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E-Commerce and Sustainable Development in the European Union: A Comprehensive Analysis of SDG2, SDG12, and SDG13

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Abstract

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The rapid expansion of e-commerce has revolutionised global trade and connectivity, bringing forth both opportunities and challenges for sustainable growth in European Union (EU) countries. This study aims to investigate the impact of e-commerce on key sustainable development goals (SDGs) in the EU, specifically focusing on SDG2 (Zero Hunger), SDG12 (Responsible Consumption and Production), and SDG13 (Climate Action). To analyse the influence of e-commerce on the selected SDGs, this study adopts two distinct approaches: the panel-corrected standard error (static estimation) approach and the system generalised method of moments (dynamic estimation) approach. The investigation yields significant insights into the role of e-commerce in shaping the achievement of the aforementioned SDGs. The findings indicate that e-commerce has the potential to enhance food distribution networks, thus improving access to nutritious food in certain regions. However, concerns are raised regarding increased food waste and its impact on food availability for vulnerable populations. Additionally, the study highlights the environmental implications of e-commerce, particularly in terms of excessive packaging waste and carbon emissions from logistics. Based on empirical findings, policymakers, businesses, and stakeholders should develop targeted strategies to capitalise on the positive impacts of e-commerce while addressing the challenges thereof in the context of sustainable development. Recommended measures include optimising delivery routes, promoting sustainable packaging practices, and integrating green technology into e-commerce operations to effectively align e-commerce with the SDGs.

Key words

responsible consumption, responsible production, climate action, no hunger, digitalisation, online shopping.

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Introduction

The rapid growth of e-commerce has indeed brought significant advancements to the global market, offering unparalleled convenience and accessibility to consumers worldwide (Wang and Liu, 2022; Akimov et al., 2021; Titko et al., 2023). However, it has also raised concerns about its environmental and societal impacts, leading to debates over its true contribution to sustainable development (Stępień et al., 2023; Spicka, 2018; Spicka et al., 2019). While proponents argue that e-commerce facilitates resource efficiency and reduces carbon emissions through the optimisation of logistics (Letunovska et al., 2023; Miśkiewicz, 2019), critics question its role in promoting overconsumption (Chen et al., 2021; Arefieva et al., 2021), wasteful packaging (Jacobsen et al., 2022), and the detrimental effects of last-mile deliveries on urban congestion (Muriel et al., 2022; Engesser et al., 2023) and air quality (Zhang et al., 2022).

In the context of the European Union (EU), where e-commerce has witnessed exponential growth in recent years, the balance between economic prosperity and sustainable development has become a critical point of contention (Dementyev et al., 2021; Trushkina et al., 2020; Miśkiewicz et al., 2022; Kwilinski et al., 2022; Jenčová et al., 2023). Considering the official report on the attainment of the Sustainable Development Goals (SDGs), EU countries are weakly positioned in the context of SDG2: Zero Hunger, SDG12: Responsible Consumption and Production, and SDG13: Climate Action. While scholars (Music et al., 2022; Melnyk et al., 2021; Ben Youssef and Dahmani, 2023) argue that e-commerce enhances food accessibility and affordability, others question whether its emphasis on fast delivery and single-use packaging aligns with responsible consumption and production practices (Jia et al., 2022; Morashti et al., 2022; Delina et al., 2023; Lopez-Villalobos

et al., 2022). Thus, it is necessary to identify and empirically justify the character of links between e-commerce and sustainable development. The primary objective of this paper is to investigate the implications of e-commerce on sustainable development within the European Union. This investigation is pursued through the utilisation of existing research and the creation of econometric models, which are tailored to evaluate the specific influence of e-commerce on SDG2, SDG12, and SDG13. The paper fills the scientific gaps (which outline the originality of this study) in attaining SDGs by developing an approach to justify the impact of e-commerce on SDG2, SDG12, and SDG13 based on a combination of the panel-corrected standard error (static estimation) and the system generalised method of moments (dynamic estimation).

The paper is structured as follows. The literature review contains an analysis of the theoretical landscape on linking e-commerce and SDG2, SDG12, and SDG13 to justify the research hypotheses; the materials and methods section explores the variables and sources, explaining the selected approaches to verifying the research hypotheses; the results section describes the empirical results of the study; and the discussion and conclusion section contains a summary of the research findings and a comparative analysis with previous investigations, and outlines the policy implications, limitations and potential directions for further research.

