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THE E-COMMERCE EXPANSION AND WASTE GENERATION IN THE EU: A PANEL VECTOR AUTOREGRESSION APPROACH

Abstract

This research study applies a multi-method framework, combining Panel Vector Autoregression (PVAR), panel threshold models, quantile regressions, and random forest analyses, to investigate how e-commerce (ECOMS) growth affects different waste streams across 27 EU Member States from 2014 to 2023. The research showed that e-commerce expansion strongly amplifies packaging waste generation, whereas total and municipal waste exhibit limited immediate responses. However, threshold analyses suggest that higher unemployment and lower resource productivity can intensify e-commerce's packaging impact, while robust recycling capacity partially mitigates this trend. Quantile regressions further reveal that high-waste countries face particularly pronounced e-commerce effects, underscoring the need for context-specific interventions. These findings highlight the pivotal role of packaging materials in online retail's environmental footprint and emphasize the importance of targeted circular economy measures, such as advanced recycling infrastructure and reduced packaging design, for effectively managing e-commerce-driven waste.

Keywords: *E-commerce, waste generation, packaging waste, panel vector autoregression, circular economy, recycling*

JEL classification: *C33, L81, Q53, Q56*

ЕКСПАНЗИЈА Е-ТРГОВИНЕ И ГЕНЕРИСАЊЕ ОТПАДА У ЕУ: ПРИСТУП ПАНЕЛ ВЕКТОРСКЕ АУТОРЕГРЕСИЈЕ

Апстракт

У овом раду се примењује комплексан методолошки оквир, у оквиру кога се комбинују панел векторска ауторегресија (PVAR), панел праг модели, квантилана регресија и random forest analiza, да би се анализирао утицај

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раста е-трговине (ECOMS) на различите токове отпада у 27 земаља ЕУ у периоду од 2014. до 2023. године. Резултати овог истраживања показују да експанзија е-трговине значајно подстиче генерисање амбалажног отпада, док је утицај на укупни и комунални отпад ограничен на кратке рокове. Међутим, панел праг анализе указују на то да виша незапосленост и нижа продуктивности ресурса могу појачати ефекат е-трговине на амбалажни отпад, одк значајан капацитет за рециклажу делимишно ублажава овај тренд. Квантилна регресија открива да земље са високим нивоом отпада трпе нарочито изражене ефекте е-трговине, наглашавајући потребу за интервенцијама прилагођеним контексту. Ови резултати истичу кључну улогу амбалажног материјала у еколошком отиску онлајн малопродаје и потврђују значај таргетираних мера циркуларне економије, попут напредне рециклажне инфраструктуре и редукованог дизајна амбалаже, за ефикасно управљање отпадом који потиче из е-трговине.

Кључне речи: *е-трговина, генерисање отпада, амбалажни отпад, панел векторска ауторегресија, циркуларна економија, рециклажа*

Introduction

Electronic commerce (e-commerce) has rapidly transformed global consumer behaviors and business strategies, supported by widespread internet connectivity, evolving logistics, and rising consumer demand for on-demand services (Abukhader & Jönson, 2003; Fichter, 2002). However, this digital transition also poses sustainability concerns (Matthews et al., 2001; Yu et al., 2023), including heightened packaging requirements, increased returns, and new waste streams (Bertram & Chi, 2017; Lonn et al., 2002; Stinson et al., 2019). Although e-commerce can reduce inefficiencies in traditional retail (Bertram & Chi, 2017), its net environmental impact remains ambiguous, as improved transport efficiency (Imran et al., 2023) may be offset by resource-intensive packaging (Yu et al., 2023). These challenges are especially pertinent in the European Union (EU), where e-commerce is growing and legislative efforts, such as the 2018 EU Waste Directives and the proposed Packaging and Packaging Waste Regulation (PPWR), aim to curb packaging and municipal waste (European Commission, 2021). Yet, limited longitudinal research has investigated how e-commerce affects multiple waste streams or considered the moderating role of recycling capacity (Siikavirta et al., 2002; Dost & Maier, 2018). Factors like industrial development, resource usage, and regional policies further complicate outcomes (Caiyi et al., 2022; Visser & Lanzendorf, 2004), pointing to a need for integrated and dynamic modeling (Fichter, 2002; Abukhader & Jönson, 2003; Yu et al., 2023).

Accordingly, this paper explores the link between e-commerce expansion and three waste indicators, waste per capita (WASTPC), municipal waste per capita (MWASTE), and packaging waste per capita (PACWASTE), in 27 EU Member States from 2014 to 2023. It examines whether municipal recycling rates (RECMWASTE) moderate these relationships (Jovanović et al., 2023) and investigates how industrial development (INDVA), resource productivity (RESP), and other macro controls interact.

Methodologically, the study applies Panel Vector Autoregression (PVAR), complemented by panel threshold (PTR), quantile regression, and machine learning to uncover dynamic and non-linear processes. PVAR captures feedback loops where rising e-commerce might spur waste and, in turn, provoke changes in online adoption, while threshold and quantile analyses reveal regime-specific effects (Hansen, 1999; Soukiazis & Proença, 2020; Imran et al., 2023). By integrating these approaches, the paper offers fresh evidence on the immediate and lagged impacts of e-commerce on EU waste generation, the mitigating role of recycling, and the implications for circular economy strategies. The next section reviews the related literature, focusing on packaging, municipal waste, and the factors shaping e-commerce's environmental outcomes.

1. Theoretical background

E-commerce has rapidly become central to modern economies and consumer culture, influencing product design, packaging, and shopping patterns (Chen et al., 2020; Fichter, 2002; Yu et al., 2023). As digital retail expands, studies increasingly investigate its short- and long-term repercussions on resource consumption and waste (Abukhader & Jönson, 2003; Bertram & Chi, 2017; Stinson et al., 2019). This section reviews how e-commerce affects waste per capita (WASTPC), municipal waste per capita (MWASTE), and packaging waste per capita (PACWASTE), along with the moderating roles of recycling infrastructure (RECMWASTE), industrial development (INDVA), unemployment (UNEMP), and resource productivity (RESP). It also highlights key methodological approaches in European Union (EU) research.

A recurring debate addresses the efficiency benefits of e-commerce versus its possible environmental drawbacks (Fichter, 2002; Matthews et al., 2001). Improved logistics can reduce greenhouse gas emissions and operational inefficiencies (Chen et al., 2020; Imran et al., 2023), yet the packaging-intensive nature of online sales often creates elevated levels of packaging waste (PACWASTE), stressing local waste-management systems (Bertram & Chi, 2017; Lonn et al., 2002; Yu et al., 2023). Although e-commerce can replace some in-person shopping, it may generate more frequent small-parcel deliveries and increased return shipments, raising total waste (Stinson et al., 2019; Dost & Maier, 2018). Consequently, net impacts on WASTPC or MWASTE often depend on region-specific logistics maturity and consumer behaviors (Caiyi et al., 2022; Visser & Lanzendorf, 2004).

Several contextual factors shape the extent of e-commerce-driven waste. Recycling infrastructure (RECMWASTE) is frequently identified as pivotal in curbing packaging waste, as robust collection and processing systems can recapture materials and minimize landfills (Jovanović et al., 2023; Popović, 2020). In the EU, policies like the 2018 EU Waste Directives and the Packaging and Packaging Waste Regulation (PPWR) emphasize the importance of expanding recycling capacities to manage escalating online-delivery waste (European Commission, 2021; Popović & Milijić, 2021). Meanwhile, industrial development (INDVA) can heighten waste outputs if e-commerce intersects with strong manufacturing sectors (Popović et al., 2022b; Yu et al., 2023), and resource productivity (RESP) can buffer or exacerbate waste generation by influencing how efficiently raw materials are converted into final products (Borjesson Rivera et al., 2014; Popović et al., 2023).

Within Europe's legislative framework, ambitious targets aim to reduce municipal and packaging waste (European Commission, 2021). The PPWR proposal seeks tighter design standards, extended producer responsibility, and recycling mandates to diminish the adverse effects of e-commerce packaging (Popović et al., 2023; Yu et al., 2023). Although uniform EU-level directives can foster convergence in recycling practices (Chen et al., 2020; Popović et al., 2022a), variations remain in data accuracy, enforcement, and circular model adoption across Member States (Popović & Milijić, 2021). Research further demonstrates that the interplay between digital consumption and sustainability remains contingent on local institutional frameworks and consumer norms (Visser & Lanzendorf, 2004).

A notable dimension is the temporal aspect of e-commerce's environmental impacts. Yu et al. (2023) argue that while short-term efficiency gains might briefly limit emissions, packaging waste can escalate long-term. Imran et al. (2023) similarly note that frequent deliveries and reverse logistics can dilute initial environmental improvements. Hence, short-run benefits may give way to surging waste pressures, particularly for packaging. Advanced econometric methods, panel vector autoregression (PVAR), threshold models, and quantile regressions help capture these dynamics (Holtz-Eakin, Newey, & Rosen, 1988; Koenker & Bassett, 1978; Hansen, 1999). Researchers also apply machine-learning tools (Breiman, 2001; Popović et al., 2023) to reveal non-linearities and gauge variable importance.

Beyond environmental metrics, e-commerce's waste challenges intersect with broader social and economic dimensions (Popović, 2020; Popović et al., 2022b). Industry 4.0 tools, robotics, AI, and digital platforms may boost efficiency yet potentially increase consumption or exacerbate inequalities (Fichter, 2002; Abukhader & Jönson, 2003). The EU's circular economy frameworks emphasize linking digitalization with well-structured policies to reduce single-use materials and encourage product-service models (Popović & Milijić, 2021; Popović et al., 2023). Nevertheless, effective outcomes depend on institutional backing, cultural acceptance, and technological readiness across diverse Member States.

Overall, the literature indicates that e-commerce has mixed effects on waste streams, with packaging being a chief concern. Contextual factors like RECMWASTE, INDVA, and RESP, combined with policy environments, shape the net outcome. Empirical gaps persist, especially regarding dynamic effects, threshold behaviors, and multi-country analyses applying advanced methods such as PVAR, panel thresholds, and machine learning, topics the following sections address in detail.

2. Research design and methodology

The primary objective of this study is to investigate how the expansion of e-commerce (ECOMS) affects different waste streams, namely waste per capita (WASTPC), municipal waste per capita (MWASTE), and packaging waste per capita (PACWASTE), across European Union (EU) Member States. In addressing this objective, the research also explores whether factors such as recycling infrastructure (RECMWASTE) and industrial development (INDVA) moderate e-commerce's influence while considering distributional heterogeneities and any potential spatial effects. Building on literature that identifies a shortage of multi-country, longitudinal analyses, this study adopts a multi-stage research design (see Figure 1) integrating Panel Vector Autoregression (PVAR), panel threshold regression (PTR), quantile regression, and machine learning checks.

A single overarching question guides the inquiry:

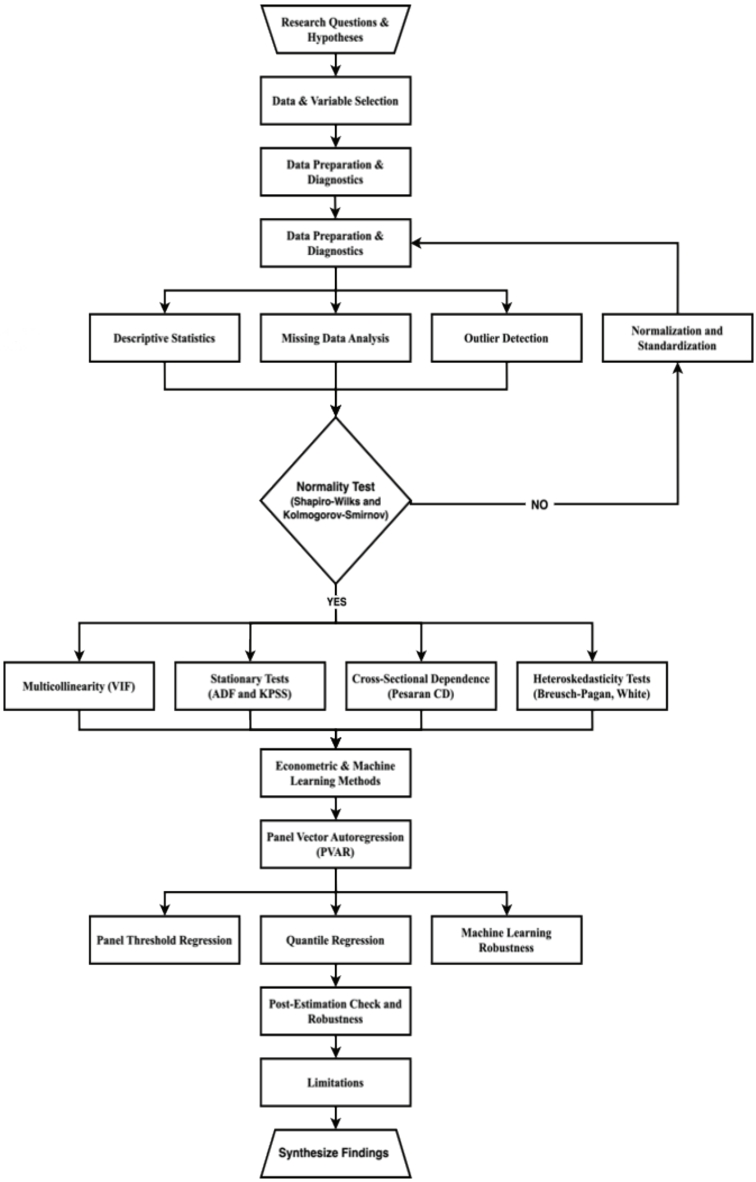
- RQ (Main): How does the expansion of e-commerce (ECOMS) influence waste generation in EU countries, and what contextual factors moderate this relationship?

To delve deeper, five supporting questions are examined:

- RQ1 (Short vs. Long-Run Effects): Are the immediate (short-run) impacts of e-commerce on waste different from the lagged (long-run) impacts?
- RQ2 (Recycling Infrastructure): Does a higher recycling rate (RECMWASTE) moderate or dampen the association between e-commerce and waste generation?
- RQ3 (Threshold Effects): Are there non-linearities or threshold points, such as in RECMWASTE or INDVA, beyond which the effect of e-commerce on waste intensifies?
- RQ4 (Spatial Spillovers): Does e-commerce expansion in one country produce cross-border effects on waste due to shared logistics networks, thereby suggesting spatial interdependence?
- RQ5 (Temporal Dynamics): Does the rise in packaging waste taper off or change character over time (as policies and consumer practices evolve)?

Five hypotheses address these questions:

- H1 (Direct Impact): E-commerce expansion (ECOMS) correlates positively with waste indicators (WASTPC, MWASTE, PACWASTE).
- H2 (Role of Recycling): Higher recycling capacity (RECMWASTE) moderates the positive impact of e-commerce on waste, reducing its magnitude.
- H3 (Threshold Effect): Beyond certain threshold values of RECMWASTE or INDVA, the effect of e-commerce on waste shifts, thus indicating non-linear behaviors.
- H4 (Spatial Spillovers): E-commerce growth in one country triggers adjacent or cross-border effects on waste due to integrated supply chains, thereby confirming spatial dependence.
- H5 (Temporal Dynamics): The initial surge in waste due to e-commerce packaging diminishes over time, suggesting changing consumer and policy responses.



Source: Own design.

A balanced panel of 27 EU Member States (2014–2023) provides 270 country-year observations. Core variables, WASTPC, MWASTE, PACWASTE, ECOMS, RECMWASTE, INDVA, UNEMP, and RESP, are compiled from Eurostat (2024) and World Bank (2024). Waste indicators capture different dimensions (total, municipal, and packaging), while e-commerce penetration (ECOMS) reflects the percentage of enterprises (≥10 employees) conducting online sales. All variables are cleaned and checked for outliers. Skewness is mitigated, and comparability is enhanced through Z-score standardization and/or Box-Cox transformations (Borjesson Rivera et al., 2014).

Data diagnostics consider normality, using Shapiro–Wilk and Kolmogorov–Smirnov tests, revealing significant skewness that justifies transformations. Variance Inflation Factors (VIF) remain below 3.5, indicating no severe multicollinearity. Augmented Dickey-Fuller (ADF) and KPSS tests confirm that most transformed series achieve stationarity, while Pesaran's CD test shows minimal cross-sectional dependence for this sample. Finally, heteroscedasticity (Breusch–Pagan, White tests) and serial correlation checks (including Wooldridge's test) prompt the use of robust errors or feasible generalized least squares in subsequent estimations (Soukiazis & Proença, 2020; Imran et al., 2023).

PVAR is employed to capture dynamic interdependencies, following Holtz-Eakin, Newey, and Rosen (1988) and Arellano and Bover (1995). E-commerce (ECOMS) and each waste indicator (WASTPC, MWASTE, or PACWASTE) are modeled as endogenous, incorporating exogenous controls (RESP, UNEMP, INDVA). The specification:

$$\boldsymbol{y}_{i,t} = \boldsymbol{A(L)}\,\boldsymbol{y}_{i,t-1} + \boldsymbol{x}_{i,t}\boldsymbol{\Gamma} + \epsilon_{i,t} \quad (1)$$

- $y_{i,t}$ *- vector of multiple endogenous variables*
- *A(L) - matrix of lag operators*
- $x_{i,t}$ *- matrix of exogenous regressors*
- Γ *– matrix of corresponding coefficients*
- $\epsilon_{i,t}$ *– residual*

allows short-run shocks to e-commerce or waste to propagate over time, while the Bayesian Information Criterion (BIC) determines the optimal lag length. Impulse Response Functions (IRFs) illustrate short-run vs. long-run adjustments, and Variance Decompositions (FEVD) indicate the relative contribution of e-commerce shocks to waste or vice versa.

To test H3, panel threshold regressions (PTR) detect non-linear regime changes for e-commerce–waste linkages once RECMWASTE or INDVA crosses an estimated threshold (Hansen, 1999). Potential spatial dependence (H4) is explored via Pesaran's CD test and, where relevant, spatial autoregressive models. Quantile regressions (Koenker & Bassett, 1978) reveal distributional nuances, clarifying whether high-waste vs. low-waste contexts respond differently to e-commerce expansions. Finally, random forest regressors (Breiman, 2001) are a robustness check, capturing potential non-linearities unaccounted for in conventional parametric approaches (Popović et al., 2023).

Various robustness checks complement the core analysis. Alternative waste indicators, such as MWASTE and PACWASTE, replace WASTPC to verify consistency, while additional interaction terms assess whether industrial development or resource productivity modifies e-commerce's impact. Structural breaks around major policy shifts are briefly examined. Granger causality tests further clarify directionality: e-commerce might drive waste, yet rising waste and subsequent policies might also dampen or reshape online retail.

