 0.05, **p < 0.01, ***p < 0.001

Source: Authors' contribution in STATA 18

When analysing the influence of digital technology integration on environmental performance, there is no statistically significant relationship with CO₂ emissions, but a strong and significant positive relationship with renewable energy consumption (as shown in Table no. 5.a). This leads to the conclusion that, in CEE countries, integrating digital technologies enhances the efficiency and optimisation of renewable energy systems, leading to increased consumption of green energy. According to Rokicki et al. (2022), innovations in renewable energy production are essential in CEE countries, where existing energy systems often differ substantially from more economically developed nations. This suggests that adopting digital technologies can help bridge efficiency gaps, as found in other relevant studies (Xie, Zhang and Zhao, 2023; Haller et al., 2024). Moreover, organisations that effectively leverage digital transformation are better positioned to innovate in green technologies and practices, with digital tools that facilitate the transition to more sustainable practices. This links digital transformation with green innovation, in line with similar studies in the field (Peng, Chen, and Li, 2023; Wu and Li, 2023). As such, hypothesis 1 is partially validated.

Nevertheless, the results analysis for the environmental performance can be influenced by external factors such as public policies, government regulations, and financial incentives that play an important role in determining the extent to which digital technologies can be successfully integrated into energy systems. For example, the effectiveness of policy support – including subsidies for renewable energy initiatives and regulatory frameworks that facilitate innovation – can significantly affect the availability and capacity of companies to adopt new technologies. Additionally, the infrastructure in the CEE countries varies greatly, affecting the way digital technologies are implemented. Poorly developed infrastructure can limit access to essential digital tools, thereby inhibiting the potential positive effects on renewable energy consumption. This underscores the need for simultaneous investments in both digital technologies and support infrastructure development.

For the social dimension, results show that the integration of digital technology has a positive and direct impact on the ratio of female to male labour force participation rate and a significant impact, albeit negative, on the unemployment rate (Table no. 5.b). This implies that digital technology enabled flexible work arrangements and remote work opportunities, while facilitating access to online education and training, empowering women with the skills needed to participate in the labour market, as underlined in other relevant studies (Kim and Lee, 2021; Chen et al., 2024). Furthermore, since integrating digital technologies creates new job opportunities (especially in tech sectors), facilitates job matching and remote work, making it easier for individuals to find employment, the results of this study are consistent to those of Rapoliene, Gedvilaite-Kordusiene and Tretjakova (2024). Consequently, hypothesis 2 is validated.

From the perspective of external factors that could influence the analysis, it is important to note that cultural attitudes toward gender roles represent a significant factor in shaping labour market outcomes. Social norms and expectations can either enhance or hinder women's participation in the workforce, affecting their access to employment opportunities and career advancement. This implies that the beneficial effects of digital technology integration may be either undermined or reinforced by the prevailing cultural context in CEE countries.

Furthermore, regional disparities in infrastructure and access to technology can create differences in how women and men benefit from digital technologies. In areas with a robust digital infrastructure, women may have greater employment opportunities, while those in regions with insufficient resources may face barriers that limit their participation.

Finally, there seems to be no statistically significant correlation regarding governance performance metrics (Table no. 5.c). Factors that influence this relationship include the quality of regulatory frameworks and the effectiveness of government institutions. While digital tools can enhance operational efficiency and transparency, these benefits do not automatically translate into improvements in regulatory quality or overall governmental effectiveness. The lack of a consistent positive correlation between digital technology and governance performance suggests that simply adopting digital tools in CEE countries may not suffice for effective ESG reporting. According to Li et al. (2023), while digital transformation can enhance innovation and efficiency at the enterprise level, its effects on governance performance may not be uniform across different sectors. Hence, hypothesis 3 is not validated. Given that digital technologies, while beneficial in many respects, do not inherently lead to improved governance performance, it becomes evident that CEE countries must actively work on integrating ESG practices into their corporate governance frameworks.

However, there are external factors that can influence the observed relationships. For example, the overall quality of regulatory frameworks can significantly affect the efficiency of using digital tools for governance purposes. Additionally, the effectiveness of government institutions can vary widely across the CEE region, influenced by factors such as administrative capacity, political stability, and institutional trust. These factors can have profound implications for how digital tools are implemented and adopted. If public institutions lack the capacity or commitment to fully leverage digital technologies, the anticipated benefits in governance performance may not materialise.

Conclusions

Examining ESG reporting in CEE nations revealed a landscape of diverse practices and significant influences from both governance structures and internal corporate dynamics. Although the region faces challenges in harmonising ESG practices with global standards, emerging trends, especially through digital integration, present pathways for improvement.

In our study, we aimed to provide a comprehensive perspective on how digital integration influences ESG metrics, while also specifying the regional context of CEE nations. The analysis involved panel regression models for the CEE countries, considering annual data from 2013 to 2023. The findings of the research revealed several main contributions, outlined as follows.