1. Literature review

Past studies (Cordes and Marinova, 2023; Chen et al., 2023; Zhanibek et al., 2022; Di Pierro et al., 2023; Criveanu, 2023) confirm that the share of enterprises with e-commerce sales has a significant impact on achieving the Sustainable Development Goals (SDGs) in various ways. The adoption

and expansion of e-commerce by businesses positively influence several SDGs, particularly those related to economic growth, innovation, and sustainable consumption (Mazhar et al., 2022; Melnychenko, 2019; Karnowski and Miśkiewicz, 2021; von Braun et al., 2023; Oruma et al., 2021). Applying the artificial neural network and cluster analysis, M. Criveanu (2023) confirmed that e-commerce boosts economic growth and sustainable development. Von Braun et al. (2023) have shown that digitalisation impacts a country's food system and reduces hunger. Similar findings are presented in a study by Oruma et al. (2021), which presents the interdependence of food security in Nigeria with Agriculture 4.0 and commercial farming. Based on the findings, they proved that digital technologies in the agri-food supply chain aim to contribute to SDGs 2, 3, and 8 for the benefit of Nigeria and the global community. Hassani et al. (2021) outlined the fact that extending Big Data and e-commerce stimulates the transformation of the food supply chain, improving food security and attaining zero hunger (SDG 2). Studies (Reardon et al., 2021; Carpio et al., 2013; Guo et al., 2021) have shown that e-commerce platforms facilitate direct connections between consumers and local food producers, enabling consumers to support small-scale farmers and local businesses. This contributes to sustainable rural development and poverty reduction, aligning with the objectives of SDG2. Scholars (Musa et al., 2023; Oláh et al., 2018; Chen et al., 2020; Sousa et al., 2021) have shown that e-commerce platforms enable producers and retailers to reach a broader customer base, including consumers who prioritise sustainable and ethically sourced products. This encourages more businesses to adopt sustainable production practices and offer eco-friendly food options, contributing to SDG2's target of ensuring sustainable food production. At the same time, other research (Lin et al., 2021; Apostolopoulos

et al., 2021) has revealed that e-commerce, particularly in the food industry, contributes to food wastage through excessive packaging, short shelf-life products, and inefficient supply chains. It may also prioritise cost and speed over sustainability, leading to an emphasis on processed and non-nutritious foods rather than promoting access to healthy and nutritious options (Letunovska et al., 2022). Additionally, the reliance of e-commerce on long-distance shipping and refrigeration increases the carbon footprint of food transportation, further impacting food security and availability (Lin et al., 2021; Apostolopoulos et al., 2021). Based on this, the following hypothesis is proposed:

Hypothesis 1: The effect of e-commerce on attaining SDG2: Zero Hunger.

Altarturi et al. (2023) outlined that the share of enterprises with e-commerce sales inclines consumer behaviour toward more responsible consumption. E-commerce platforms have the potential to promote sustainable products, provide information on eco-friendly options, and encourage consumers to make conscious choices, reducing the overall environmental impact. Ji et al. (2023) examined China's efforts to achieve the sustainable development goals by reducing carbon emissions and utilising digitalisation. Additionally, the research highlights that digitalisation plays a crucial role in driving sustainable development. Chiu et al. (2020) underlined that by providing consumers with access to sustainable and eco-friendly products, e-commerce influences purchasing decisions and encourages responsible consumption practices that directly relate to SDG 12. Based on the questionnaire from 421 respondents, Nogueira et al. (2021) concluded that demographic characteristics impact the decision to buy green products via e-platforms. At the same time, they outlined that sustainable production and consumption require relevant

digital knowledge (Kwilinski et al., 2020; 2022; Melnychenko, 2021a; 2021b; Kwilinski, 2019; Trzeciak et al., Dzwigol, 2019; 2021; 2022a; 2022b; 2023; Dzwigol et al., 2023), competencies, and infrastructure. Using survey data (among EU and African countries) and applying cluster analyses and ANOVA tests, Kwilinski et al. (2019) showed that e-commerce policy is crucial in extending responsible consumption and production. At the same time, they outlined that EU countries more actively implement relevant policies on the spread of digitalisation than African countries.