Hence, this multi-method design, PVAR, PTR, quantile regressions, and machine learning, aims to address identified gaps by capturing both dynamic (short-run vs. long-run) and distributional (low-waste vs. high-waste) characteristics. The subsequent section presents the empirical results, detailing how e-commerce relates to waste in the EU and examining implications for circular economy strategies, especially regarding packaging reduction, recycling, and labor-market transitions.

3. Research results

This section presents the empirical findings derived from a multi-stage framework encompassing descriptive analyses, Panel Vector Autoregression (PVAR) models (A–C, D, and Scenarios E–F), panel threshold regressions, quantile regressions, and machine learning robustness checks. The overarching goal is to clarify how e-commerce (ECOMS) expansion affects waste per capita (WASTPC), municipal waste per capita (MWASTE), and packaging waste per capita (PACWASTE) in EU Member States, alongside potential moderating factors such as recycling infrastructure (RECMWASTE) and industrial development (INDVA).

3.1. Descriptive statistics and data diagnostics

Table 1 displays the mean, standard deviation, and range for eight variables (N=270). Notable points include significant heterogeneity in waste indicators. Waste per capita (WASTPC) averages 6,333 kg but can rise to almost 24,872 kg, highlighting substantial cross-country differences. E-commerce adoption (ECOMS) ranges between ~7.2% and ~42.5% of enterprises (≥10 employees), reflecting varying degrees of digital market maturity. Municipal waste per capita (MWASTE) also varies widely (247–844 kg), as does packaging waste per capita (PACWASTE) (48–246 kg).

Table 1: Descriptive Statistics

Variables	Count	Mean	St. Dev.	Min	25%	50%	75%	Max
WASTPC	270	6333.19	5589.82	879.00	2482.75	4297.00	7783.50	24872.00
ECOMS	270	21.28	7.74	7.20	15.23	20.10	26.55	42.50
MWASTE	270	510.96	130.81	247.00	425.25	488.00	589.50	844.00
PACWASTE	270	147.42	46.25	48.33	114.87	152.79	175.36	246.14
RECMWASTE	270	38.52	14.98	9.10	29.18	39.70	49.50	70.30
RESP	270	1.84	1.12	0.30	0.95	1.46	2.65	5.46
UNEMP	270	7.46	4.06	2.02	5.03	6.56	8.50	26.71
INDVA	270	22.45	6.21	9.97	18.94	22.07	26.67	41.49

Source: Own calculations.

A balanced panel with no missing observations strengthens the dataset's robustness. Potential outliers in WASTPC, RESP, UNEMP, and INDVA were verified and retained to capture true variation. Shapiro-Wilk and Kolmogorov-Smirnov tests (Table 2) reveal significant skewness, prompting Box-Cox transformations and z-score standardization (Borjesson Rivera et al., 2014). Variance Inflation Factors (VIF) remain below 3.5, indicating minimal multicollinearity (Soukiazis & Proença, 2020).

Table 2: Normality Check

Variable	Shapiro-Wilk Statistic	Shapiro-Wilk p-value	Kolmogorov-Smirnov Statistic	Kolmogorov-Smirnov p-value
		Original Dataset		
WASTPC	0.7884	0.0000	0.2221	0.0000
ECOMS	0.9772	0.0003	0.0711	0.1244
MWASTE	0.9575	0.0000	0.1223	0.0006
PACWASTE	0.9823	0.0020	0.0504	0.4838
RECMWASTE	0.9772	0.0003	0.0654	0.1898
RESP	0.9282	0.0000	0.1382	0.0001
UNEMP	0.8194	0.0000	0.1647	0.0000
INDVA	0.9837	0.0036	0.0466	0.5848

Source: Own calculations.

Augmented Dickey-Fuller (ADF) and KPSS tests (Table 3) confirm that most variables approach stationarity once standardized, while Pesaran's CD test shows weak cross-sectional dependence.

Table 3: Augmented Dickey-Fuller (ADF) and KPSS Tests Results

Variable	ADF Stat	ADFp-value	ADF Lags	KPSS Stat	KPSS p-value	KPSS Lags
WASTPC_z	-2.7982	0.0585	10	0.1240	0.1000	10
ECOMS_z	-5.0563	0.0000	0	0.0945	0.1000	9
MWASTE_z	-4.2920	0.0005	0	0.5201	0.0371	9
PACWASTE_z	-3.7724	0.0032	0	0.2607	0.1000	10
RECMWASTE_z	-4.3792	0.0003	0	0.0599	0.1000	9
RESP_z	-3.6440	0.0050	10	0.0904	0.1000	10
UNEMP_z	-4.8897	0.0000	10	0.0863	0.1000	9
INDVA_z	-3.2895	0.0154	10	0.0958	0.1000	9

Source: Own calculations.

Heteroscedasticity, identified by Breusch–Pagan and White tests (Table 4), led to the use of robust standard errors or feasible generalized least squares. Serial correlation was addressed via system GMM or robust covariance estimators (Imran et al., 2023).

Table 4: Breusch-Pagan and White Tests

Metric	Breusch-Pagan Test	White Test
LM Statistic	99.1023	193.2545
LM p-value	1.65×10^{-18}	8.65×10^{-24}
F-value	21.7046	16.8354
F p-value	4.92×10^{-23}	2.59×10^{-46}

Source: Own calculations.

Overall, this dataset provides a solid basis for subsequent analyses. It contains no missing values, accommodates outliers legitimately, and satisfies transformations to handle skewness. Stationarity checks, low VIFs, and minimal cross-sectional dependence reinforce its suitability for PVAR, panel threshold, quantile regressions, and machine learning (Matthews et al., 2001). The next subsections detail the PVAR results, followed by threshold and quantile findings and robustness checks.

3.2. PVAR Results: Models A, B, and C

This section presents the Panel Vector Autoregression (PVAR) estimations for three two-variable models that pair e-commerce (ECOMS) with different waste indicators. Model A analyzes e-commerce and waste per capita (WASTPC), Model B examines e-commerce and municipal waste per capita (MWASTE), and Model C focuses on e-commerce and packaging waste per capita (PACWASTE). Each model employs two lags, determined by the Bayesian Information Criterion (BIC), to capture dynamic feedback in the connection between e-commerce and waste.

3.2.1. Lag selection

All three two-variable PVAR systems underwent an internal lag selection procedure. Table 5 shows that a 2-lag specification generally outperforms a 1-lag model in each scenario, as reflected in lower BIC values. This result suggests meaningful dynamic effects across two periods.

Table 5: Lag Selection

Model	Lags	RSS	Num. Params	Nobs	LLF	AIC	BIC
A	1	25.9545	6	243	-73.0409	158.0819	179.0402
A	2	20.5291	10	216	-52.3197	124.6395	158.3923
B	1	37.7344	6	243	-118.51	249.0194	269.9778
B	2	32.8734	10	216	-103.168	226.3368	260.0895
C	1	28.4769	6	243	-84.3098	180.6196	201.578
C	2	23.3144	10	216	-66.0605	152.1211	185.8739

Notes: RSS (Residual Sum of Squares); LLF (Log Likelihood Function); AIC (Akaike Information Criterion); BIC (Bayesian Information Criterion);

Source: Own calculations.

3.2.2. Model A (WASTPC & ECOMS)

Model A explores how e-commerce (ECOMS) and waste per capita (WASTPC) influence each other. Table 6 summarizes the key coefficients.

Table 6: PVAR Results for Model A (WASTPC & ECOMS)

Dep. Var.	Regressor	Coeff.	t-stat	p-value
WASTPC_z	$WASTPC_{t-1}$	1.1812	12.1413	0.0000
WASTPC_z	$ECOMS_{t-1}$	0.0164	0.7434	0.4582
WASTPC_z	$WASTPC_{t-2}$	-0.4607	-5.6554	0.0000
WASTPC_z	$ECOMS_{t-2}$	-0.0058	-0.3368	0.7367
WASTPC_z	$WASTPC_{t-1}$	-0.1368	-0.6459	0.5192

WASTPC_z	$ECOMS_{t-1}$	0.6337	7.9014	0.0000
WASTPC_z	$WASTPC_{t-2}$	0.2267	1.0327	0.3031
WASTPC_z	$ECOMS_{t-2}$	0.1672	1.9829	0.0489

Source: Own calculations.

- WASTPC displays strong inertia (coefficient ~1.1812), with a partial mean-reversion term at the second lag (–0.4607, p<0.001).
- ECOMS does not significantly predict short-run variations in WASTPC, implying that online retail may not alter total waste per capita immediately.
- ECOMS primarily depends on its own history (coefficient ~0.6337), suggesting an internal momentum in e-commerce growth.

Granger Causality. Table 7 shows no robust evidence of short-run causality in either direction, with p-values over 0.50.

Table 7: Model A Granger Causality Tests

Dependent Variable	Causal Variable	Test Statistic	p-value
WASTPC_z	ECOMS_z	0.7372	0.6917
ECOMS_z	WASTPC_z	1.2144	0.5449

Source: Own calculations.

Impulse Response Functions (IRFs). Table 8 suggests a mild (and sometimes negative) WASTPC response to an e-commerce shock, whereas WASTPC shocks do not strongly affect ECOMS beyond the initial lag.

Table 8: Model A: Selected IRF (5-period horizon)

Horizon	IRF (ECOMS→WASTPC)	IRF (WASTPC→ECOMS)	Lower B. (ECOMS)	Upper B. (ECOMS)	Lower B. (WASTPC)	Upper B. (WASTPC)
0	0.00	0.00	0.0000	0.0000	0.0000	0.0000
1	0.02	-0.14	-0.5351	0.2619	1.0144	1.3539
2	0.03	-0.25	-1.0072	0.4696	1.0277	1.8312
3	0.04	-0.35	-1.4843	0.6766	1.0410	2.4754
4	0.05	-0.44	-1.9482	0.8466	1.0541	3.3453
5	0.07	-0.55	-2.4862	1.0580	1.0640	4.5206

Source: Own calculations.

Forecast Error Variance Decomposition (FEVD). Table 9 confirms that 99% of WASTPC's variance is self-driven, while ECOMS shocks account for only ~1%. Overall, Model A indicates limited immediate effects of e-commerce on total waste per capita.

Table 9: FEVD for Model A (Selected Horizons)

Horizon	FEVD (WASTPC from WASTPC)	FEVD (WASTPC from ECOMS)	FEVD (ECOMS from WASTPC)	FEVD (ECOMS from ECOMS)
0	1.0000	0.0000	0.0000	1.0000
1	0.9998	0.0002	0.0445	0.9555
2	0.9995	0.0005	0.2788	0.7212
3	0.9994	0.0006	0.6613	0.3387
5	0.9992	0.0008	0.9741	0.0259

Source: Own calculations.

3.2.3. Model B (MWASTE & ECOMS)

In Model B, e-commerce (ECOMS) pairs with municipal waste per capita (MWASTE). Table 10 highlights the main coefficients.

Table 10: PVAR Results for Model B (MWASTE & ECOMS)

Dep. Var.	Regressor	Coeff.	t-stat	p-value
MWASTE_z	$MWASTE_{t-1}$	0.7211	7.1086	0.0000
MWASTE_z	$ECOMS_{t-1}$	0.0114	0.2016	0.8405
MWASTE_z	$MWASTE_{t-2}$	-0.0578	-0.9458	0.3455
MWASTE_z	$ECOMS_{t-2}$	0.0491	0.7786	0.4372
ECOMS_z	$MWASTE_{t-1}$	0.0302	0.3610	0.7185
ECOMS_z	$ECOMS_{t-1}$	0.6367	7.7125	0.0000
ECOMS_z	$MWASTE_{t-2}$	0.0127	0.1662	0.8682
ECOMS_z	$ECOMS_{t-2}$	0.1537	1.7088	0.0892

Source: Own calculations.

- MWASTE strongly depends on its previous value (~0.7211), consistent with entrenched municipal waste patterns.
- ECOMS lags do not significantly predict MWASTE, suggesting that short-term changes in e-commerce do not alter municipal waste generation.
- As in Model A, ECOMS remains largely self-driven (Coefficient ~0.6367).

Granger Causality. Table 11 indicates no significant short-run predictive power from ECOMS to MWASTE or vice versa.

Table 11: Model B Granger Causality Tests

Dependent Variable	Causal Variable	Test Statistic	p-value
MWASTE_z	ECOMS_z	1.93714	0.3796
ECOMS_z	MWASTE_z	0.56683	0.7532

Source: Own calculations.

Impulse Responses and FEVD. Tables 12 and 13 show minimal MWASTE response to e-commerce shocks, with MWASTE's own history explaining ~99% of its variance. Thus, e-commerce exhibits little immediate impact on municipal waste in Model B.

Table 12: Model B: Selected IRF (5-period horizon)

Horizon	IRF (ECOMS → MWASTE)	IRF (MWASTE → ECOMS)	Lower Bound (ECOMS)	Upper Bound (ECOMS)	Lower Bound (MWASTE)	Upper Bound (MWASTE)
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0302	0.7211	-0.1224	0.1673	0.5018	0.8852
2	0.0410	0.5203	-0.1664	0.2282	0.2546	0.7800
3	0.0419	0.3756	-0.1604	0.2464	0.1327	0.6855
4	0.0380	0.2713	-0.1470	0.2322	0.0671	0.6031
5	0.0324	0.1961	-0.1309	0.2180	0.0352	0.5317

Source: Own calculations.

Table 13: FEVD for Model B (Selected Horizons)

Horizon	FEVD (MWASTE from MWASTE)	FEVD (MWASTE from ECOMS)	FEVD (ECOMS from MWASTE)	FEVD (ECOMS from ECOMS)
0	1.0000	0.0000	0.0000	1.0000
1	0.9998	0.0002	0.0022	0.9978
2	0.9991	0.0009	0.0101	0.9899
3	0.9982	0.0018	0.0255	0.9745
5	0.9961	0.0039	0.0859	0.9141

Source: Own calculations.

3.2.4. Model C (PACWASTE & ECOMS)

Model C pairs e-commerce (ECOMS) with packaging waste per capita (PACWASTE). Unlike WASTPC or MWASTE, PACWASTE demonstrates a stronger linkage to e-commerce. Table 14 presents the key results.

Table 14: PVAR Results for Model C (PACWASTE & ECOMS)

Dep. Var.	Regressor	Coeff.	t-stat	p-value
PACWASTE_z	$PACWASTE_{t-1}$	0.5420	5.8150	0.0000
PACWASTE_z	$ECOMS_{t-1}$	0.0737	2.6240	0.0094
PACWASTE_z	$PACWASTE_{t-2}$	0.2543	3.0592	0.0025
PACWASTE_z	$ECOMS_{t-2}$	0.0227	0.7671	0.4440
ECOMS_z	$PACWASTE_{t-1}$	0.2354	1.5825	0.1152
ECOMS_z	$ECOMS_{t-1}$	0.5836	6.9648	0.0000
ECOMS_z	$PACWASTE_{t-2}$	0.0891	0.5951	0.5525
ECOMS_z	$ECOMS_{t-2}$	0.0921	1.0120	0.3129

Source: Own calculations.

- PACWASTE Persistence. $PACWASTE_{t-1}$ has a strong positive effect (~0.5420), indicating high persistence.

- E-Commerce Influence. $ECOMS_{t-1}$ is significantly positive (~0.0737, p=0.0094) for PACWASTE, suggesting that rising e-commerce quickly elevates packaging waste.

Table 15 shows Granger causality in both directions (p<0.01), implying a feedback loop where e-commerce growth drives packaging waste, and rising packaging waste may reinforce e-commerce logistics.

Table 15: Model C Granger Causality Tests

Dependent Variable	Causal Variable	Test Statistic	p-value
PACWASTE_z	ECOMS_z	11.8385	0.0027
ECOMS_z	PACWASTE_z	9.3951	0.0091

Source: Own calculations.

IRFs and FEVD. Tables 16 and 17 reveal that e-commerce shocks can explain up to 22% of PACWASTE variance by horizon 5. This stands in contrast to WASTPC or MWASTE, where e-commerce accounted for ≤2%.

Table 16: Model C: Selected IRF (5-period horizon)

Horizon	IRF (ECOMS → PACWASTE)	IRF (PACWASTE → ECOMS)	Lower Bound (ECOMS)	Upper Bound (ECOMS)	Lower Bound (PACWASTE)	Upper Bound (PACWASTE)
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.2354	0.5419	-0.0369	0.5081	0.3587	0.7151
2	0.2650	0.3111	-0.0415	0.5651	0.1421	0.5306
3	0.2279	0.1881	-0.0354	0.5219	0.0596	0.3978
4	0.1773	0.1187	-0.0304	0.4596	0.0287	0.3096
5	0.1314	0.0774	-0.0251	0.3811	0.0131	0.2382

Source: Own calculations.

Table 17: FEVD for Model C (Selected Horizons)

Horizon	FEVD (PACWASTE from PACWASTE)	FEVD (PACWASTE from ECOMS)	FEVD (ECOMS from PACWASTE)	FEVD (ECOMS from ECOMS)
0	1	0	0	1
1	0.9819	0.0181	0.14	0.86
2	0.9337	0.0663	0.3541	0.6459
3	0.8744	0.1256	0.4989	0.5011
5	0.8209	0.1791	0.5826	0.4174

Source: Own calculations.

Hence, Model C offers robust evidence of a direct and short-run e-commerce impact on packaging disposal. In practical terms, these findings highlight that online retail fosters a significant increase in packaging materials, corrugated cardboard, plastics, protective wraps, and so forth, which manifest as higher packaging waste in the short to medium term.

Overall, Model C indicates a short-run, bidirectional nexus between e-commerce and packaging waste. These findings highlight that online retail more immediately affects packaging streams than total or municipal waste, underscoring the importance of targeted policy measures for packaging-intensive channels.

3.3. PVAR extensions: Models D, scenario E, and scenario F

Beyond the two-variable setups in Models A, B, and C, the analysis expands to Model D, a principal-component–based index, and two multi-variable scenarios (E and F). These extensions investigate how e-commerce (ECOMS) might indirectly influence additional waste variables, industrial development, resource productivity, and labor market conditions. They follow the PVAR approach described earlier but vary in endogenous and exogenous variables.

3.3.1. Model D: PCA-based index (INDEX) and E-commerce (ECOMS)

Model D condenses four standardized waste and recycling measures, WASTPC_z, MWASTE_z, PACWASTE_z, and RECMWASTE_z, into a single principal component (INDEX). This aggregated index gauges a country's combined waste–recycling performance. Once again, Bayesian Information Criterion (BIC) was consulted to decide on lags. Table 18 (mentioned below) shows that a 2-lag specification yields a consistently lower BIC, reinforcing the earlier choice of two lags.