In CEE countries, the adoption of digital technologies may not directly lead to reductions in greenhouse gas emissions, suggesting that other factors may play a more critical role in influencing emissions levels. Conversely, the adoption of digital technologies plays a crucial role in enhancing the efficiency and optimisation of renewable energy systems. As a result, this leads to increased consumption of green energy, suggesting that digital technologies can be leveraged to improve the overall performance of renewable energy systems in the region, indicating a path toward more sustainable energy practices in CEE countries. Companies that successfully leverage digital technologies to improve renewable energy consumption can underline their commitment to sustainability and provide evidence of their contributions to meeting climate goals. This is particularly relevant as ESG reporting often evaluates aspects related to a company's environmental performance, including energy efficiency and the transition to renewable energy sources. In ESG reporting, companies can highlight initiatives

that integrate digital tools for better energy management, thereby aligning with investor expectations and regulatory requirements pertaining to sustainability.

Digital technologies contribute to increased female engagement in the workforce, demonstrating advancements toward gender equality in labour markets. Such a relationship implies that digital technology is helping to dismantle traditional barriers in the labour market that previously favoured men over women in employment. As businesses in CEE countries increasingly adopt digital tools, they can create more inclusive work environments. This aligns with the commitment to social responsibility within the ESG framework, which emphasises diversity and equal opportunity in employment. Companies that report effectively on their ESG practices often highlight initiatives aimed at increasing women's participation in the workforce, thus underlining their commitment to social equity.

Furthermore, the adoption of digital technologies is associated with a decrease in unemployment, suggesting that it creates more job opportunities, particularly in the tech sector. CEE companies engaged in ESG reporting can thus reinforce their roles in enhancing economic stability and growth within their communities. However, they must account for both the benefits and limitations of digital technology integration. They should aim to provide transparent and detailed disclosures regarding their social impacts, particularly in fostering gender equality and reducing unemployment. In doing so, they will not only comply with ESG reporting standards, but will also build greater stakeholder trust and improve their reputational standing in the market.

However, digital technology, while potentially beneficial in other areas, does not appear to have a consistent impact on improving governance outcomes. Digital tools, although capable of enhancing operational efficiency and transparency, do not necessarily lead to tangible improvements in the quality of regulations or the overall effectiveness of governance. This highlights the complexity of governance systems, which may require more than technological integration to effect meaningful change, and reinforces the notion that while digital transformation has the potential to drive innovation and organisational change, its influence on governance performance is complex and not straightforwardly positive. This presents a significant challenge for ESG reporting, which relies heavily on the quality of regulatory frameworks and the effectiveness of institutions. Achieving meaningful advancements in ESG reporting, particularly in terms of regulatory quality and governmental effectiveness, may imply for CEE countries to go beyond mere digital transformations.

Nevertheless, it is important to acknowledge certain potential limits of our study. First, we considered only CEE countries, which means that the results cannot be generalised. Also, these countries were approached as a group (similar to the studies of Brodny and Tutak, 2022; Batrancea, 2023; Jóźwik, Doğan and Gürsoy, 2023; Gonzaga et al., 2024), but there may be varying results within the group, since there are factors, such as culture, economy, and regulations, that are specific for each country, regardless of the common macroeconomic and historical context.

Another potential limit is related to the fact that, as shown previously, there are different rules and regulations concerning ESG reporting in these countries, therefore, the full effects cannot be seen immediately, which may lead to inconsistencies in how organisations interpret and implement these standards, ultimately affecting the comparability and reliability of ESG data across the region. This divergence in regulatory frameworks can hinder effective benchmarking and may complicate efforts to draw meaningful conclusions about the impact

of ESG practices on organisational performance and sustainability outcomes. Consequently, the nuanced regulatory landscape requires a more tailored approach to ESG analysis in order to account for these complexities.

Our study emphasised that effective integration of digital technologies can greatly enhance corporate transparency and sustainability in CEE countries. However, research that is more systematic is needed to explore the specific barriers faced by companies in varying industries within this region. Future research should delve deeper into sector-specific analyses and the long-term impacts of ESG commitments on corporate performance across varied CEE contexts. Additionally, scholars like Juniarti et al. (2025) emphasise the importance of longitudinal studies to understand how ESG disclosures evolve in tandem with digital initiatives within different contextual frameworks.

Moreover, the variables used in the research to evaluate performance – although based on previous studies – do not fully capture the complexity of the three ESG dimensions. Therefore, future research should focus on integrating micro-level indicators, using company-level data (where available and comparable) to provide a more detailed perspective on the impact of digital technologies on specific ESG aspects such as corporate governance, employee rights, or waste management. Furthermore, as ESG reporting methodologies evolve and data become more accessible at the national level, new indicators can be added to future analyses.

Future studies could also explore integrating quantitative analyses with qualitative methodologies, such as interviews and case studies, to effectively identify and analyse the barriers and success factors associated with the adoption of digital technologies. This approach would offer a more nuanced understanding of the complexities involved in digital transformation efforts, providing insights that quantitative data alone cannot reveal.

While digital integration presents significant opportunities for enhancing ESG reporting practices in CEE countries, the path forward requires addressing regulatory, operational, and financial challenges to fully capitalise on the potential benefits of these technologies. Ongoing research and supportive policies are essential to navigate the accompanying challenges. By addressing these issues, policymakers and corporate leaders can foster environments conducive to sustainable development and improved corporate transparency.

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