Scholars (Xie et al., 2021; Ji et al., 2023) have proven that e-commerce contributes to overconsumption and unnecessary purchases due to easy access to a wide range of products. Such consumer behaviour leads to increased waste generation and resource depletion. Moreover, the use of single-use packaging and inefficient product returns in e-commerce add to the environmental burden. Thus, the second research hypothesis is outlined as follows:

Hypothesis 2: The effect of e-commerce on attaining SDG12: Responsible Consumption and Production.

Based on the results of the literature review, Siikavirta et al. (2002) outline that e-commerce, specifically e-grocery home delivery services, presents an opportunity to reduce greenhouse gas (GHG) emissions in the food production and consumption system by 18% to 87% compared to traditional in-store shopping. However, the current market potential for emission reduction is limited to approximately 0.3% to 1.3% due to low market share. Achieving significant GHG reductions would necessitate system-level innovations and more research to assess the effectiveness of e-commerce and e-grocery in this context. Liang et al. (2021) explored the correlation between e-commerce and carbon dioxide emissions by means of panel data from various Chinese cities spanning

2001-2017. The results indicated that greater trade openness leads to reduced carbon emissions, while increased foreign direct investment (FDI) and market size are associated with higher emissions. Furthermore, the research supports a quadratic-shaped carbon Kuznets curve (CKC) for China, Eastern China, and Western China and a cubic-shaped CKC for Central China, offering significant insights for formulating e-commerce regulations at regional and national levels to mitigate carbon emissions (Liang et al., 2021). Tiwari and Singh (2021) investigated the environmental effects of e-commerce, highlighting the importance of raising awareness about its potential consequences. Although e-commerce has become a lucrative industry with significant revenue generation, its rapid expansion has had both beneficial and detrimental impacts on the environment, underscoring the necessity for agencies and industries involved in its development to prioritise sustainability measures. Using panel data from Chinese cities between 2006 and 2016 and the staggered difference-in-differences method, Wang et al. (2023) examined the impact of e-commerce pilot policies on carbon emissions. The results indicate that an e-commerce pilot policy leads to a significant reduction in carbon emissions, especially in non-old industrial and non-resource-based cities, achieved through the optimisation of resource allocation, a reduction in energy consumption, and industrial structure upgrades. Furthermore, the e-commerce pilot policy demonstrates positive synergies with other carbon reduction measures, providing empirical evidence for reducing carbon emissions and implications for fostering sustainable urban development. However, scholars (Khrais, 2020; Jiménez-Rodríguez et al., 2022; Pérez-Martínez et al., 2023) have proven that the impact of e-commerce on SDGs is not always uniformly positive. In regions with limited internet access and digital literacy, certain communities and

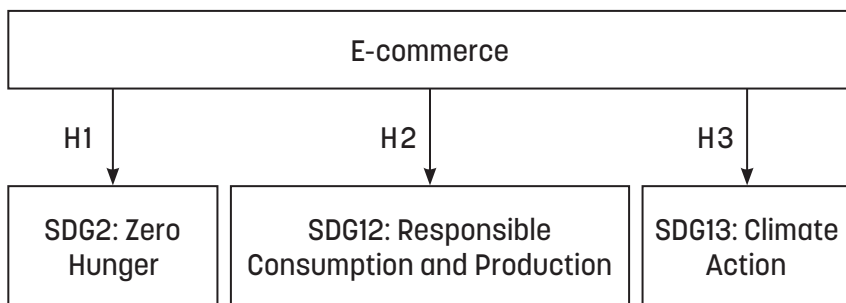
populations are left behind, exacerbating existing inequalities. While e-commerce promotes responsible consumption, it also leads to increased packaging waste and energy consumption due to transportation and logistics. In addition, e-commerce growth could raise concerns about labour practices and working conditions, particularly in the

gig economy, where workers face precarious employment. The third research hypothesis is as follows:

Hypothesis 3: The effect of e-commerce on attaining SDG13: Climate Action.

The research framework of this study is shown in Figure 1.