Table 18: Lag Selection Model D

Model	Lags	RSS	Num. Params	Nobs	LLF	AIC	BIC
D	1	33.1829	6	243	-102.893	217.7852	238.7436
D	2	27.5942	10	216	-84.2619	188.5238	222.2766

Source: Own calculations.

Table 19 (presented next) shows that INDEX remains highly dependent on its own first lag (~0.6705, p<0.001). By contrast, e-commerce exerts only a modest and statistically insignificant short-run effect on this composite index (coefficient ~0.0539, p≈0.19). In the ECOMS equation, however, e-commerce strongly depends on its own lag (~0.6162, p<0.001), mirroring the momentum seen in earlier models.

Table 19: PVAR Results for Model D (INDEX & ECOMS)

Dep. Var.	Regressor	Coeff.	t-stat	p-value
MWASTE_z	$INDEX_{t-1}$	0.6705	7.8441	<0.0010
MWASTE_z	$ECOMS_{t-1}$	0.0539	1.3242	0.1871
MWASTE_z	$INDEX_{t-2}$	0.1072	1.5405	0.1251
MWASTE_z	$ECOMS_{t-2}$	0.0231	0.5063	0.6133
ECOMS_z	$INDEX_{t-1}$	-0.0603	-0.5525	0.5813
ECOMS_z	$ECOMS_{t-1}$	0.6162	7.6459	<0.0010
ECOMS_z	$INDEX_{t-2}$	0.1642	1.7005	0.0907
ECOMS_z	$ECOMS_{t-2}$	0.1279	1.4023	0.1625

Source: Own calculations.

Table 20 shows borderline Granger causality in both directions (ECOMS → INDEX at p≈0.0697; INDEX → ECOMS at p≈0.0499). Impulse responses indicate that an e-commerce shock modestly raises the composite index, yet less dramatically than in the packaging-specific setting (Model C). Forecast error variance decompositions (FEVD) confirm that INDEX is mainly driven by its own past, with e-commerce shocks explaining around 7–12% of its mid-horizon variance. Overall, the aggregated nature of INDEX dampens e-commerce's immediate effect compared to packaging waste, although some two-way interaction may emerge over time.

Table 20: Model D Granger Causality Tests

Dependent Variable	Causal Variable	Test Statistic	p-value
INDEX_z	ECOMS_z	5.3269	0.0697
ECOMS_z	INDEX_z	5.9964	0.0499

Source: Own calculations.

3.3.2. Scenario E: Multi-variable system

Scenario E moves from a two-variable to a five-variable PVAR, incorporating the following as endogenous variables: INDEX (the PCA-based composite of WASTPC, MWASTE, PACWASTE, RECMWASTE), ECOMS RESP (resource productivity), UNEMP (unemployment rate), and INDVA (industrial value added).

To confirm the lag length, Table 21 again points to two lags. This setup explores whether industrial structure, labor dynamics, or resource productivity shape e-commerce's link to a broader waste–recycling context.

Table 21: Lag Selection Scenario E

Model	Lags	RSS	Num. Params	Nobs	LLF	AIC	BIC
Sc. E	60.9292	30	243	-176.725	413.4504	518.2422	60.92921
Sc. E	48.8923	55	216	-146.04	402.0792	587.7195	48.8923

Source: Own calculations.

Table 22 reveals several key insights. The index is highly persistent (~0.7701, p<0.001) but negatively influenced by rising unemployment, while e-commerce (ECOMS) again demonstrates inertia (~0.6897, p<0.001). Resource productivity (RESP) shows significant self-persistence (~0.7032) yet remains largely unaffected by e-commerce or the overall index. Meanwhile, unemployment (UNEMP) is persistent (~0.6765) yet may decline if industrial value added improves and industrial development (INDVA) interacts positively with e-commerce (Coefficient ~0.0561, p≈0.0415). These patterns suggest that labor conditions and industrial factors can indirectly modulate the interaction between e-commerce and waste, although direct e-commerce impacts on the index remain modest.

Table 22: PVAR Results for Scenario E Multi-Variable System

Dep. Var.	Regressor	Coeff.	t-stat	p-value
INDEX	$INDEX_{t-1}$	0.7701	16.1974	<0.0010
INDEX	$ECOMS\_z,_{t-1}$	0.0511	1.7219	0.0866
INDEX	$RESP\_z,_{t-1}$	-0.1274	-1.4068	0.1610
INDEX	$UNEMP\_z,_{t-1}$	-0.0685	-1.9842	0.0485
INDEX	$INDVA\_z,_{t-1}$	-0.0395	-0.7776	0.4377
ECOMS_z	$INDEX_{t-1}$	0.0280	0.4815	0.6306
ECOMS_z	$ECOMS\_z,_{t-1}$	0.6897	11.998	<0.0010
ECOMS_z	$RESP\_z,_{t-1}$	-0.1597	-0.7509	0.4535
ECOMS_z	$UNEMP\_z,_{t-1}$	-0.1715	-3.1956	0.0016
ECOMS_z	$INDVA\_z,_{t-1}$	-0.0908	-0.8107	0.4185
RESP_z	$INDEX_{t-1}$	-0.0157	-0.8202	0.4130
RESP_z	$ECOMS\_z,_{t-1}$	0.0249	1.7080	0.0891
RESP_z	$RESP\_z,_{t-1}$	0.7032	9.1462	<0.0010
RESP_z	$UNEMP\_z,_{t-1}$	-0.0314	-1.8769	0.0619
RESP_z	$INDVA\_z,_{t-1}$	-0.0104	-0.2679	0.7890
UNEMP_z	$INDEX_{t-1}$	-0.1187	-2.2052	0.0285
UNEMP_z	$ECOMS\_z,_{t-1}$	0.0067	0.1572	0.8753
UNEMP_z	$RESP\_z,_{t-1}$	-0.1274	-0.8091	0.4194
UNEMP_z	$UNEMP\_z,_{t-1}$	0.6765	13.1502	<0.0010
UNEMP_z	$INDVA\_z,_{t-1}$	-0.2024	-2.4414	0.0155
INDVA_z	$INDEX_{t-1}$	-0.0171	-0.4374	0.6622
INDVA_z	$ECOMS\_z,_{t-1}$	0.0561	2.0507	0.0415
INDVA_z	$RESP\_z,_{t-1}$	0.1185	0.8940	0.3723
INDVA_z	$UNEMP\_z,_{t-1}$	0.0668	2.2374	0.0263
INDVA_z	$INDVA\_z,_{t-1}$	0.2334	1.6474	0.1010

Source: Own calculations.

3.3.3. Scenario F: Partially exogenous

ScenarioScenario F treats RESP, UNEMP, and INDVA as exogenous, focusing on the two main endogenous variables, INDEX and ECOMS, while holding the others constant. The results broadly mirror Scenario E, implying:

- INDEX retains strong self-dependence (Coefficient ~0.6640), with minimal direct influence from e-commerce.
- ECOMS remains strongly autoregressive, reflecting its inherent momentum.

Although borderline Granger causality hints that e-commerce may influence the index over short horizons, the evidence is not conclusive once lagged index values are considered. Impulse responses confirm that e-commerce explains only around 12% of the index's variance, even by Horizon 5. Hence, structural exogenous factors (labor market, resource use, industrial activity) do not drastically amplify e-commerce's immediate role in shaping a combined waste–recycling index.

Table 23: PVAR Results for Scenario F Partially Exogenous

Dep. Var.	Regressor	Coeff.	t-stat	p-value
INDEX	$INDEX_{t-1}$	0.6640	7.4744	<0.0010
INDEX	$ECOMS\_z,_{t-1}$	0.0566	1.3668	0.1734
INDEX	$INDEX_{t-2}$	0.1029	1.4002	0.1631
INDEX	$ECOMS\_z,_{t-2}$	0.0273	0.6072	0.5445
INDEX	RESP_z	-0.0295	-0.2723	0.7857
INDEX	UNEMP_z	-0.0164	-0.3856	0.7003
INDEX	INDVA_z	-0.0829	-0.8603	0.3908
ECOMS_z	$INDEX_{t-1}$	-0.0608	-0.5514	0.5820
ECOMS_z	$ECOMS\_z,_{t-1}$	0.5975	7.3978	<0.0010
ECOMS_z	$INDEX_{t-2}$	0.1317	1.3348	0.1836
ECOMS_z	$ECOMS\_z,_{t-2}$	0.1223	1.4113	0.1599
ECOMS_z	RESP_z	-0.1112	-0.6218	0.5348
ECOMS_z	UNEMP_z	-0.1185	-1.9481	0.0529
ECOMS_z	INDVA_z	0.1558	1.0834	0.2800

Source: Own calculations.

These larger frameworks underscore that e-commerce exerts a pronounced, direct effect on packaging waste (Model C) but has smaller short-run impacts when aggregated with broader waste or recycling indicators. Model D suggests that packaging stands out among waste streams for e-commerce-driven increases, while the combined index reduces e-commerce's immediate significance. Scenarios E and F further show that industrial development, unemployment, and resource productivity overshadow e-commerce's direct influence, often operating through broader economic or labor-market pathways.

Thus, packaging emerges as the crucial channel for e-commerce-induced waste escalation. This highlights the importance of targeted policy and industrial responses, such as minimizing packaging material and improving recycling, to counteract online retail's environmental costs. The following sections delve into how these findings inform policy design and ongoing circular economy strategies.

3.4. Panel threshold regressions (PTR)

This section examines whether specific economic or labor-market conditions alter the relationship between e-commerce (ECOMS) and waste once a cutoff is crossed in the moderator variable. Three possible thresholds, unemployment (UNEMP_z), resource productivity (RESP_z), and industrial development (INDVA_z), are tested across all three models (A: WASTPC; B: MWASTE; C: PACWASTE). Single-threshold panel threshold regressions (PTR) were run to see how e-commerce's impact shifts under low vs. high regimes of these contextual factors.

Before turning to the results, Table 23 summarizes the key findings across Models A, B, and C, listing the best threshold and slope changes ($\beta 1$, $\beta 2$) under each moderator.

Table 23: Panel Threshold Regressions (PTR) Summary

Model	Yvar	Xvar.	TH Var.	Best TH	Param α	Param β1	Param β2	SR
A	WASTPC_z	ECOMS_z	RESP_z	-0.134	-0.005	-0.173	0.047	9.712
A	WASTPC_z	ECOMS_z	UNEMP_z	0.704	0.010	0.003	0.247	9.615
A	WASTPC_z	ECOMS_z	INDVA_z	-0.022	0.003	0.094	-0.016	9.756
B	MWASTE_z	ECOMS_z	RESP_z	-0.064	0.008	0.450	0.176	35.108
B	MWASTE_z	ECOMS_z	UNEMP_z	-0.097	0.030	0.107	0.391	35.008
B	MWASTE_z	ECOMS_z	INDVA_z	0.269	-0.001	0.236	0.454	35.817
C	PACWASTE_z	ECOMS_z	RESP_z	0.083	-0.007	0.342	0.485	13.167
C	PACWASTE_z	ECOMS_z	UNEMP_z	0.524	0.014	0.330	0.552	12.954
C	PACWASTE_z	ECOMS_z	INDVA_z	0.104	-0.003	0.328	0.530	12.936

Source: Own calculations.

1. Model A (WASTPC_z, ECOMS_z):
- Unemployment Threshold (~ 0.7042): E-commerce's slope rises from near zero to about +0.2468 in the higher unemployment regime, although the overall residual sum of squares (SSR) shift is modest.
- RESP or INDVA: Splits here yield slope changes in the range of $\beta1 \approx -0.17$ vs. $\beta2 \approx +0.05$, mostly borderline significant.
- High unemployment or lower resource productivity can amplify e-commerce's effect on total waste per capita, albeit less strongly than in packaging contexts.

2. Model B (MWASTE_z, ECOMS_z):
- Unemployment Threshold (~ -0.0972): Once unemployment dips below this level, the slope for e-commerce on MWASTE rises from about +0.1074 to +0.3909. Regions with lower unemployment appear more susceptible to short-run connections between e-commerce and MWASTE.
- Though earlier PVAR models found little short-run e-commerce influence on municipal waste, PTR suggests that under certain labor conditions, such as high employment, MWASTE may climb in tandem with e-commerce, likely reflecting higher consumption in more stable job markets.

3. Model C (PACWASTE_z, ECOMS_z):
- Unemployment Threshold (~ 0.5245): E-commerce's slope on packaging waste jumps from +0.0144 in the lower unemployment regime to +0.3302 in the higher unemployment regime, indicating a significant threshold change.
- Packaging Sensitivity: Packaging waste responds strongly to e-commerce expansion when unemployment is elevated, possibly due to shifting consumer habits or more frequent home deliveries in precarious labor contexts. The jump dwarfs that seen in total or municipal waste, underscoring packaging's vulnerability to online retail growth.

Across these threshold tests, H3 (Threshold Effect) is partly confirmed: e-commerce can exert a stronger influence on waste under specific labor or industrial conditions. The largest threshold effect surfaces in Model C, aligning with previous findings that packaging is the most e-commerce-sensitive stream (Caiyi et al., 2022). Policy or managerial actions, such as targeted recycling incentives or packaging regulations, may be especially crucial where unemployment or industrial structures exacerbate packaging inflows.

3.5. Quantile regressions

Quantile regressions next assess how e-commerce's impact on waste varies across the distribution, particularly among low- vs. high-waste countries. This approach moves beyond mean-based estimations to reveal differing effects along various percentiles.

Before detailing results, Table 24 (mentioned below) lists the quantile regression outcomes for Models A (WASTPC), B (MWASTE), and C (PACWASTE), with slopes at quantiles $\tau \in \{0.10, 0.25, 0.5, 0.75, 0.9\}$.

Table 24: Quantile Regressions

Model	Quantile	Yvar	Xvar	Param Const	Param Slope
A	0.1	WASTPC_z	ECOMS_z	-0.2055	0.0258
A	0.25	WASTPC_z	ECOMS_z	-0.0747	0.0304
A	0.5	WASTPC_z	ECOMS_z	0.0075	0.0063
A	0.75	WASTPC_z	ECOMS_z	0.0850	0.0694
A	0.9	WASTPC_z	ECOMS_z	0.1948	0.0717
B	0.1	MWASTE_z	ECOMS_z	-0.3819	0.2840
B	0.25	MWASTE_z	ECOMS_z	-0.1256	0.1661
B	0.5	MWASTE_z	ECOMS_z	0.0118	0.1590
B	0.75	MWASTE_z	ECOMS_z	0.1504	0.2301
B	0.9	MWASTE_z	ECOMS_z	0.3049	0.3554
C	0.1	PACWASTE_z	ECOMS_z	-0.2678	0.3451
C	0.25	PACWASTE_z	ECOMS_z	-0.1356	0.3716
C	0.5	PACWASTE_z	ECOMS_z	-0.0008	0.3523
C	0.75	PACWASTE_z	ECOMS_z	0.1361	0.3735
C	0.9	PACWASTE_z	ECOMS_z	0.2703	0.4284

Source: Own calculations.

1. Model A (WASTPC): At lower quantiles (τ=0.10,0.25,0.50), e-commerce's slope hovers near zero. At upper quantiles (τ=0.75,0.90), however, it rises (0.069–0.072), implying a "rebound" effect in high-waste settings (Fichter, 2002).
2. Model B (MWASTE): Positive slopes across all quantiles, growing from ~0.284 at τ=0.10 to ~0.355 at τ=0.90. This suggests that in higher MWASTE contexts, e-commerce has an even stronger positive correlation with municipal waste, an effect that average-based panel estimates might miss.
3. Model C (PACWASTE): E-commerce strongly correlates with packaging waste from low (τ=0.10) to high (τ=0.90) quantiles, with slopes around 0.345–0.428. High-waste countries thus see an even steeper e-commerce effect, echoing earlier packaging-focused PVAR findings.

3.6. Machine learning robustness checks

Random forest regressions were performed on WASTPC_z, MWASTE_z, and PACWASTE_z using e-commerce, recycling, industrial value added, and unemployment as features. Table 25 reports MSE and R-squared, whereas Table 26 shows feature importance.

Table 25. Machine Learning (Random Forest) Model Performance

Target	Mean Squared Error (MSE)	R-squared
WASTPC_z	0.219028	0.761683
MWASTE_z	0.349699	0.703557
PACWASTE_z	0.102336	0.894982

Source: Own calculations.

Table 26. Machine Learning (Random Forest) Feature Importance

Target	Feature	Importance
WASTPC_z	ECOMS_z	0.149054
WASTPC_z	RECMWASTE_z	0.233295
WASTPC_z	INDVA_z	0.413758
WASTPC_z	UNEMP_z	0.203893
MWASTE_z	ECOMS_z	0.085691
MWASTE_z	RECMWASTE_z	0.372636
MWASTE_z	INDVA_z	0.373102
MWASTE_z	UNEMP_z	0.168571
PACWASTE_z	ECOMS_z	0.157299
PACWASTE_z	RECMWASTE_z	0.501397
PACWASTE_z	INDVA_z	0.233315
PACWASTE_z	UNEMP_z	0.107988

Source: Own calculations.

1. Model Performance: Packaging waste (PACWASTE_z) yields the highest R^2 (~0.89). For total and municipal waste, industrial value added (INDVA_z) and recycling rates (RECMWASTE_z) appear slightly more important than e-commerce (ECOMS_z).
2. Partial Dependence Insights: Incremental e-commerce growth notably increases packaging waste, more so than total or municipal waste. Random forest results confirm that packaging is highly sensitive to online retail, while broader waste categories are shaped by factors like recycling infrastructure or industrial composition (Yu et al., 2023).

Thus, machine learning checks reinforce the main econometric findings: e-commerce is a key predictor for packaging, but not the sole driver of overall waste streams. This underscores the need for targeted interventions, such as reusable packaging and more advanced recycling, to curb e-commerce-driven waste surges.

3.7. Comparisons to prior studies and summary of key findings

This multi-method, multi-country approach extends beyond single-model or single-nation analyses (e.g., Stinson et al., 2019). While e-commerce's net impact can be partially offset by logistical efficiencies, the packaging domain proves particularly susceptible, aligning with earlier studies (Bertram & Chi, 2017; Yu et al., 2023). Threshold tests show that factors like unemployment and resource productivity can amplify e-commerce's impact, especially on packaging waste, whereas quantile regressions reveal that high-waste countries experience stronger correlations between e-commerce and waste. Finally, random forests confirm packaging as the most e-commerce-sensitive stream, while total and municipal waste hinge more on macro-structural variables like industrial value added (Fichter, 2002).

Overall, e-commerce demonstrates limited short-run effects on total or municipal waste but exerts a robust, often threshold-dependent influence on packaging waste. This finding holds key policy implications: legislation might prioritize packaging regulations, recycling enhancements, or industrial transitions in regions where labor-market or structural conditions heighten e-commerce's environmental footprint.