Figure 1. Theoretical framework of the investigation



Source: own elaboration

2. Materials and methods

This paper aims to explore the impact of e-commerce on sustainable development in the European Union. To achieve this,

the study leveraged existing research and devised econometric models focused on assessing the influence of e-commerce on SDG2, SDG12, and SDG13:

$$SDG2_{it} = b_1 Ecommerce_{it} + \delta_j X_{jt} + \epsilon_{it} \quad (1)$$

where $SDG2_{it}$ – the SDG2 Index Score of country i at time t ; $Ecommerce_{it}$ – the level of e-commerce of country i at time t ; X_{jt} – the set of control variables for country i at time t ; b_1 – the estimator associated with the e-commerce variable; δ_j – the estimator associated with the control variables; and ϵ_{it} – the residual term representing the error in the model.

SDG2 primarily deals with food security and sustainable agriculture. It aims to ensure that everyone has access to sufficient,

safe, and nutritious food while also promoting sustainable farming practices. The link between SDG2 and e-commerce may not be direct, as e-commerce sales are more related to trade and business practices. However, in the context of agriculture and food supply chains, e-commerce platforms play a role in facilitating the distribution and sales of agricultural products, especially for smallholder farmers. E-commerce gives them access to larger markets and fair prices, ultimately contributing to food security.

$$SDG12_{it} = b_2 Ecommerce_{it} + \delta_j X_{jt} + \epsilon_{it} \quad (2)$$

where $SDG12_{it}$ – the SDG12 Index Score of country i at time t ; b_2 – the estimator associated with the e-commerce variable.

SDG12 focuses on sustainable consumption and production patterns. It aims to ensure that economic growth is

decoupled from resource use, environmental degradation, and negative ecosystem impacts. E-commerce could be a tool by means of which to promote sustainable consumption by enabling businesses to adopt more efficient and eco-friendly production

$$SDG13_{it} = b_3 Ecommerce_{it} + \delta_j X_{jt} + \varepsilon_{it} \quad (3)$$

where $SDG13_{it}$ – the SDG13 Index Score of country i at time t ; b_3 – the estimator associated with the e-commerce variable

SDG13 is centred around climate action to combat the impacts of climate change. It involves efforts to reduce greenhouse gas emissions, build resilience to climate-related hazards, and promote sustainable practices. E-commerce can contribute to SDG13 by reducing the carbon footprint associated with traditional retail. Online shopping can be more energy-efficient, as it eliminates the need for physical stores and can optimise transportation routes for deliveries.

In equations (1) to (3), the dependent variables SDG2, SDG12, and SDG13 are measured on a scale ranging from 0 (indicating worst performance) to 100 (indicating best performance) (Sachs et al., 2022). Consistent with previous studies (Zhu et al., 2023; Dharmawansa et al., 2023), the explanatory variable used to describe the level of e-commerce in these models is the percentage of enterprises with e-commerce sales accounting for at least 1% of their turnover.

The following control variables were included in the models to account for other factors that may influence the relationship between e-commerce and the SDGs:

- Trade openness (TO), which measures the degree of a country's integration into the global economy, can influence both the adoption of e-commerce and the attainment of SDGs (Hussain et al., 2021; Szczepańska-Woszczyzna et al., 2022; Kharazishvili and Kwilinski, 2022; Karnowski and Rzońca, 2023). Countries with a higher level of trade openness

processes. It also facilitates the development of sharing economies and the circular economy, reducing waste and promoting the reuse of products. By encouraging e-commerce that prioritises sustainable practices, SDG12 objectives could be advanced.

might have greater exposure to international markets, affecting the supply of and demand for e-commerce. Moreover, trade openness can impact a country's ability to achieve certain SDGs, particularly SDG12 (Responsible Consumption and Production) and SDG13 (Climate Action).

- Government expenditure on environmental protection (GovEnv) reflects a country's commitment to addressing environmental challenges and mitigating climate change (Hu et al., 2022; Bashir et al., 2022; Fremstad & Paul, 2022). It captures the level of support and investment in sustainable practices, which can influence both e-commerce strategies and progress toward climate-related SDGs.
- Government efficiency (WGI) reflects how effectively and transparently a country's government operates. Countries with more efficient governments might be better at implementing policies that support e-commerce adoption and achieving SDGs. Including this control variable helps account for the institutional and governance context that may influence the relationships under investigation (Kryshtanovych et al., 2022; Ahi et al., 2023). The assessment of WGI serves as an aggregate average indicator encompassing six overarching dimensions of governance: voice and accountability; political stability and absence of violence/terrorism; government effectiveness; regulatory quality; rule of law; and control of corruption. The assessment scale ranges from -2.5 (indicating poor governance performance) to 2.5 (reflecting strong governance performance).

The research employed a panel data approach to empirically estimate the regression model using annual data from EU countries gathered between 2009 and 2021, sourced from Eurostat and the World Bank. However, e-commerce data for Belgium, Bulgaria, Greece, and Malta were unavailable for the

chosen period. As a result, the number of cross-sectional units (N) exceeded the time period (T). Specifically, N was 23, and T was 13. All variables in the models were expressed in logarithmic form. Table 1 shows the variables utilised in the study, accompanied by their associated descriptive statistics.

Table 1. Descriptive statistics of the variables

Variable	Units	Source	Mean	CV	Min	Max
SDG2	Index Score	Sachs et al. (2022)	68.120	0.071	57.816	77.571
SDG12	Index Score	Sachs et al. (2022)	67.728	0.141	46.705	85.595
SDG13	Index Score	Sachs et al. (2022)	63.422	0.187	33.333	87.866
Ecommerce	Percentage of enterprises	Eurostat (2023)	16.205	0.537	1.100	47.200
TO	% of GDP	World Bank (2023)	123.259	0.504	45.419	388.120
GovEnv	% of GDP	Eurostat (2023)	0.705	0.424	0.100	1.700
WGI	Index Score	World Bank (2023)	1.082	0.431	0.087	1.873

Notes: CV – Coefficient of variation; Min – minimum value; Max – maximum value; Mean – average value.

Source: own elaboration

Given the nature of the dataset, which exhibits an imbalanced panel structure with more cross-sectional units than time periods, two distinct estimation approaches were applied to address its specific characteristics.

The panel-corrected standard error (PCSE) approach (static estimation) was chosen to address heteroscedasticity and within-group correlation in the panel data (Rodríguez-Pose and Ketterer, 2012; Jiang and Zheng, 2023). While well-suited to static estimation in balanced panels, this method may not be the best choice for handling the imbalanced panel structure present in this study. However, the PCSE approach was still employed to compare its performance with the dynamic estimation approach.

To effectively account for the challenges posed by the imbalanced panel structure and to address potential endogeneity issues arising from unobserved heterogeneity, the System GMM estimator was employed

(Wawro, 2002; Agan and Balcilar, 2023; Saha, 2023). This dynamic estimation approach is specifically designed to handle datasets with more cross-sectional units than time periods. By utilising instrumental variables, the system GMM estimator provided a robust framework for analysing the dynamics of the variables in the panel data. The validity of the instruments utilised in GMM estimation was assessed by employing Hansen and Arellano-Bond's AR(2) tests for autocorrelation (Saidi and Hammami, 2017; Omri and Kahouli, 2014; Hansen, 1982; Arellano and Bond, 1991; Roodman, 2006).

Before using the panel-corrected standard error (PCSE) approach for static estimation and the system GMM estimator, the following tests were utilised to assess assumptions and address potential issues in the data and model:

- Modified Wald and Breusch-Pagan/Cook-Weisberg heteroscedasticity test (Baptista et al., 2013; Roy and Rayhan,

2011): These tests were used to check for heteroscedasticity, which occurs when the variance of the error terms is not constant across observations. Heteroskedasticity can lead to inefficient and biased parameter estimates. If these tests detect heteroscedasticity, it indicates that the traditional standard errors might not be appropriate, and the PCSE approach can be utilised to correct for heteroscedasticity and obtain consistent estimates;

- Wooldridge test for autocorrelation (Wooldridge, 1990): This test was employed to detect the presence of autocorrelation in the error terms, which implies that the error terms are correlated across time periods. Autocorrelation violates the assumption of independently and identically distributed errors, leading to biased and inefficient estimators. If autocorrelation is detected, the System GMM estimator, which can handle dynamic panel data with autocorrelated errors, might be more suitable;
- VIF test for multicollinearity (Lin et al., 2011; Curto and Pinto, 2011): The variance inflation factor (VIF) test was used to assess multicollinearity, which occurs when independent variables are highly

correlated. Multicollinearity can lead to unstable and unreliable coefficient estimates. If significant multicollinearity is detected, it is essential to address it to obtain accurate coefficient estimates;

- Cross-sectional dependence test by Pesaran: The cross-sectional dependence test developed by Pesaran (2007) and Baltagi and Pesaran (2007) was used to assess whether a cross-sectional correlation exists in the data. The PCSE approach is more appropriate when cross-sectional dependence exists, as it provides consistent standard errors that account for cross-sectional correlation.