4. Discussion

This study's findings depict a complex interplay between e-commerce (ECOMS) and various waste indicators in the European Union (EU), relying on a Panel Vector Autoregression (PVAR) framework complemented by panel threshold regressions (PTR), quantile regressions, and machine learning. By investigating whether e-commerce directly affects waste per capita (WASTPC), municipal waste per capita (MWASTE), and packaging waste per capita (PACWASTE), it also examines how recycling infrastructure (RECMWASTE), industrial development (INDVA), and resource productivity (RESP) might moderate these relationships. The results underscore how contextual factors shape diverging outcomes for different waste streams.

PVAR Models A (WASTPC & ECOMS) and B (MWASTE & ECOMS) show that e-commerce exerts negligible short-run effects on total or municipal waste per capita. These results echo Fichter's (2002) assertion that partial offsets, such as optimized logistics, can limit e-commerce's direct impacts on broad waste indicators. By contrast, Model C (PACWASTE & ECOMS) indicates a pronounced positive correlation, with e-commerce shocks explaining up to 22% of PACWASTE variance. This finding confirms that H1 applies most strongly to packaging waste, likely due to the resource-intensive nature of shipping materials (Bertram & Chi, 2017; Yu et al., 2023).

Subsequent analyses (Model D, Scenario E/F) reinforce that e-commerce's clearest short-run environmental effects center on packaging rather than entire waste streams. Although there is no explicit interaction term between e-commerce and recycling, machine learning feature importances highlight RECMWASTE's role in shaping overall waste outcomes. Particularly in packaging, strong recycling capacity (Popović & Milijić, 2021) could partially mitigate e-commerce-driven inflows, offering limited support for H2. Nevertheless, advanced recycling alone does not negate e-commerce's impact on packaging.

Panel threshold regressions confirm that in specific labor or industrial contexts, e-commerce-induced waste surges intensify. PACWASTE again exhibits the most pronounced threshold jump, from roughly +0.0144 to +0.3302 in higher unemployment settings, suggesting that precarious labor markets may amplify e-commerce's packaging footprint (Bertram & Chi, 2017; Caiyi et al., 2022). This supports H3, particularly for packaging scenarios, although municipal waste sees a smaller threshold effect. Meanwhile, limited cross-sectional dependence (Pesaran CD) implies that e-commerce expansion in one Member State does not significantly affect neighboring waste levels, undercutting H4.

Regarding timing, short-run IRFs suggest no immediate surge in total or municipal waste, while packaging sees a marked rise after 2–3 periods. Model C's impulse responses and random forest partial dependence both confirm that packaging implications do not disappear over time, signaling a persistent e-commerce effect. Thus, H5 is partially supported: although no long-run cointegration tests were performed, multi-lag PVAR results imply that packaging inflows can persist unless moderated by regulation. The EU's Packaging and Packaging Waste Regulation (PPWR) may eventually curb such effects, but near-term policies remain crucial.

These outcomes align with previous literature (Matthews et al., 2001; Bertram & Chi, 2017; Yu et al., 2023), emphasizing packaging as e-commerce's primary environmental liability, while broad waste indicators (WASTPC, MWASTE) see muted direct impacts. In line with Fichter (2002), partial logistical efficiencies can neutralize some net increases in total waste. However, threshold analyses highlight how labor-market vulnerabilities (e.g., higher unemployment) can exacerbate packaging streams. This dynamic intersects with structural factors, such as industrial composition and resource productivity, that shape the distribution and magnitude of e-commerce-driven waste (Visser & Lanzendorf, 2004).

Quantile regression findings reinforce these insights, revealing that high-waste countries exhibit a stronger correlation between e-commerce and waste, particularly for packaging. Meanwhile, multi-variable PVAR expansions (Scenario E/F) show that industrial value-added and unemployment constrain or redirect e-commerce's environmental impacts, overshadowing them for total or municipal waste in certain contexts (Imran et al., 2023; Popović et al., 2023). Consequently, no uniform e-commerce effect applies across all Member States; policies must adapt to local labor and industrial structures.

From a policy standpoint, packaging stands out as the key domain for targeted interventions. As e-commerce fuels short-to-medium-term packaging increases, especially where unemployment is high, policymakers might prioritize measures such as:

- Stricter EU-level standards (PPWR) and extended producer responsibility (EPR) schemes to curtail single-use plastics.
- Enhanced recycling capacities, ensuring efficient collection and reuse.
- Incentives for minimal-packaging design, biodegradable materials, or reusable shipping containers.

Although e-commerce alone does not dominate broader waste trajectories, contextual forces (industrial composition, labor markets) play critical roles in fueling consumption or shaping disposal patterns. Future studies should address data granularity, such as subnational or firm-level, to uncover finer-scale variations in returns and reverse logistics.

More advanced threshold or spatial models (Durbin) may also clarify how regional trade corridors transmit e-commerce-related waste. Finally, researchers could explore whether policy-driven design changes weaken e-commerce's packaging footprint over time.

Overall, these findings highlight e-commerce's nuanced environmental imprint in the EU. Although total and municipal waste often see moderate short-run changes, packaging emerges as the domain of immediate concern, magnified by specific economic conditions. By emphasizing context-dependent strategies, particularly in packaging management, this research informs policymakers and industry stakeholders seeking to reconcile digital market growth with sustainable waste outcomes.

Conclusion

This paper has provided new insights into how e-commerce expansion affects waste generation across the European Union (EU), focusing on total, municipal, and packaging waste. By employing a multi-method approach, Panel Vector Autoregression (PVAR), panel threshold regression, quantile regression, and machine learning, this study has shown that e-commerce's most immediate impact emerges in packaging waste, while total and municipal waste exhibit weaker short-run responses. These findings highlight that packaging streams, rather than aggregated or municipal indicators, serve as the primary channel through which digital commerce exerts short-term pressure on waste.

The research further reveals that certain contextual factors, such as unemployment levels or industrial composition, can magnify the packaging-specific effects of e-commerce. Meanwhile, higher recycling capacity demonstrates the potential to moderate packaging inflows but does not fully negate e-commerce's role in boosting packaging waste. Overall, the results imply that policymakers and industry actors aiming to mitigate the environmental footprint of online retail should consider targeted measures for packaging materials, especially in labor contexts prone to greater e-commerce-driven surges.

Future studies could explore subnational heterogeneities, more fine-grained data on reverse logistics, and longer time horizons to capture how shifts in policy or consumer behavior might alter the packaging-intensive nature of e-commerce. Despite certain limitations regarding data granularity and cross-border analyses, this work advances the literature by delineating the varied, context-dependent pathways through which digital retail can shape waste patterns within the EU's complex policy and economic landscape.

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THE RELEVANCE OF TECHNOLOGICAL QUALITY FOR THE SUSTAINABLE BUSINESS OPERATIONS OF ECONOMIC ENTITIES

Abstract

The technological level of contemporary economic entities is closely linked to global trends in new technologies. Revolutionary trends in the development of new technologies create modern and efficient economic entities and enable them to operate in the global market through various computerized structural models. An economic entity striving for success pays special attention to technological improvement as an output indicator of sustainable operations, incorporating sustainable development into its business strategy. This paper examines the validation of technological quality and the selected factors relevant to the sustainable operations of economic entities. The core idea is to identify the central value of the achieved technological level of national economic entities as a relevant factor in generating their sustainability in the market. The assumption is that the level of operations and the duration of functioning significantly impact the differences in the technological levels of national economic entities.

Keywords: *technological level, sustainable business, economic entities, business level, duration of functioning.*

JEL classification: *L24, M14, O14, O33*

РЕЛАЦИЈЕ ТЕХНОЛОШКОГ КВАЛИТЕТА ЗА ОДРЖИВО ПОСЛОВАЊЕ ПРИВРЕДНИХ СУБЈЕКАТА

Апстракт

Технолошки ниво савремених привредних субјеката уско је повезан са модерним трендовима нових технологија на глобалном нивоу. Револуционарни трендови развоја нових технологија креирају савремене и ефикасне привредне субјекте и омогућавају им пословање на светском тржишту кроз различите информа-

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тизоване структурне моделе. Привредни субјект који стреми успеху, посебну пажњу придаје технолошком побољшању као излазном индикатору одрживог пословања које укључује усвајање одрживог развоја у пословну стратегију. Предмет истраживања у овом раду је валидација технолошког квалитета и селектованих фактора релевантних за одрживо пословање привредних субјеката. Основна идеја је проналажење централне вредности оствареног технолошког нивоа националних привредних субјеката као релевантног фактора генерисања њихове одрживости на тржишту. Претпоставка је да ниво пословања и дужина функционисања играју значајну улогу на разлике у технолошком нивоу националних привредних субјеката.

Кључне речи: *технолошки ниво, одрживо пословање, привредни субјекти, ниво пословања, дужина функционисања.*

Introduction

The issues of sustainable business (Ruggerio, 2021) and the overall complexity of technological changes are crucial subjects of contemporary social and economic research (Šušić, 2018). The concept of sustainable business has become key to creating a sustainable future, addressing the impact of business on the environment and society. Corporate social responsibility, through its policies and practices that consist of economic, social, and ecological dimensions, plays a pivotal role in achieving sustainable development, thus interlinking socially responsible business practices (Grubor et. al., 2020) and sustainable development. Clearly, the focus today is on the economy, organization, and technology. All entities in this chain are interconnected through various networks, whether social, economic, or organizational, in which they play different roles. Each network represents an organization with its rules and structure, influencing people's lives in unique ways.

Technology, as a concept, refers to the industrial revolution, information technologies, and everything related to economic development in environments increasingly dependent on infrastructure facilitating the functioning of individuals and organizations, including computers, smart devices connected to the internet, GPS, and other tools that have become indispensable in daily life (https://sr.nsp-ie.org/ventajas-desventajas-3892#menu-1). Technological changes bring modifications in the approach to inputs or methods that alter measurable performance (Sabherwal & Jeyaraj, 2015) of products or processes. Economic entities utilize specific technologies that include accumulated and materialized knowledge and experience from previous generations in generating product quality and high growth (Petrović & Leković, 2019; Buntak, et. al. 2011).

The rapid pace of technological development is undeniable, with trends (Abimbola, 2021) offering economic entities new competencies (Torkkeli & Tuominen, 2002). The expansion of technological progress has reduced monopolies on knowledge, allowing anyone organizationally and financially prepared to compete in the global market. Based on increasingly innovative technological possibilities (Stanković, 2020), new products and ways to meet both old and new needs are being developed. Accelerated technological development (Đuričić et. al. 2009), which has generated numerous new technologies, confirms its role as the strongest driver of sustainable development (Beckerman, 2002) for contemporary economic entities. This foundation facilitates their adaptation to new economic structures and the growing need to maximize the use of new technologies and innovations (Bharadwaj, 2000). Given the different technologies used by economic entities, their organizational structure will also vary, influenced by changes in the environment.

New technologies and innovations (Lecerf & Omrani, 2019; Zhu et. al. 2006) offer more economical operations, with an increasing number of technological solutions already in widespread use or entering the mainstream. Modern technologies are applied in product promotion, sales, goods delivery, services provision, corporate governance, and supporting management or supervisory functions. The influence of new technologies also alters the market structure of capital (Mudrinić, 2022, p. 95), leading to new organizational forms of business operations. These technologies are global, interconnected, decentralized, autonomous, and automated. In this sense, "the flow of information will be unstoppable and in real-time; everything will be personalized, and individual desires and needs will be anticipated by companies to design products and services; existing products and entities will be broken down into the simplest possible parts, which will then be combined and recombined in infinite ways to meet human curiosity about what can be made or destroyed and recreated..." (Kelly, 2016).

The desire to adopt advanced technologies to accelerate business capabilities (Mitra, 2005) is an undeniable need for national economic entities, regardless of their duration of operation or level of business. Each entity must understand the technological environment, including the available market technologies they do not possess or utilize. To stay competitive, technological competence and cost capability (Stoiljković et. al. 2024) are crucial for the sustainable operations of economic entities (Blewitt, 2008), and continuous investment is required (Margaritis & Psillaki, 2010).

Technological competence (Acur et.al. 2010; Duysters, Hagedoorn, 2000) can accumulate but also erode and disappear, losing the competitive advantage (Kurti, 2016), potentially jeopardizing the entity's survival. As the number of national economic entities utilizing new technologies increases, other national organizations, if they wish to remain on the market (Oliveira, Martins, 2011), must introduce new technologies through innovations, licensing, international technology transfer, etc. (Glass et. al. 2008). New technologies will require changes in organizational structures (Edgar & Lockwood, 2008), sometimes significant, and management must be prepared for this.

To fully benefit from technological and digital advancement, it is critical for Serbian enterprises to be technologically aware and adaptable to acquiring necessary skills, cultural changes, and the continuous need for adaptation, learning, and corporate governance (Saleem, 2020). This implies that the best offerings from new intensive technologies (Drejer & Sorensen, 2002) should be harnessed to automate business processes and generate sustainable operations and business excellence.

Finally, although the development of new technologies offers numerous advantages, it also introduces substantial risks (https://www.glasamerike.net/a/a-34-2006-04-13-voa4-86803417/7395 12.htm). Thus, there is a need to establish mechanisms within the corporate governance system to manage the risks posed by the implementation of new technologies, to avoid misuse and ensure ethical application (Mudrinić, 2022, p. 95).

1. Research subject and methodology

Numerous studies conducted from various perspectives have confirmed the strong need for manufacturing companies to enhance their technological capabilities, as they recognize it as a key tool for improving business performance and sustainable development (Bai et.al. 2023; Boston Consulting Group BCG, 2023; Bazata, 2018; McKinsey & Company 2023), while also serving as an active tool for technological transition in the entity.

This study assumes that in the current economic environment, a high level of technological proficiency is one of the conditions for achieving high business performance in manufacturing entities. The research involves validating selected elements presumed important for improving the sustainable operations of economic entities in Serbia. Relevant parameters considered include the technological level of economic entities, their openness to innovation, the quality of products offered in the market, and their competitive readiness. The focus is primarily on the impact of the relationship between business level and duration of operations on technological quality assessment, along with a comparative analysis of economic entities with specific scopes of operations in evaluating their technological levels. In addition to several essential factors, qualified leadership is certainly a critical prerequisite for creating an entity that ensures sustainable business operations. The duration of business operations and the scope of functioning influence technological quality, which contributes to generating sustainable development and gaining an edge in creating value and quality products for the market.

The research was conducted as a cross-sectional deterministic study. The methodological framework included an exploratory approach, bibliographic speculation, and statistical comparison methods. A purposeful selection of 104 companies chosen from the Serbian Business Registers Agency's database served as the basis for the study, including (16%) micro-organizations, (33%) small organizations, (31%) medium-sized organizations, and (20%) large organizations. The research was conducted using an online questionnaire. The survey was anonymous, and responses were provided by owners or senior managers within the organizations. The survey aimed to collect data regarding the significance of national firms' technological accomplishments and to evaluate their intensity in the context of the interaction between business duration and scope. The responses were processed using ANOVA and non-parametric $\chi 2$ tests, and the data was presented in tabular and descriptive formats.

2. Results and discussion

A reliable assessment of technological competence within the framework of sustainable business practices enables the management of national economic entities to make more informed strategic decisions and minimize the risk of errors caused by incorrect assumptions in evaluating the level of technological preparedness. Descriptive statistics were used to assess business operations as variables whose values depend on independent variables, with a focus on the technological level of economic entities to identify connections and relationships while comparing selected characteristics. Respondents from economic entities operating at different levels and with specific durations of operation were asked to evaluate selected parameters from a set of questions in a survey, rating them on a scale from 1 to 5, where 1 is the lowest score and 5 is the highest. The results for individual selected characteristics, with emphasis on technological level, are presented in Table 1.

Table 1. Validation of technological quality and selected factors relevant for the sustainable operations of national economic entities

Properties of elements	Af	Rf[1]	Af	Rf[2]	Af	Rf[3]	Af	Rf[4]	Af	Rf[5]	Estimates
Technological intensity of the business entity	0	0	14	10,0	21	15,4	58	42,7	46	33,7	
The openness of the business entity to innovation	2	1,8	5	3,7	37	27,1	45	33,4	49	35,4	
The quality of the product on the market where the business entity operates	2	1,6	11	8,2	49	36,1	41	30,2	35	25,8	
The degree of competitive readiness of the business entity	4	2,9	9	6,2	31	22,9	58	42,3	37	27,2	

Note: Af – absolute frequencies; Rf – relative frequencies (percentages).

Source: Authors

Table 2 shows the ranking of the listed characteristics based on the average scores (mean values) for each attribute.

Table 2. Ranking of considered properties

Properties	Technological intensity of the company	The company's openness to innovation	Product quality on the market where the company operates	The degree of competitive readiness of the company
Mean values	3,98	3,99	3,71	3,87
Attribute rank	1	5	4	2

Source: Authors

The obtained results indicate that the technological level in economic entities, along with their openness to innovations covered by the sample, is rated the highest (with an average score close to 4) compared to other considered characteristics. The potential influence of the length of operation and the level of business (local, national, regional, and international) on the differences in the characteristics of economic entities was evaluated through a two-factor analysis, as a prerequisite for national economic entities to achieve a respectable and sustainable level of business and development. A significance level of 0.05 was adopted (for all values of Sig ≤ 0.05, there is a statistically significant difference). The characteristic focused on in the study was the technological level of economic entities. Mean values for the technological level of domestic economic entities, operating for different periods and in various markets, are provided in Table 3, for every level and duration of operation. N is the number of respondents in the sample, and the standard deviation (Std. Deviation) is the deviation of the mean score. It is evident that the technological level was rated the highest by economic entities operating in regional markets, particularly those operating between 6 and 10 years and between 21 and 30 years.

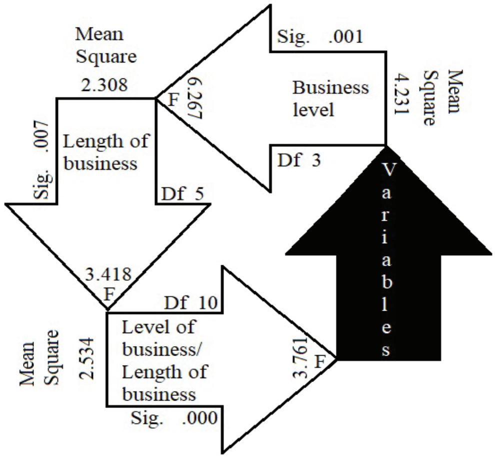
Table 3. Mean score of technological intensity in economic entities

Business level	Length of an organization's business	Mean	Std. Deviation	N
Local market	From 6 to 10	3.00	1.155	4
	From 11 to 20	4.00	.000	3
	From 21 to 30	4.50	.535	8
	Over 40 years	2.00	.000	2
	Total	3.76	1.091	17
National market	Up to 5	4.71	.488	7
	From 6 to 10	4.00	.000	2
	From 11 to 20	3.11	1.054	9
	From 21 to 30	3.20	.919	10
	From 31 to 40	4.00	.000	2
	Over 40 years	3.50	.577	4
	Total	3.62	.985	34
Regional market	From 6 to 10	5.00	.000	2
	From 11 to 20	3.50	.535	8
	From 21 to 30	5.00	.000	4
	Over 40 years	4.44	.527	9
	Total	4.26	.752	23
International market	From 6 to 10	3.93	1.223	15
	From 11 to 20	4.42	.515	12
	From 21 to 30	3.90	.995	21
	From 31 to 40	4.00	.000	3
	Over 40 years	4.27	.786	11
	Total	4.08	.929	62
Total	Up to 5	4.71	.488	7
	From 6 to 10	3.87	1.180	23
	From 11 to 20	3.78	.870	32
	From 21 to 30	3.95	.999	43
	From 31 to 40	4.00	.000	5
	Over 40 years	4.04	.916	26
	Total	3.96	.957	136

Source: Authors

The impact of the interaction between the duration of operation and the level of operation on the technological intensity rating is shown in Table 4. In the column for Business Level/Duration of Operation, Sig = 0.000, which is less than 0.05, suggesting that significant differences exist in the technological level ratings of economic entities operating at different levels and for different periods. There is a statistically significant interaction effect between the business level and duration of operation. After analyzing the overall impact, the study moved on to assess the individual impacts. In particular, a value of 0.001 was discovered in the Sig column for business level, which is less than 0.05, indicating that the business level of economic entities has a significant impact on the ratings of their technological intensity as a key factor in sustainable operations. Similarly, Sig for the duration of operation was less than 0.05, at 0.006, also significantly influencing differences in the technological level rating of the economic entity. It can be concluded that both the level of business and duration of operation play a significant role in the technological differences observed among companies.

Table 4. The impact of interaction between business level and duration of operation on the evaluation of technological intensity in national economic entities



Source: Authors

It is evident that there are distinct individual impacts of business level and duration of operation on the technological quality of economic entities. Tukey's test was then used to determine whether economic organizations had significantly different ratings according to their business level. Table 5 presents that significant differences exist in the technological intensity between entities operating in national and regional markets and between those operating in national and international markets.

Table 5. Comparative analysis of national economic entities with different business levels in technological intensity ratings

(I) Business level of the business entity	(J) Business level of the business entity	Mean difference (I-J)	Standard deviation	Deviation significa-nce (Sig)	95% Confidence interval	
					Lower limit	Lower limit
Local market	National market	.15	.244	.931	-.49	.78
	Regional market	-.50	.263	.239	-1.18	.19
	International market	-.32	.225	.499	-.90	.27
National market	Local market	-.15	.244	.931	-.78	.49
	Regional market	-.64(*)	.222	.023	-1.22	-.07
	International market	-.46(*)	.175	.046	-.92	-.01
Regional market	Local market	.50	.263	.239	-.19	1.18
	National market	.64(*)	.222	.023	.07	1.22
	International market	.18	.201	.806	-.34	.70
International market	Local market	.32	.225	.499	-.27	.90
	National market	.46(*)	.175	.046	.01	.92
	Regional market	-.18	.201	.806	-.70	.34

Source: Authors

Conclusion

This study was conducted on a sample of national economic entities of varying sizes, levels, and durations of operation, with proportional representation based on size. The assumptions presented in this study indicate that sustainable business operations are not achievable unless management strengthens the technological competence of the economic entity. The results reveal significant differences in the technological competence ratings of economic entities operating at different business levels and durations. Factors such as the duration of operation and the scope of operations, which were the focus of the evaluation, both individually and in interaction, confirm the fact that the technological level can be a decisive factor in the quality of products offered by economic entities in the market.

Further conclusions indicate that the technological level of economic entities is rated highest by those operating in regional markets, particularly those operating for 6 to 10 years and 21 to 30 years. The impact of the interaction between business level and duration of operation is statistically significant. Tukey's test reveals that individual impacts of the business level and duration of operation on technological specifics differ across economic entities. Notably, there are differences in the technological level of entities operating in national and regional markets compared to those operating in national and international markets.

In conclusion, the results suggest that the technological level is fundamental to the sustainable survival of national economic entities in the market, into which continuous investment is necessary. The duration of operation and the level of operation significantly affect the properties of entities considered business-sustainable. The technological level of national economic entities holds potential for changes that can reduce the negative impact on the environment. To generate a business future through technology, economic entities must strengthen their awareness of improving the technical-technological foundation of operations and adaptability in acquiring necessary skills and continuous correction and learning.

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INTERDEPENDENCE OF SUSTAINABILITY AND VALUE CREATION

Abstract

Sustainable business means cleaner and more environmentally focused business, which will meet current needs, but also leave the opportunity for future generations to use the benefits of natural resources. Companies are interested in sustainable business, because in this way they can influence the creation of value and the achievement of better business performance. Creating sustainable value contributes to building a sustainable environment and better environmental stewardship while delivering shareholder benefits, which are emphasized in the traditional concept of value creation. Therefore, the purpose of this paper is to explain the interdependence of sustainability and value creation.

Keywords: *sustainable business, value creation*

JEL classification: *G32, Q56*

МЕЂУЗАВИСНОСТ ОДРЖИВОСТИ И КРЕИРАЊА ВРЕДНОСТИ

Апстракт

Одрживо пословање подразумева чистије и еколошки фокусирано пословање, које ће задовољити тренутне потребе, али и оставити могућност за будуће генерације да користе благодети природних ресурса. Предузећа су заинтересована за одрживо пословање, јер на тај начин могу да утичу на креирање вредности и остварење бољих осталих пословних перформанси. Креирање одрживе вредности доприноси изградњи одрживог окружења и бољем управљању животном средином уз остваривање користи за акционаре, који се потенцирају у традиционалном концепту креирања вредности. Стога, сврха овог рада је да објасни међузависност одрживости и креирања вредности.

Кључне речи: *одрживо пословање, креирање вредности*

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Introduction

The emergence of the idea of sustainability is related with the end of the 20th century. At the beginning of the development of the concept, being involved in sustainable business was often considered an eccentricity, a trend, a whim or merely desire to be different. However, this attitude was quickly changed. It is understood that through sustainable business, many benefits can be achieved for the company and the environment. Investing in environmental activities is not just a cost, as it was previously thought. Engaging in sustainable business activities can foster innovation, which leads to the improvement of business.

Increasing exploitation of forests and levels of pollution of water, air, soil, destruction of ecosystems, urbanization, etc., have led to a shortage of certain natural resources. Since the Industrial Revolution, environmental problems have become more pronounced, affecting the need for more responsible management of resources at all levels (Kopnina & Blewitt, 2015).

On the other hand, the value of a company is defined as the market value of its tangible and intangible assets. Maximizing the value of the company is important because it leads to maximizing the efficiency of the business activities. There are different methods of measuring the value created by a company, from EVA (Economic Value Added) to Tobin's Q (Zhang et al., 2023).

The company's strategy should be focused on creating value, which largely depends on the resources used and the capabilities that the company possesses. In addition, it depends on the way employees conduct their activities. Consequently, it is crucial to motivate employees to create value for the company, familiarize them with the activities they need to conduct and specify the tasks that contribute to this (Bowman & Ambrosini, 2016).

After presenting the theoretical concept of business sustainability, the aim of this research is to explore the relationship between sustainable business and value creation. Given that the concept of sustainable value is relatively new, the paper aims to show its significance, as well as the differences from the traditional concept of value.

1. Conceptual framework of business sustainability

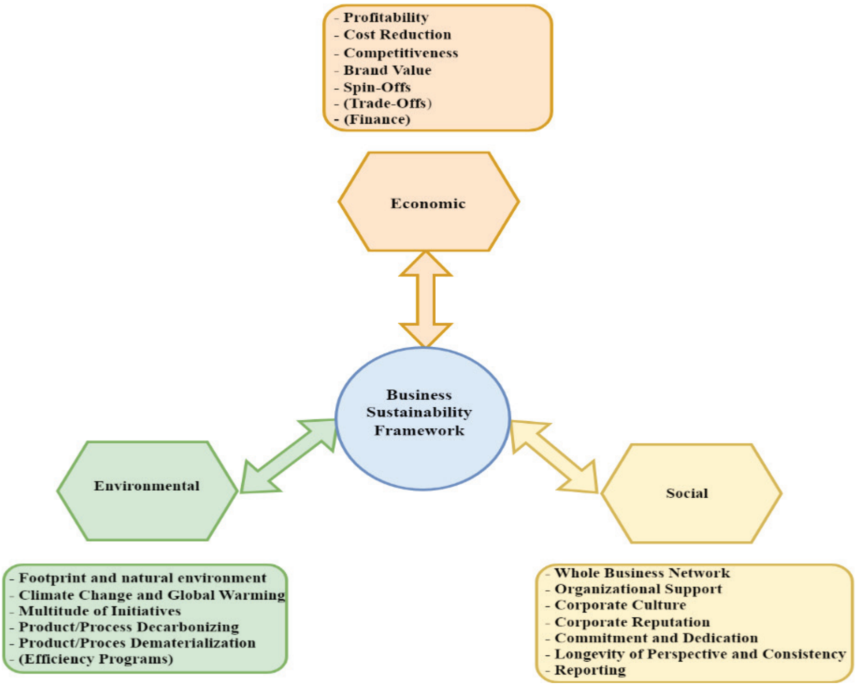
Human activity that leads to the degradation of any aspect of the natural environment is considered an undesirable, polluting activity. With the growth of the global population, there is an increase in the amount of waste, pollution emissions, the use of chemicals, the exploitation of natural resources, deforestation, etc. All this affects the reduction of biodiversity, the extinction of plant and animal species, but also the deterioration of human health and increased mortality caused by pollution. Developing countries are particularly in trouble, as they cannot effectively manage protection processes and take measures to reduce the negative effects of environmental accidents due to inadequate legislation and low awareness of the importance of environmental protection. Moreover, companies from less developed countries, in accordance with the environment in which they are located, do not sufficiently apply environmentally friendly business (Ukaogo et al., 2020).

In the initial stages of sustainable business development, sustainability was seen as a way to transform traditional business into newer, more sophisticated business systems. Today, it is a way to gain a competitive advantage. Unlike traditional systems, sustainable business systems include concepts, principles, and goals that enable the integration of sustainability into a value system (Geissdoerfer et al., 2018).

Sustainability, as a response to environmental problems, means changing the way sustainable value is produced, delivered and exchanged. It is linked to the circular economy and should be integrated into all activities across the value chain (Marković, 2023). To enable greater efficiency in the use of resources, sustainability needs to be embedded in a sustainable business model (Goni et al., 2021). The environment, society and economy are closely related to sustainable business. To achieve sustainability, integrating corporate sustainability (CS) into an organization's strategy has become an essential challenge (Nguyen & Kanbach, 2023).

The business sustainability framework shown in Figure 1 presents the latest insights into the "triple bottom line" (TBL) concept. This concept recognizes the first three essential dimensions of business sustainability (Laurel et al., 2019). To generate a competitive advantage in the context of business sustainability, it is necessary to balance the interests of stakeholders, environmental objectives and the well-being of the community (Wilshusen & MacDonald, 2017).

Figure 1. Business sustainability framework



Source: Authors' elaboration based on Lozano (2020, p. 25) and Laurel et al. (2019)

Sustainability is the interaction of economic, environmental and social dimensions (Abouelnaga et al., 2020, p. 523). Economic sustainability is essential for long-term growth, which refers to an organization's ability to generate profits and use resources efficiently without negatively impacting environmental, social, and other aspects. Environmental sustainability is the ability of companies to use natural resources to avoid or minimize the negative impact of business practices on the environment. Social sustainability aims to promote social harmony and improve values and interpersonal behaviour (Abouelnaga et al., 2020, p. 523).

Corporate sustainability can contribute to the enhancement of non-financial aspects of a business, such as brand, reputation, and employee loyalty. Contrary to the earlier understanding of sustainability in companies, which was seen as a philanthropic activity that does not bring any tangible benefits, today the results of research and operations of companies that apply sustainable business show completely opposite effects (Camilleri, 2017).

Sustainable business integrates care for the community, human rights and ensures that there is no negative impact on the environment throughout the entire chain - from the procurement process to delivery. However, there are companies that implement partially sustainable business activities in traditional models, so for example, sustainability is kept only at the company level, and not spread to suppliers or customers. Some of the benefits of applying the principles of sustainability for the company are (Chungyalpa, 2019):

- Streamlining processes, reducing operating costs and increasing effectiveness and efficiency;
- Possibility of benchmarking with other companies and internally in relation to previous periods of business:
- The possibility of conducting corrective actions if negative impacts on the environment are identified;
- Meeting the expectations of stakeholders in terms of moral principles;
- Building a good reputation and image;
- The possibility of using incentives from the state for environmentally responsible business practices;
- Ability to collaborate with non-governmental organizations;
- The possibility of expanding the market because business is conducted following environmental requirements.

Large companies are, as a rule, the biggest potential polluters. Regulations at the international level that are related to sustainable development are particularly relevant to these companies. For example, large corporations of EU member states implement the European Union Strategy, which also contains the Environmental Management Plan (Dragomir et al., 2023). The energy crisis caused by the Russia-Ukraine conflict has helped companies understand the importance of energy efficiency management and the use of alternative energy sources. The companies ranked as the largest polluters belong to the production, processing and sale of oil and gas, i.e. they are related to the energy sector (Statista, n.d.). Most of them are U.S. companies, as well as companies from developed countries.

2. Sustainable business and value creation – sustainable value

For a long time, value creation has been seen as the primary goal of the company. Numerous studies on value creation have different interpretations: some emphasize the importance of creating value for shareholders, while others believe that value should be for all stakeholders.

The traditional view of value creation has been based on looking at the revenues and costs. The focus was on analysing the relationship between the costs perceived by consumers and the benefits they receive by purchasing a particular product or service. Today, the field of environmental protection is increasingly included in the concept of value creation. The inclusion of environmental and social impacts, in addition to economic ones, is becoming increasingly important. Incorporating sustainability into value creation contributes to increased stability and reduces risks and uncertainty. There are also positive effects on reputation and image (Laukkanen & Tura, 2020).

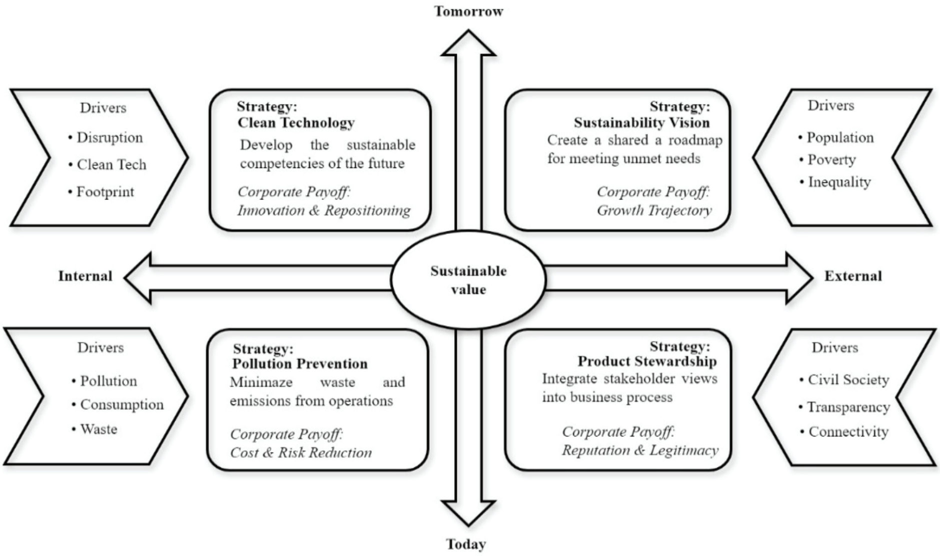
When examining the literature relating to strategic management, the term "value" refers primarily to economic value. Economic value is the difference between the benefits earned by consumers and the costs incurred by the company to create value. It is considered essential to strike a balance between investing in stakeholder relations and creating value for the company. In practice, two extremes can occur. The first involves significant investments in stakeholder relationships which carry a certain degree of risk due to the potential for unsuccessful outcomes. The second, which is characterized by minimal investments, can lead to underutilized capacities that could otherwise be used from these relationships (Barakat & Gabriel, 2022).

On the other hand, discussions about corporate social responsibility began in the 1960s. A previously neglected concept, it has gained importance due to the recognition of numerous environmental problems. Until then, the economic dimension of the business was only in focus. A sustainable business can contribute to a better image of a company, as well as a better reputation. It also brings benefits for society and social actors, reduce employee turnover and increase job satisfaction. Companies are implementing sustainable business models in their operations. Creating and delivering sustainable value is at the core of sustainable business. By modifying traditional transactional business practices to include sustainability components, this approach is becoming more common in practice. In addition, incorporating the circular economy into the concept of sustainable business creates an opportunity to generate additional value for the company (Goni et al., 2021).

Figure 2 shows the sustainable value framework, which is a strategic tool and a comprehensive approach to how businesses can generate value and consider environmental and social impacts. The four types of drivers are located along the "Internal-External" horizontal axis and the "Today-Tomorrow" vertical axis. Internal drivers (bottom left box) such as air pollution, consumption of non-renewable energy and resources, and waste, refer to the negative effects that businesses can have on the environment. External drivers (bottom right box) such as civil society, transparency, and connectivity, refer to the emergence of a global approach that involves various stakeholders in improving a company's products or services. The upper left quadrant shows the drivers related to today's disruptions, clean technology, and footprint, which enable the development of new competencies to rejuvenate declining industries. On the other hand, the upper right quadrant emphasizes future drivers focused on promoting justice, equality, and growth.

To create sustainable value, companies need to design and implement strategies in every dimension.

Figure 2. Sustainable value framework



Source: Adapted from Hart & Milstein (2003, p. 60)

Value creation, as a concept, gains in complexity by linking it to sustainable business. In the scientific community, the authors look at sustainable value creation from a variety of perspectives. According to Bocken et al. (2013), value creation arises from mutual interactions, where sustainable value is formed through the analysis of value that has been destroyed or missed. Later research (Brennan & Tennant, 2018) believes that sustainable value creation is achieved by linking tangible factors of production, i.e. structural resources with cultural resources. Other authors define sustainable value creation as the generation of value for multiple stakeholders and the natural environment (Dembek et al., 2018). Sustainable value creation can also be represented as the sum of the costs and revenues that arise from the activities of companies in terms of the environmental, economic, and social measures they take. Lüdeke-Freund (2020) views sustainable value creation as the use of sustainability directly to create value for companies and all stakeholders.

Sustainable value creation encompasses economic, social, and environmental value. Economic value means savings, profits, and a return on investment. Forms of social value refer to the provision of benefits for different members of society through job creation, community development, provision a safe environment, and healthcare. Creating environmental value means protecting the environment by reducing water, air, and soil pollution (Vladimirova, 2019). Value creation based on economic postulates offers the possibility of easier management and assessment in relation to sustainable value creation, since it is based on quantitative indicators. By including the environmental dimension, the monitoring of qualitative indicators is carried out, which leads to an increase in the degree of complexity in management. As a solution, it is suggested to use the Balanced Scorecard (BSC) tool (Hristov et al., 2019).

Implementing sustainability principles in business should contribute to building a sustainable world and better environmental management, as well as profits for shareholders. Sustainable business activities do not only concern the environment but also address issues such as poverty, inequality, climate change, peace, and justice. Companies that have adopted the concept of sustainable value creation should focus their business on the inclusion of as many sustainability-related categories as possible. Today's understanding of sustainable value creation also involves addressing issues such as globalization, economic fluctuations, knowledge innovation, and more (Cardoni et al., 2020).

Building sustainable value implies a higher degree of ethics, as well as the involvement of all stakeholders. Sustainable value creation must apply to every aspect of a company's operations that contributes to sustainability at the level of the company. Therefore, it is necessary to implement it in areas such as finance, human resource management, and supply chain management. In supply chain management, the management of product, information and physical flows can contribute to economic, social, and environmental goals if sustainable value is sought (Boruchowitch & Fritz, 2022).

As a condition for the implementation and creation of sustainable value, it is necessary for leaders, managers, but also all employees, to be informed about the goals and the concept itself, which brings with it opportunities, but also challenges that may arise along the way. Sustainability can serve as a motivator, but this requires training and communication from the company's leadership. Initially, it is necessary to overcome resistance that may arise as a reaction to change. However, it is crucial to communicate the necessity of incorporating, primarily, the environmental dimension into the value creation process, given the current global situation and the urgency regarding environmental protection (Larson et al., 2024).

Sebhatu & Enquist (2007) investigated the business of the Swedish company Flugger AB, following media and social pressure related to the company's socially irresponsible practices and negligence for environmental issues. In response, the company introduced the ISO 14001 standard, which contributed to increasing eco-efficiency and restoring its reputation. Such environmental activity has also had a positive impact on the value for shareholders and other stakeholders. However, no further analysis has been conducted as to whether the application of ISO 14001 alone contributed to these results or whether this is the result of all the efforts undertaken by the company.

Hurtado-Jaramillo et al. (2018) conducted an analysis of companies in the water sector for the period 2005-2015. With the analysis, they wanted to obtain all relevant data related to the connection between sustainability and business performance, aspects of sustainability that contribute to value growth such as financial performance and other performances, as well as the degree of application of sustainability in companies. They concluded that sustainability, in most cases, was seen as a factor contributing to increased value and more stable business operations.

Fernández-Guadaño and Sarria-Pedroza (2018) conducted a survey based on data from the Madrid Stock Exchange for the period 2012-2016. The analysis included companies of all sizes, while excluding those that did not report the examined variables in all years of observation, as well as banks and insurance companies due to the specifics of their operations. The final sample comprised 40 companies. The results indicate a positive and significant impact of corporate social responsibility on the state, a negative impact on employees, and no effect on other stakeholders. Additionally, the hypothesis that corporate social responsibility has a positive impact on shareholder value creation was refuted.

Broccardo & Zicari (2020) conducted a study that included small and medium-sized enterprises (SMEs) in Italy that are engaged in wine production. A questionnaire was sent to 794 companies, with 106 companies completing the full questionnaire, forming the final sample. The study covered companies from all parts of Italy: 28% from the Northwest, 15% from the Northeast, 18% from Central Italy, 22% from the South, and 17% from the islands. The observation period spanned three years (2014-2016). The research categorized the companies into two groups: family-owned and non-family-owned. It was found that family-owned businesses more frequently implement sustainability measures, which positively affect financial performance. Research has also determined that sustainable business can create value for owners and other stakeholders, especially if sustainability is based on innovation.

The research, which covered 20 companies from the Nordic and Baltic markets for the period 2015-2020, revealed the positive impact of sustainability on value creation, particularly over the long term (Umaraite & Lapinskaite, 2022). The study analysed the impact of sustainability on various financial performances. It found a significant positive impact on EBITDA (Earnings Before Interest, Taxes, Depreciation, and Amortization), while no significant statistical relationship was observed with ROA (Return on Assets), ROE (Return on Equity), or ROCE (Return on Capital Employed).

Conclusion

Interest in sustainable business and environmental protection has been increasing since the end of the 20th century. The heightened exploitation of natural resources, pollution of soil, air, and water, insufficient use of renewable energy sources, increased waste production, and emissions of harmful gases have forced companies to pay more attention to sustainable business practices. Although sustainable business and the implementation of environmental protection measures were seen as a cost, companies realized that they could also benefit from the implementation of this business concept. It contributes to a better reputation and image in society, meeting the expectations of stakeholders in terms of respecting the moral principles of business, enabling expansion into foreign markets, obtaining subsidies, and facilitating cooperation with non-governmental organizations.

Large companies and specific industries, such as mining and oil extraction, contribute significantly to overall pollution. This is supported by the Reports on the companies that are the largest polluters, and which are in the field of oil industry. These companies need to pay close attention to their operations and work more intensively to reduce the negative environmental impacts of their natural resource extraction activities. In addition to the economic dimension, sustainable value creation also includes the environmental and social dimensions. This requires a systematic approach, the involvement of as many stakeholders as possible, and the application of ethical principles. This can also have a positive effect on employee motivation, in addition to the benefits that can be achieved for the company and entire society.

Studies examining the impact of sustainability on value creation for owners and other stakeholders generally find a positive effect of sustainability on value creation, with fewer studies reporting a negative impact. The introduction of ISO 14001 also positively influences a company's financial performance and the value. The transition to sustainable business requires a planned and continuous approach, by incorporating environmental goals into the company's already existing set of goals. Furthermore, it is necessary to train employees for the implementation of activities envisaged by the sustainable development policy (Larson et al., 2024).

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ECO-INNOVATIONS AS A SEGMENT OF GREEN INTELLECTUAL CAPITAL WITH THE AIM OF STRENGTHENING THE BUSINESS SUSTAINABILITY

Abstract

Sustainable business operations require a long-term perspective that integrates social, economic and environmental goals. Today, enterprises are expected to develop and use environmentally better, eco-efficient ways of producing products and providing services, contributing to the growth of national wealth and employment while respecting changing demands in terms of socially responsible behavior. In order to protect the environment, concepts such as green image, eco-innovation, green innovation, responsible innovation, sustainable innovation, eco-marketing, eco-production and eco-management are becoming more and more popular. Bearing in mind the above, the aim of this paper is to indicate the position of eco-innovation in green intellectual capital concept and identify the importance of eco-innovation for the sustainable goals achieving of a modern enterprise.

Keywords: *eco-innovations, intellectual capital, sustainability, business operations, enterprise*

JEL classification: *Q56*

ЕКО-ИНОВАЦИЈЕ КАО СЕГМЕНТ ЗЕЛЕНОГ ИНТЕЛЕКТУАЛНОГ КАПИТАЛА У ЦИЉУ ЈАЧАЊА ОДРЖИВОСТИ ПОСЛОВАЊА

Апстракт

Одрживо пословање захтева дугорочну перспективу која интегрише друштвене, економске и еколошке циљеве. Данас се од предузећа очекује да развијају и користе еколошки боље, еколошки ефикасне начине производње производа и пружања услуга, доприносећи расту националног богатства и

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запослености, поштујући промењливе захтеве у погледу друштвено одговорног понашања. У циљу заштите животне средине, концепти као што су зелени имиџ, еко-иновација, зелена иновација, одговорна иновација, одржива иновација, еко-маркетинг, еко-производња и еко-менаџмент постају све популарнији. Имајући у виду наведено, циљ овог рада је да укаже на позицију еко-иновације у концепту зеленог интелектуалног капитала и идентификује значај еко-иновације за постизање одрживих циљева савременог предузећа.

Кључне речи: *еко-иновације, зелени интелектуални капитал, одрживост, пословање предузећа, предузеће*

Introduction

In modern business conditions, in which society and the planet face challenges such as climate change, environmental degradation, limited resources and social inequalities, eco-innovations are the key to achieving compromises in relation to realizing economic goals and preserving resources for future generations. These innovations, which are also characterized as green, sustainable and responsible, simultaneously contribute to economic growth and the preservation of the environment, without jeopardizing social well-being.

Excessive exploitation of the planet's natural wealth, especially in developed countries, and the pursuit of industrial progress and economic prosperity, have led to excessive pollution of water and soil, reduction of fertile land, endangerment of biodiversity, etc. In the ever-increasing need of society to provide a sufficient amount of resources, there has also been a disparity in the relationship between needs and nature's ability to satisfy those needs. Sustainable, eco-innovation places great importance on reducing the ecological footprint. This means reducing harmful gases, using resources more efficiently, supporting renewable energy sources and promoting cyclical, regenerative thinking about materials and resources.

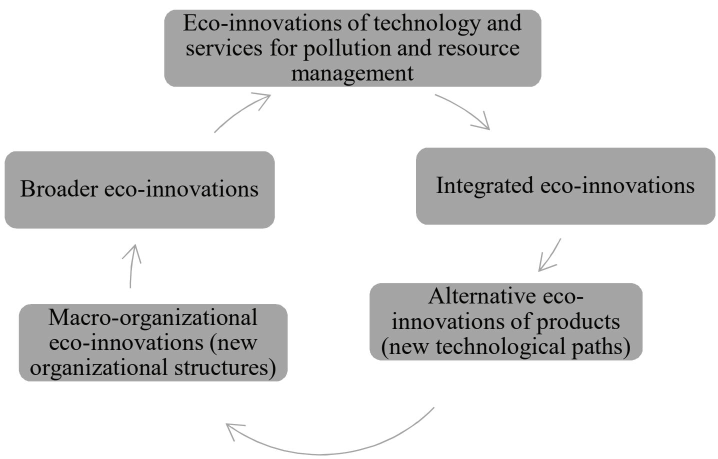
Eco-innovations are closely related to the concept of green intellectual capital of an enterprise. Namely, green human capital implies the knowledge, abilities and attitudes of employees in relation to environmental safety and proper management of environmental issues. Green structural capital refers to organizational culture, corporate image and managerial capabilities for environmental management and development. Green relational capital is key to managing environmental issues in an organization and requires collaboration with external stakeholders regarding the creation and implementation of environmental strategies. Eco-innovations can be seen as a part of the green structural capital of an enterprise.

1. Environmental, sustainable and responsible innovation - a conceptual framework

Eco-innovation or environmental innovation consists of new or modified processes, techniques, systems and products to avoid or reduce environmental degradation (Horbach, 2005). In addition, it can be characterized as green innovation. Andersen (2008) identified five different types of eco-innovation (Figure 1):

1. *Eco-innovations of technology and services for pollution and resource management*. - Products and services that aim to improve environmental performance (not necessarily have to be green, but deals with environmental solutions such as technologies or services that clean, dilute, recycle, control, measure and transport emissions as well as with resources such as natural resource and energy supply and extraction);
2. *Integrated eco-innovations*. - Clean technological processes and clean products that make the product or production process more environmentally efficient than conventional or similar products or processes, enabling energy and resource efficiency, replacing toxic materials and improving recycling (green product is a result of these innovations);
3. *Alternative ecological innovations of products (new technological paths)*. – It creates a radical technological discontinuity (based on new theories, capabilities and practices and can initiate a radical shift from the existing pattern of production and consumption to a radically new pattern of production and consumption such as renewable energy technology that contrasts with fossil fuel technologies and organic agriculture);
4. *Macro-organizational eco-innovations (new organizational structures)*. – It offers radical, new solutions regarding the efficiency of the organization and society and a new way of managing production and consumption at a systemic level, reflecting the functional interaction between enterprise and organizations, as well as between workplaces and families (industrial symbiosis and urban ecology as a new approach to managing cities and technical infrastructure);
5. *Broader eco-innovations*. - A number of other technological innovations that significantly affect the economy and the innovation process (the use of technology, such as nanotechnology, biotechnology, etc. that have a positive impact on further eco-innovation research).

Figure 1. Tipology of eco-innovations



Source: According to Andersen (2008)

Sustainable innovations represent the creation of something improved, which would improve performance in three dimensions of sustainable development: social, environmental and economic. Improvements can refer to changes in processes, operational practices and business models. Sustainable innovation can contribute to the competitive advantage of organizations, because enterprises are in a better position to take into account the opinions of stakeholders (Szekely & Strebel, 2013). Although the term sustainable innovation and eco-innovation are often used as synonyms, eco-innovation only deals with ecological and economic dimensions, while sustainable innovation also includes ethical and social aspects. In addition, sustainable innovation is a broader concept than eco-innovation, since it includes a social dimension and requires three main drivers: at the macro level - government policies and actions, at the enterpise level - the development of new business models, and at the individual level - changes in attitudes and behavior of people (Hansen, Grosse-Dunker & Reichwald, 2009).

A sustainable innovation is the implementation of a new product, process or practice by an enterprise or a modification of an existing product, process or practice that significantly reduces the impact of the enterprise's activities on the environment. It can be distinguished three types of sustainable innovation (Serrano-García et al., 2023):

- innovations that reduce the use of resources or innovations for the efficiency of resource use,
- innovations that eliminate the use of resources and
- innovations that replace the use of resources.

Sustainable innovations include not only the environmental dimension but also economic, social and institutional aspects. They improve the realization of sustainable development goals and represent a segment of all innovation systems. Due to the complexity of the ecological, economic and social system, the simultaneous focus on all those aspects implies the complexity of sustainable innovations and the innovation process, as well as the complexity of their creation and implementation in practice.

The process of creating responsible innovations implies a transparent, interactive process through which social actors and innovators become mutually responsible to each other with the aim of ethical acceptability, sustainability and social desirability of the innovation process and its marketable products in order to enable the proper integration of scientific and technological progress results into society (Smolka & Böschen, 2023). There are four crucial dimensions for the flow of responsible innovation, including: *anticipation, reflection, inclusion and responsiveness.*

Anticipation involves systematic thinking about all the possible implications of the innovation to be developed. It plays a key role in the initiation of innovation and requires that the subjects involved in the innovation process understand the dynamics that help shape the innovation. Also, the complexity and uncertainty that accompany innovation is acknowledged and taken into account. The challenge is to make certain assessments more specific, while being open to other perspectives. This should be done at a time when it can be constructive, but not too late to accommodate the innovation. This requires the early involvement of stakeholders and the general public who engage in a dedicated effort to anticipate potential problems and evaluate possible alternatives.

Reflexivity refers to a critical consideration of one's activities, obligations and assumptions, as well as awareness of the limits of knowledge and the fact that the reality experienced by an individual may not be universally accepted. Innovators must think about their value systems and theories and how they influence the development of innovation. Observing the underlying values, assumptions and beliefs is a common theme in various conceptualizations of responsible innovation, which can be enhanced by early involvement of stakeholders and the public.

Inclusion is the actual involvement of stakeholders and the general public through dialogue or other means to improve the innovation management process. Different aspects of inclusion are based on the intensity, openness and quality of discussion. Actors must initiate discussions about the social, political and ethical consequences of the innovation.

Responsible innovations require active engagement of various stakeholders in order to improve decision-making and mutual learning process. Responsiveness represents the ability to change shape or direction in response to stakeholder values, the values of the general public and changing circumstances. It refers to responding to new knowledge, perspectives, attitudes and norms that emerge during innovation and requires a collective institutionalized response and co-responsibility for the innovation development process (Burget, Bardone & Pedaste, 2017).

2. The relations between eco-innovation and green intellectual capital elements of an enterprise

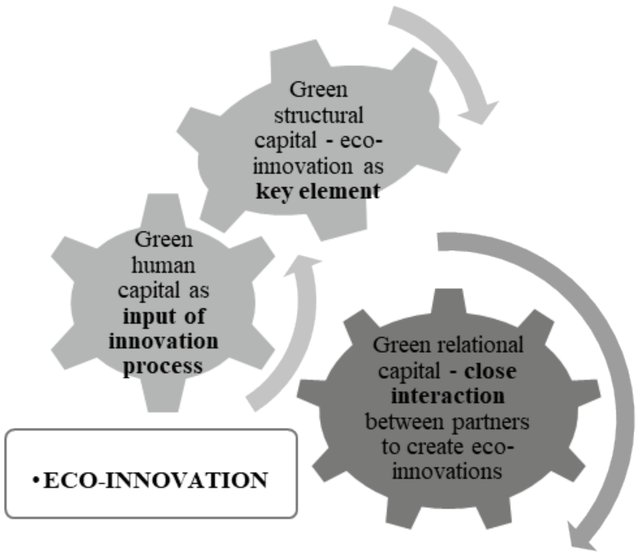
The recent concept of green intellectual capital refers to the intellectual, non-material resources of an enterprise that are aimed at solving environmental protection problems. Training programs that can help develop green capabilities and increase skills of employees involved in operational positions can be considered as a source of creating green human capital of an enterprise. Therefore, green human capital enables an organization to recognize its intangible resources (knowledge, skills and abilities) and can help implement green strategies in a dynamic competitive environment in order to have better business performance. Translating the enterprise's goals to all levels and their realization depends on the commitment of top management. The role of top management's commitment in the adoption of green initiatives is very significant (Chang & Chen, 2012).

Chen (2008) defined green structural capital as organizational assets that demonstrate environmental concern or green innovation within the enterprise and these assets are called strategies related to organizational commitments, organizational capabilities, reward systems, organizational culture, databases, knowledge management systems, information technology, company image, copyrights and trademarks. Environmental concerns are not changed by human capital alone because the support of organizational culture and organizational systems is needed for strategic decisions. Structural capital helps the enterprise organize its processes and systems, which further enables the necessary technological knowledge and turns into organizational capabilities. In addition, organizational capabilities become a precursor to achieving a higher level of sustainable performance. Some authors (Chen, 2008; Chang & Chen, 2012) have highlighted the significant connection between organizational culture and green human resource management due to organizational environmental culture, which is based on a various of assumptions and symbols. Also, information technology has a significant role in the development of green structural capital.

Chen (2008) determined green relational capital as an intangible asset based on the relationship between the organization and suppliers, customers, green innovation, network members and partners in corporate environmental management with the aim of gaining a competitive advantage.

Human capital is a key input for innovation process while the knowledge, abilities and capacities possessed by employees are important for sustaining an enterprise in the context of currently rapidly developing technology. Differentiation through the need to invest in green human capital can drive significant eco-innovation. If an enterprise has a higher level of green human capital, it will be more successful in eco-innovation creation. Namely, green intellectual capital (Chiou et al., 2012) can be seen as a platform to connect employees' environmental knowledge with eco-innovation, so that enterprises can use their green human resources for green process and product innovation (Figure 2).

Figure 2. Relations among eco-innovation and elements of green intellectual capital



Source: According to Chiou et al. (2012)

In the knowledge economy, innovation is a social process, not the domain of individuals. This indicates that for the creation of eco-innovations, cooperation within the enterprise, between employees, but also cooperation between the enterprise and external stakeholders (relational capital) is important. This is especially referring to cooperation relations with suppliers, consumers, strategic partners, the community, and all in the context of joint solutions to environmental problems. In this sense, the terms green supply chains, green products, green consumers, green procurement, green image appear.

This can foster collective innovative knowledge and improve the achievement of green, eco-innovation. Therefore, enterprises with green relational capital can develop new environmental technologies, ideas and opportunities within a collaborative network. An enterprise with poor systems and an environmental culture could not achieve eco-innovation. Thus, with the integration of environmental knowledge at the organizational level, the enterprise recognizes a strong supportive environmental culture that motivates it to acquire new environmental knowledge and implement green innovation. When valuable knowledge about environmental protection is codified, it can be systematically transferred and disseminated within the enterprise, so that it can be used for eco-innovation (Subramaniam & Youndt, 2005).

The social community, through legal regulation, also has an important influence on the strengthening of eco-innovations. Enterprises that are not focused on implementing innovative activities face more potentially strict environmental regulations than enterprises that attach great importance to innovation (Kesidou & Demirel, 2012). Based on interaction, motivation, but also the creation of voluntary codes of conduct, states can influence the greater willingness of enterprises to accept and apply eco-politics. Some researchers (Doran & Ryan, 2012) claim that creating eco-innovations and achieving a higher profit margin at the same time is not easy, which points to the fact that policy makers can contribute to the growth of a "greener society". National regulation greatly influences the decision of enterprises to innovate. Environmental innovation can be encouraged by adopting regulations from other countries. Based on the regulations adopted in the USA, innovative devices to reduce air pollution have been introduced in Japan. One research (del Río González, 2005) found that corporate image and compliance with the regulatory framework were the main determinants of an enterprise's adoption of "green" technology. In addition, the impact of regulations may vary in different areas of environmental technology (Frondel, Horbach & Rennings, 2007). The application of technologies "at the end of the production process" is regulated by certain environmental regulations and standards. Also, cost savings as well as the implementation of environmental management systems are imperative for the advancement of "green" technology.

Organizational capital represents the institutionalized knowledge and codified experience embedded in structures, management systems, knowledge management systems and operations that influence enterprise's innovative capability. On the other hand, organizational structure, culture, policies and guidelines foster innovation-related competencies that lead to improved innovation activities. Similarly, enterprises build organizational capital to develop their organizational learning capability, which improves their innovation performance. Enterprises also implement knowledge transformation and exploitation to improve their green innovation performance. In addition, investing in environmental projects and sharing results and best practices among all business units, functions and employees can also improve enterprises overall eco-innovation performance. Therefore, green organizational capital can increase the level of eco-process innovation performance of enterprises (Sahoo, Kumar & Upadhyay, 2023).

One of the possible classifications of eco-innovations places them in four groups (Jovanović Vujatović, Ognjanović & Popović, 2022):

- Organizational innovations,
- Product and service innovations,
- Green system innovations,
- Ecological technologies.

The given classification of eco-innovations indicates the relationship of these elements with the elements of green intellectual capital. In order to successfully implement eco-innovations in an enterprise, it is necessary to have sufficient knowledge and skills of employees about environmental problems, as well as the need to solve them. Enterprises with higher quality of green human capital also have a greater chance for the success of green innovations. Also, they are the dominant drivers of eco-innovations in the enterprise. When making strategies and decisions, managers must also take into account some basic issues in order to make the right decisions based on them. It includes the issues related to the problem of global warming, reduction of biodiversity, consumption of resources, water and air pollution.

3. The role of eco-innovation in achieving sustainable business performance of an enterprise

Enterprises establish relationships with various stakeholders. A healthy environment is one of the "stakeholders" because successful work and the survival of society depend on a healthy environment. The environment as a "stakeholder" will be preserved if (Krstić, 2022):

- Shareholders do not put their profit goal and the goal of increasing their wealth before social goals,
- Potential investors and financial analysts highly value every effort made in terms of investing resources in the implementation of environmental programs,
- Employees and enterprise management rise environmental awareness through the support of various environmental programs,
- Consumers, by choosing an ecological product of the enterprise, give an impetus to its development and growth,
- Suppliers base their activities on the principles of ecological supply,
- State authorities, through various legal forms.

In all these segments, the goals of eco-innovation and the goals of achieving sustainable enterprise performance coincide.

Various studies show that the application of eco-innovations has a positive effect on business operations and the reputation of enterprises. Through eco-innovations, enterprises also influence the reduction of the negative effects of business on the environment in order to achieve the following sustainable performances (Jovanović Vujatović, Ognjanović & Popović, 2022):

a) presenting as market leaders, responsible and innovative,
b) avoiding surprises in the future - to anticipate changes in regulation and the market environment, instead of reacting to changes when they happen,
c) creating a positive image of the enterprises on the market,
d) securing investments thanks to the appropriate regulation.

Eco-innovations represent an answer to environmental problems, but at the same time it can also be a natural reaction to high resource prices. As such, it is closely related to the way of using limited natural resources, with their efficiency and sustainable performance (Andabaka, Basarac Sertić & Harc, 2019). In order to reduce the risk of environmental disasters, increase the reputation and create the trust of the social community, many enterprises apply green technologies and explore innovative ways to reduce the negative impact on the environment. This also applies to the application of eco-innovations in the enterprise's sustainable operations.

Eco-innovation includes technological improvements that can lead to energy savings, pollution minimization, waste recycling, green product development and management of environmental protection (Cheng, Yang & Sheu, 2014). Enterprises that pioneer green innovation will improve their corporate image and gain a sustainable competitive advantage. Leading enterprises have built their approaches to sustainable development on sustainable, green, eco-innovations including the following: 1) the enterprise understands what society expects of it, in turn clearly expressing what the enterprise itself stands for; 2) developing tools and approaches to improve performance in the social, environmental and economic pillars of sustainable development and incorporating these tools into routine business processes; 3) setting focused goals and establishing means of measuring performance, as well as confirming that goals are achieved.

The final results of eco-innovations can appear in many forms, including the achievement of various sustainable goals of business operations. They can be technological (as in the case of eco-innovations), service-related (also known as servitization), as well as innovations that shape systems and consist of related sets of innovations. The implications of innovations that shape systems are to change cities, sectors, economies or other systems towards more sustainable development, which is necessary considering the challenges of the modern age: climate change, excessive emissions and the greenhouse effect (Draper, 2013).

Conclusion

Enterprises should spread the concept of sustainability throughout the enterprise and consider themselves part of society, not separate from it. This requires that the values and aspirations of the top management and owners are aligned with the concept of sustainability. This conception implies that sustainability is not an attribute of an individual enterprise, but can only be applied at the system level, which requires cooperation with actors from the private sector, the public sector and includes civil society partners (green relational capital) and investment in system solutions. This new approach to innovation should be communicated throughout the enterprise and integrated into the employee reward system, in order to improve green human and structural capital.

Collaboration with different stakeholders helps to engage in dialogue, gain social legitimacy, find opportunities to acquire new knowledge and also helps to find creative and responsive solutions such as eco-innovations. Stakeholders need to learn how they can find, form and operate within new innovation systems, which are characterize as eco, green and sustainable. This can be achieved by experimenting and learning with new approaches to sustainability, while maintaining the existing business model. This allows enterprises to adapt knowledge management processes risk-free to their business model, while developing an effective management approach that integrates foresight and new stakeholder collaborations. It is also important to note that not only the environmental and economic implications are taken into account, but also the social, political and ethical implications of the innovation.

The challenge for enterprises is to find new ways to align innovation with public expectations and thereby provide a governance framework that is based on discussion, decision making and then delivering sustainable value. Leading enterprises have realized that this depends on understanding the evolving nature of society and redefining the relationships they want to build with customers, employees and suppliers, with governments and the public at large. This approach implies recognizing the connection between rights, roles and responsibilities in society.

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FOREIGN DIRECT INVESTMENT DYNAMICS IN THE WESTERN BALKANS: ASSESSING THE EFFECTS OF COVID-19 PANDEMIC AND THE RUSSO-UKRAINIAN WAR

Abstract

The paper aims to offer a comprehensive analysis of foreign direct investments (FDI) within the economies of the Western Balkan countries against the backdrop of the COVID-19 pandemic and the ongoing Russo-Ukrainian war. Central to this inquiry is the examination of FDI inflows into the Western Balkans amidst these extraordinary circumstances. Specifically, the study investigates the scope, positioning, and proportion of FDI inflows across individual economies within the Western Balkans in relation to the overall FDI inflows within the region, as well as changes in their dynamics caused by the crisis events. Bearing in mind the level of development and dependence on foreign capital, the economies of the Western Balkan region are intrinsically reliant on the stability and size of FDI for various economic imperatives. Consequently, these countries show increased sensitivity to fluctuations in FDI patterns, necessitating a continuous surveillance of FDI inflow trends. Remaining in an unfavorable and changing macroeconomic environment, the economies of the Western Balkans face permanent challenges that inevitably affect their FDI inflows, thus emphasizing the imperative for continuous vigilance and analysis of them.

Key words: *FDI, Western Balkan, COVID-19, Russo-Ukrainian war*

JEL classification: *F21, P29*

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ДИНАМИКА СТРАНИХ ДИРЕКТНИХ ИНВЕСТИЦИЈА НА ЗАПАДНОМ БАЛКАНУ: ПРОЦЕНА ЕФЕКАТА ПАНДЕМИЈЕ КОВИД-19 И РУСКО-УКРАЈИНСКОГ РАТА

Апстракт

Рад има за циљ да понуди свеобухватну анализу страних директних инвестиција у привредама земаља Западног Балкана у контексту пандемије COVID-19 и текућег руско-украјинског рата. Централно место у раду заузима испитивање прилива страних директних инвестиција на Западни Балкан услед ових ванредних околности. Конкретно, студија истражује обим, позиционирање и пропорцију прилива страних директних инвестиција по појединачним привредама у оквиру Западног Балкана у односу на укупан прилив страних директних инвестиција у региону, као и промене у њиховој динамици изазване кризним догађајима. Имајући у виду степен развијености и зависност од страног капитала, привреде региона Западног Балкана суштински се ослањају на стабилност и величину страних директних инвестиција за реализацију различитих економских циљева. Сходно томе, ове земље показују повећану осетљивост на флуктуације у обрасцима страних директних инвестиција, што захтева континуирано праћење трендова прилива страних директних инвестиција. Задржавајући се у неповољном и променљивом макроекономском окружењу, привреде Западног Балкана суочавају се са сталним изазовима који неминовно утичу на њихове приливе страних директних инвестиција, наглашавајући императив континуираног праћења и анализе истих.

Кључне речи: *стране директне инвестиције, Западни Балкан, КОВИД-19, руско-украјински рат.*

Introduction

A few crises and challenges have occurred on the global scene in recent times, including health and economic COVID-19 crisis and the ongoing Russo-Ukrainian war with all their implications, affecting national economies worldwide (Stojadinović-Jovanović et al., 2020). The good macroeconomic prospects of the Western Balkans for 2020 were disrupted by the COVID-19 (OECD, 2020). The containment measures and external shock resulted in a significant decline throughout the region. “And just as the year 2022 was marked as the culmination of the pandemic recovery” (UNCTAD, 2023a, p. 35), the global scene changed dramatically in 2022 with the onset of the war in Ukraine. The war brought food insecurity, unavailability and high energy prices, as well as difficult international financing due to high inflation and rising interest rates (UNCTAD, 2022). The aftermath of these events precipitated a comprehensive deceleration of economic activity across Western Balkan countries, mirroring the repercussions of Russia’s military intervention. This downturn manifested through various channels, including diminished levels of business and consumer confidence, a notable upsurge in inflationary pressures, pronounced monetary policy tightening measures, and disruptions in energy supply chains. The countries of the Western Balkans have slowed down their economic growth due to high energy prices, disruptions in supply chains and certain restrictive monetary policy measures (WB, 2023).

The paper delves into an analysis of the repercussions of the COVID-19 pandemic and the Russo-Ukrainian war on the FDI dynamics within the Western Balkan economies (WBs). These economies, collectively referred to as the WB5, encompass Albania, Bosnia and Herzegovina, Montenegro, North Macedonia, and Serbia. The examination situates the FDI trends of the Western Balkans within the broader context of European countries, elucidating the specific impacts of these multifaceted geopolitical and global health challenges on the investment landscape of the region.

1. Literature review

Numerous theoretical models that explain FDI can be classified into: early studies on FDI, the study of FDI and its determinants according to the neoclassical trade theory, ownership advantages as FDI determinants, aggregate variables as FDI determinants, FDI determinants within the OLI model, determinants of horizontal and vertical FDI, FDI determinants according to the knowledge model, FDI determinants according to risk diversification models and variables of the FDI policy of the host country as a FDI determinant (Faeth, 2009). These approaches explain different aspects of FDI by complementing each other. Empirical findings on the FDI determinants are numerous (Blonigen, 2005).

The impacts of FDI on both host and home countries are numerous (Navaretti & Venables, 2004, pp. 151-185, 217-240) and can be as well as positive as negative (Stojadinović Jovanović, 2008, pp. 130-166; Ercegovac & Beker, 2021). The various impacts of FDI indicate the importance and need to monitor their flows and changes in them (Stojadinović Jovanović, 2015, p. 81). The importance of FDI, especially for host countries, is explained by numerous papers that indicate the effects that the inflow of these investments can bring to the country. It is widely believed that FDI increases the growth of host countries through various channels such as: capital inflows and employment growth, stimulating technological change through the adoption of foreign technology and spillover effects, introducing new processes and products, facilitating technology transfer and improving the stock of knowledge in the recipient country through training and education, contributions to the adoption of innovative management techniques and the improvement of the manufacturing process's efficiency. Therefore, FDI can be very helpful in enhancing the national economy and fostering economic growth (Wan, 2010). For the host countries, the positive effects that FDI inflows can bring are particularly significant, such as the positive effects of the transfer of various resources, including capital, technology and management, positive effects on the balance of payments, competition, industrial structure and entrepreneurship, economic growth, employment, trade and connections with the domestic economy and others (Stojadinović Jovanović, 2008, pp. 142-153).

In the predominant role of host countries appears small and less developed economies. Small-scale economies are exposed to numerous risks, encompassing a reliance on imported essential commodities, susceptibility to external shocks, restricted operational scale, limited infrastructural connectivity, highly concentrated economic frameworks, dependency on external sources of financing, and heightened vulnerability to the impacts of natural calamities and climate variability (WB Group, 2023b, pp. 7-8). These risks contribute to the uneven FDI pattern in these economies and lead to heterogeneous FDI flows. And reliance on external financing through FDI makes these economies sensitive to changes in the value of FDI inflows.

Pandemics, crisis and wars are sources of uncertainty that significantly affect FDI flows and consequently the economies for which FDI inflows are important. There are studies that showed that pandemic and global uncertainty had significant negative effects on FDI flows in various parts of the world. For example, Adarov and Gabor (2020) have reported that FDI in Central, Eastern and Southeastern Europe fell by over 50% in 2020 due to COVID-19; Zhan (2020) has showed the international pandemic's effect on FDI flows; Ho and Gan (2021) have showed that health pandemics matter for FDI; Lee et al. (2022) have shown pandemic i.e. public health as a new country risk measure in context of FDI; Okunoye and Akpa (2023) have showed that COVID-19 have been associated with decreased FDI inflows in Eastern Europe; and Okunoye et al. (2023) have shown that global economic uncertainty affect FDI. There are also studies that showed the war impact on FDI. For example, Li et al. (2017) have shown that the secondary and tertiary sectors of observed countries suffered negative consequences due to war; Witte et al. (2017) have shown varied effect of political risks on greenfield FDI; while Pindyuk (2023) has shown that Russo-Ukrainian war have caused a reversal of FDI trends. The Russo-Ukrainian war has delayed the countries' recovery given the withdrawal of FDI during the pandemic (Okunoye & Akpa, 2023). Therefore, the paper examines WBs' FDI in macroeconomic environment prominently marked with COVID-19 pandemic and the ongoing Russo-Ukrainian war. This group of countries (WB5) primarily appears in the role of FDI host countries. For them FDI inflows are a source of accelerating economic growth, employment creation, technological advancement and other possible positive FDI effects, representing their main source of external financing. Consequently, the economies of these countries are very sensitive to the changes in FDI inflows creating the need for FDI inflows to be continuously monitored and observed.

2. Research methodology

Various research methodologies are employed to fulfil the goals of this study. Specifically, the analysis of FDI flows needs the utilization of an analytical approach. The FDI inflows in WB economies, the differences in positions, volumes and shares of individual WB economies' FDI inflows in total WB region's FDI inflows are examined by applying the method of comparative analysis and the inductive and deductive method. To conduct the comparative analysis and identification, the integrative review method is used. Research methods also include the analysis of official statistical data, scientific and professional literature and databases and publications of international organizations. Data from various sources are used including UNCTAD data, World Bank Group data and OECD data as well as findings from relevant international publications. The selected data are displayed in tables and figures that enable the presentation of the findings.

3. WBs' FDI in macroeconomic environment of pandemic and ongoing war – research results and discussion

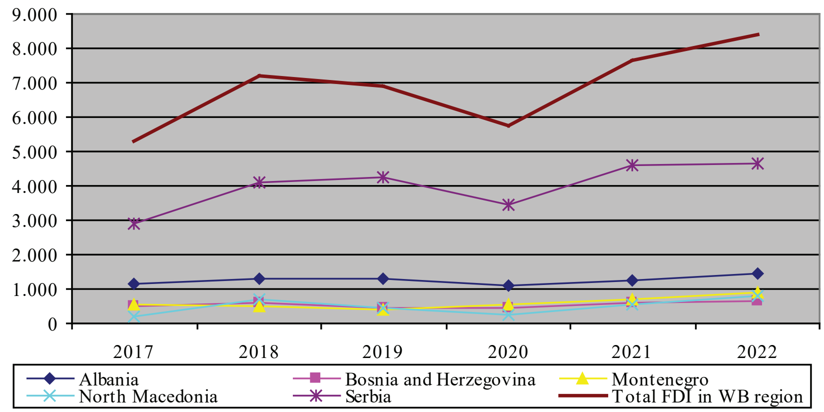
Over the last period 2017-2022, more than 41 billion USD of FDI inflows have arrived in the Western Balkan region. The average FDI inflows in the region amount to 6.9 billion annually (Table 1). The distribution of FDI inflows in the WB region varied among countries and ranged from 58%, which accounts on Serbia, to 7.2%, which accounts on North Macedonia. Its values are also different by country as well as the dynamics of decline, recovery and growth (Figure 1).

Table 1: FDI inflows in Western Balkan economies, 2017-2022

	FDI Inflows (millions of dollars) (share in total WBs' FDI, percentage)							
	2017	2018	2019	2020	2021	2022	Total 2017-2022	2017-2022 average
Albania	1 149	1 290	1 288	1 108	1 234	1 434	7 503	1250.5
	21.7%	18.0%	18.7%	19.2%	16.1%	17.1%	18.2%	18.2%
BiH	492	581	458	429	587	661	3 208	534.7
	9.3%	8.1%	6.7%	7.4%	7.6%	7.9%	7.8%	7.8%
Montenegro	559	490	416	532	699	877	3 573	595.5
	10.6%	6.8%	6.0%	9.2%	9.1%	10.4%	8.7%	8.7%
North Macedonia	205	725	446	230	556	794	2 956	492.7
	3.9%	10.1%	6.5%	4.0%	7.2%	9.4%	7.2%	7.2%
Serbia	2 878	4 091	4 270	3 469	4 590	4 646	23 944	3 990.7
	54.5%	57.0%	62.1%	60.2%	60.0%	55.2%	58.1%	58.1%
Total WBs	5 283	7 177	6 878	5 768	7 666	8 412	41 184	6 864
	100%	100%	100%	100%	100%	100%	100%	100%

Source: Authors' calculations based on FDI country data from UNCTAD (2023). World Investment Report 2023. UN. New York and Geneva, p. 196.

Figure 1: Western Balkans' FDI inflows, total and by economy, 2017-2022 (millions of dollars)



Source: Authors' graphical presentation of the data from Table 1.

Prior to the pandemic, FDI was the main source of economic growth, innovation, and employment rates in the Western Balkans (OECD, 2020). FDI inflows to these countries account for an average of 6% of their GDP (Table 2).

Table 2: Net foreign direct investment inflows of WBs (percent of GDP)

	2017	2018	2019	2020	2021	2022	2023e	2024f	2025f
Albania	8.6	8.0	7.6	6.7	6.5	6.7	6.8	6.8	6.8
Bosnia and Herzegovina	2.3	3.0	2.0	1.8	2.3	2.5	2.4	2.4	2.3
North Macedonia	1.8	5.6	3.2	1.4	3.3	5.2	5.2	4.7	4.2
Montenegro	11.3	6.9	7.0	11.2	11.7	13.2	8.0	8.1	7.9
Serbia	6.2	7.4	7.8	6.3	6.9	7.1	6.1	5.6	5.4
WBs (average)	6.0	6.2	5.5	5.5	6.1	6.9	5.7	5.5	5.3
WBs (average)	5.9			5.5	6.5		5.7	5.4	

Note: e – estimate, f – forecast

Source: Authors' calculations based on country data from WB Group (2021). Western Balkans Regular Economic Report, Spring 2021: Subdued Recovery. The World Bank, Washington, different pages; and WB *Group (2023b). Western Balkans Regular Economic Report, Fall 2023: Toward Sustainable Growth. The World Bank, Washington, different pages.*

The GDP of Western Balkan economies has been dramatically affected by COVID-19 crisis with real GDP growth decreasing for 8.8 percentage points: from an average of 3.4 per cent in period 2017-2019 to -5.4 per cent in 2020 (Table 3).

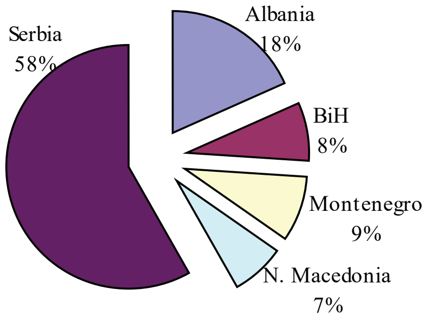
Table 3: Real GDP growth of WBs (per cent)

	2017	2018	2019	2020	2021	2022	2023e	2024f	2025f
Albania	3.8	4.1	2.2	-3.3	8.9	4.8	3.6	3.2	3.2
Bosnia and Herzegovina	3.2	3.7	2.8	-3.0	7.4	3.9	2.2	2.8	3.4
North Macedonia	1.1	2.9	3.2	-4.7	3.9	2.1	1.8	2.5	2.9
Montenegro	4.7	5.1	4.1	-15.3	13.0	6.4	4.8	3.2	3.1
Serbia	2.0	4.4	4.2	-0.9	7.5	2.3	2.0	3.0	3.8
WBs (average)	3.0	4.0	3.3	-5.4	8.1	3.9	2.9	2.9	3.3
WBs (average)	3.4			-5.4	6.0		2.9	3.1	

Source: Authors' calculations and graphical presentation of the data from Table 2 and Table 3.

The largest recipient of FDI in the WB region is Serbia, with a total value of FDI inflows of almost USD 24 billion in the period 2017-2022 and with an average annual value of FDI inflows of almost 4 billion USD, which make up 58% of the total FDI inflows to the region (Figure 3). Albania is next, with a total value of FDI inflows of USD 7.5 billion and an average annual value of FDI inflows of USD 1.2 billion, accounting for 18.2% of total FDI inflows to the region; then Montenegro with the total value of FDI inflows of USD 3.5 billion and the average annual value of FDI inflows of USD 596 million, which make up 8.7% of total region's FDI inflows to the region; Bosnia and Herzegovina with a total value of FDI inflows of USD 3.2 billion and an average annual value of FDI inflows of USD 535 million, which make up 7.8% of total region's FDI inflows; and North Macedonia with a total value of FDI inflows of approximately 3 billion USD and an average annual value of FDI inflows of 493 million USD, which constitute 7.2% of total region's FDI inflows (Table 1).

Figure 3: Share in total Western Balkans' FDI inflows, 2017-2022 (per cent)



Source: Authors' graphical presentation of the data from Table 1

Leading investors in the region have mostly originated from the EU members (Austria, Germany, Greece, Italy, the Netherlands, and Slovenia), the Russian Federation, the United States, and the United Kingdom. This highly concentrated source of foreign investment in the WB5 highlights the region's high dependency as well as vulnerability to the pandemic impact. The decline in FDI inflows in the countries of the Western Balkans was expected because the countries from which the investments come were significantly affected by the pandemic (OECD, 2020).

Anticipated repercussions of the lockdown measures included an expected deceleration in both public and private investments across the WB5, attributable to the adverse impact on enterprise revenues, disruptions in supply chains, and pessimistic economic forecasts prevalent in key investing nations. Nonetheless, the profound uncertainty and economic upheaval induced by the pandemic precipitated a substantial contraction in private investment. Conversely, public investment surged in half of the region, reflective of concerted efforts to stimulate economic activity and mitigate the severity of the economic downturn. Notably, Serbia witnessed a pronounced escalation in public investment, underpinned by a substantial government stimulus initiative that effectively offset the decline in private investment (WB Group, 2021).

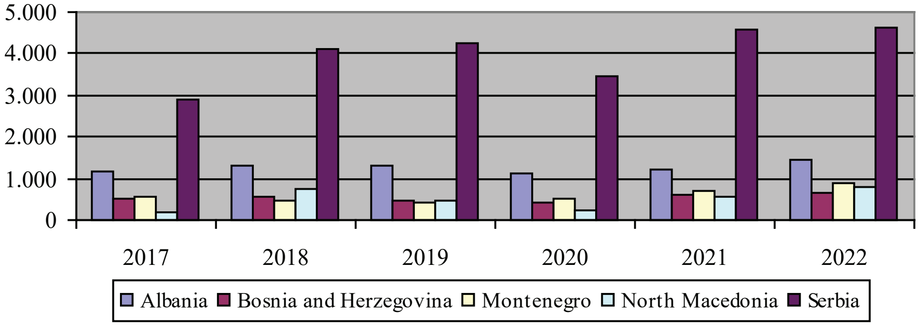
The macroeconomic environment and key economic activities of WB5 were characterized by very unfavorable developments. The disruptions to travel and trade, along with a drop in domestic demand, have reduced imports and exports of goods and services of WB5 (WB Group, 2021). Exports in Serbia fell more than imports, as well as in Montenegro, which is highly dependent on the tourism sector. The tourism sector has experienced severe consequences due to social distancing measures. Wholesale and retail trade declined after the pandemic and in most countries did not return to the previous level by the end of 2020, unlike industry and the construction sector, which already recorded development in the second half of 2020. The construction industry in Albania has held up well due to the investment following the earthquake in 2019 (WB Group, 2021)

The pandemic caused increased budget allocations for the purchase of medical equipment and medicines, as well as for the salaries of health personnel. In addition, the governments of the countries of the Western Balkans closed airports and borders and introduced measures to prohibit gatherings and the operation of restaurants and shops (OECD, 2020). Unprecedented governmental interventions were implemented throughout the region, aiming to mitigate the adverse effects of the pandemic. By April 2020, all Western Balkan nations had enacted measures to keep jobs, which included partial or complete compensation for wage costs (WB Group, 2021). Additionally, health protection initiatives, tax alleviation strategies, guarantee schemes, subsidized credit facilities, and social aid programs were introduced (WB Group, 2021). These measures remained in effect until the conclusion of 2020. Notably, certain countries opted to prolong these measures into 2021, underscoring the sustained commitment to addressing the enduring economic challenges posed by the pandemic.

The weakening of economic activity was a consequence of the measures to suppress the pandemic. The pandemic significantly disrupted the economic conditions of the Western Balkan economies in 2020, leading to a recession. The second quarter of 2020 was marked by a decline in economic activity, but in the third quarter there was a recovery, especially in tourism. Although in the fourth quarter of 2020 infections raised again, the impact of the second wave of the COVID-19 pandemic was mitigated by higher public spending and less rigorous social distancing measures (WB Group, 2021).

In the pre-crisis period of 2017-2019 WB economies' FDI inflows accounted, on average, for 6% of their GDP (Table 2). In the pandemic 2020 year, the share of FDI inflows in the GDP of the WB5 fell to 5.5%. The recovery of FDI inflows in WB5 in 2021 and 2022 led to an increase in their share in the GDP of all WB5 (except Albania) in 2021 and of all WB5 in 2022, reaching the share in their GDP of 6.5% (Table 2). In the pre-crisis period of 2017-2019 a total of USD 19.3 billion of FDI arrived in the WB region, which is an average annual FDI inflow of USD 6.4 billion (Table 1). In 2020, total FDI inflows to the region declined to USD 5.8 billion. Affected by the pandemic, FDI was significantly less in 2020 than in 2019 and 2018 in all WB5 except in Montenegro (Figure 4).

Figure 4: Western Balkans' FDI inflows, by year and economy, 2017-2022 (millions of dollars)



Source: Authors' graphical presentation of the data from UNCTAD. (2023). World Investment Report 2023. UN. New York and Geneva, p. 196.

The main source of external financing for the most WB5 economies, FDI, has been significantly and differently affected by COVID-19 pandemic and Russo-Ukrainian war. For Albania, BiH, North Macedonia and Serbia net FDI (as a share of GDP) was lower in 2020 than in 2019 (Table 2). Only Montenegro recorded an increase in the net inflow of FDI as a % of GDP due to the reduction of outgoing FDI and the repatriation of dividends (WB Group, 2021). FDI finances a large part of the current account deficit in the region (42% in Montenegro, 55% in BiH and North Macedonia and 100% in Serbia) (WB Group, 2021). FDI brings to the country innovative solutions, better paid jobs and innovative methods of production so that they influence faster recovery after crisis periods. The stated positive effects were to the greatest extent in Albania and North Macedonia (WB Group, 2021, pp. 29-30).

FDI fell by more than 58% in the first half of the crisis year 2020 when looking at Central, Eastern and Southeastern Europe. This is certainly a greater drop in FDI than the drop at the world level, which was 49%, but at the same time smaller than the decline in advanced economies (Adarov & Gabor, 2020).

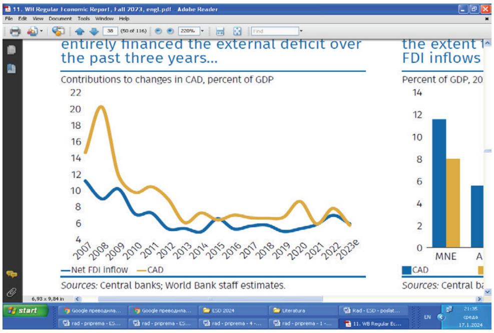
The crisis year of 2020 and following recovery changed the volume of FDI and the share of FDI inflows of individual economies in the total region's FDI inflows in 2022 compared to the level reached in the pre-crisis year of 2019. Thus, in the case of certain countries, the volume of FDI inflows in 2022 increased compared to 2019, but their share in the total, increased, FDI inflows of the region decreased. The increase in individual countries' FDI inflows was lower than the increase in the region's FDI inflows. This is the case with Albania (decline from 18.7% in 2019 to 17.1% in 2022) and Serbia (decline from 62.1% in 2019 to 55.2% in 2022). This decline is the result of both the increase in the volume of FDI inflows of other countries in the region (Bosnia and Herzegovina, Montenegro and North Macedonia) and the increase in the share of their FDI inflows in the total region's FDI inflows on behalf of the share of Albania and Serbia (Table 1).

With the recovery, FDI inflows to the region grew to 7.7 billion USD in 2021, and to 8.4 billion USD in 2022, that is an average of 8 billion USD per year, which is 1.6 billion USD more than in the period 2017-2019.

The year 2021 was marked by a strong post-COVID-19 recovery. And the year 2022 marked the culmination of the pandemic recovery. During 2021 and beyond, FDI inflows to WB5 have been recovering (Table 1). All WB economies increased the value of their FDI inflows in 2021 (Figure 1). Serbia had the biggest recovery in the absolute value of FDI inflows in 2021 (by 1.1 billion USD, reaching 4.6 billion USD of FDI inflows) and further in 2022 (exceeding 4.6 billion USD). North Macedonia had the largest increase in its relative share in WBs' FDI inflows in 2021 (by 3.2%, reaching 7.2% share in total WBs' FDI inflows) and further in 2022 (reaching 9.4% share in total WBs' FDI inflows). FDI in Bosnia and Herzegovina had the slowest recovery (with the smallest increase of 158 million USD in 2021 compared to 2020 and an increase in share in the region's FDI by 0.2%).

As of 2021, net FDI inflows were still essential for financing the current account deficits (CADs) in the Western Balkans (Figure 5).

Figure 5: Western Balkans' CADs financed by FDI inflows



Source: WB Group (2023). Western Balkans Regular Economic Report, Fall 2023: Toward Sustainable Growth. The World Bank, Washington, p. 38.

In 2022, the recovery of FDI inflows continued with a further increase in their volume in all WB5 economies (Table 1). FDI inflows in 2022 in all WB5 economies exceeded their pre-crisis volumes in 2017-2019.

However, after a partial recovery from the pandemic, the world faced a major conflict in Ukraine. This conflict has caused consequences around the world, including a crisis in food, fuel and energy supplies (UNCTAD, 2022). The war, with its implications and its rolling effects through sanctions, supply shortages in energy and basic commodities, have broad macroeconomic impact on national economies including WB5 economies.

The countries of the Western Balkans recorded rapid economic growth in 2021. However, global demand slowed down, so in 2022 and early 2023, the economic growth of the WB5 countries began to slow down as well (WB Group, 2023b). Industrial production was particularly affected. The WB5 economies had slower growth in 2022, primarily because of weaker consumption and exports. The economic growth of the countries of the Western Balkans has slowed considerably due to the conflict in Ukraine, inflation and increased borrowing costs (WB Group, 2023b). FDI will remain key in financing the external imbalance in the countries of the Western Balkans (Figure 5).

The industrial sector continues to face adverse impacts from both the COVID-19 pandemic and the energy shock. This predicament is worsened by the limited geographical diversification of trade, wherein a substantial portion of goods exports from Albania, Bosnia and Herzegovina, North Macedonia, and Serbia are directed toward advanced economies in Europe and Central Asia. This trade concentration, compounded by inherent structural challenges, further amplifies the vulnerability of the industrial sector to external shocks. Conversely, the services sector, particularly travel services, has exhibited resilience amidst the prevailing economic challenges. Global demand for services, including travel services, has demonstrated sustained momentum, thereby benefitting countries such as Albania and Montenegro. Notably, these nations have witnessed unprecedented growth in services exports, attaining new record highs, amidst a backdrop of evolving global dynamics (WB Group, 2023b).

However, there are still threats to the economic situation in the Western Balkans. Risks include a prolongation of the war in Ukraine, other geopolitical tensions, continued interest rate hikes, and further energy uncertainty (WB Group, 2023a, pp. 62-63). In the future, the countries of the Western Balkans will fear a slowdown in the growth of the Eurozone countries, because reduced exports would have negative consequences. Growth should accelerate in the period 2024-2025, due to the recovery of EU countries.

Conclusion

The economies of the Western Balkans have met profound challenges stemming from the dual impacts of the COVID-19 pandemic and the ongoing Russo-Ukrainian war. Within this adverse macroeconomic environment, FDI inflows into both individual economies within the Western Balkans and the region have experienced significant downturns. These shifts have not only altered the volumes of FDI inflows into Western Balkan economies but have also reshaped their relative positions and shares within the broader regional FDI landscape, as well as their contributions to the GDP of these nations and the region at large.

Given the role of these economies as host countries for FDI, the ramifications of fluctuations in FDI inflows are particularly pronounced. FDI plays a pivotal role in driving economic growth and development in the Western Balkans, offering numerous potential benefits to these countries. Consequently, changes in FDI inflows hold substantial implications for their economic trajectories and the realization of these benefits. While there have been signs of FDI recovery in the Western Balkan region since 2020, evidenced by positive trends observed in 2021 and 2022, projections suggest a more subdued outlook, with expectations tempered by prevailing uncertainties.

Despite signs of recovery, the Western Balkan countries persist within an unfavorable and volatile macroeconomic milieu, characterized by ongoing challenges that represent persistent obstacles to economic stability and growth. The cyclical nature of economic disruptions underscores the vulnerability of the Western Balkans to external shocks, highlighting the imperative for sustained vigilance and proactive measures to navigate these turbulent circumstances and bolster resilience against future uncertainties.

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