3. Results

The outcomes shown in Table 2 unveil notable diminutions in correlation coefficients observed among the variables, with the most elevated coefficient being documented at 0.527. As delineated by studies (Kwilinski et al., 2023), a robust correlation becomes evident when the coefficient exceeds the threshold of 0.80. Employing this criterion established by Kennedy, it is possible to deduce that the present study remains unburdened by concerns pertaining to multicollinearity.

Table 2. Correlation matrix

Variable		Ecommerce	TO	GovEnv	WGI
Ecommerce	const	1.000			
	p value				
TO	const	0.133	1.000		
	p value	0.021			
GovEnv	const	0.040	0.063	1.000	
	p value	0.496	0.281		
WGI	const	0.527	0.222	0.247	1.000
	p value	0.000	0.000	0.000	

Source: own elaboration

Furthermore, the variance inflation factor (VIF) falls below 10, suggesting the non-existence of multicollinearity among the

independent variables, as noted by Lin et al. (2011) and Curto and Pinto (2011). The empirical results of VIF are shown in Table 3.

Table 3. The empirical results of the multicollinearity test (VIF)

Variable	Ecommerce	TO	GovEnv	WGI
SDG2	1.45	1.07	1.13	1.61
SDG12	1.45	1.07	1.13	1.61
SDG13	1.45	1.07	1.13	1.61

Source: own elaboration

The results of the diagnostic tests (Table 4) suggest the presence of heteroskedasticity, autocorrelation, and cross-sectional dependence in the model. For the dependent variable SDG2, the modified Wald statistic is highly significant at 0.000, indicating the presence of heteroskedasticity. The Breusch-Pagan/Cook-Weisberg test also shows significance at a level of 0.037, further confirming the presence of heteroskedasticity. Similarly, the Wooldridge test highlights autocorrelation with a significant statistic of 2.309 and a p value of 0.011. The Pesaran test for cross-sectional dependence yields a statistic of 2.802 and a p value of 0.005, indicating the presence of cross-sectional dependence for SDG2.

For the variable SDG12, the modified Wald statistic is highly significant at 0.000, indicating heteroscedasticity. The

Breusch-Pagan/Cook-Weisberg test confirms this with a significant statistic of 4.55 and a p value of 0.032. The Wooldridge test suggests the presence of autocorrelation, with a statistic of 3.961 and a p value of 0.000. Additionally, the Pesaran test indicates cross-sectional dependence, with a statistic of 19.969 and a p value of 0.000 for SDG12.

For the variable SDG13, the modified Wald statistic is highly significant at 0.000, indicating heteroscedasticity. The Breusch-Pagan/Cook-Weisberg test supports this with a significant statistic of 8.11 and a p value of 0.004. The Wooldridge test suggests autocorrelation with a statistic of 3.756 and a p value of 0.000. Similarly, the Pesaran test indicates cross-sectional dependence, with a statistic of 11.986 and a p value of 0.000 for SDG13.

Table 4. Heteroskedasticity, autocorrelation and cross-sectional dependence diagnostic tests

Variable	Modified Wald		Breusch-Pagan/ Cook-Weisberg		Wooldridge		Pesaran	
	Statistic	p value	Statistic	p value	Statistic	p value	Statistic	p value
SDG2	4389.79	0.000	4.33	0.037	2.309	0.011	2.802	0.005
SDG12	1176.75	0.000	4.55	0.032	3.961	0.000	19.969	0.000
SDG13	3534.35	0.000	8.11	0.004	3.756	0.000	11.986	0.000

Source: own elaboration

To ensure the robustness of the regression results, the method of sequentially introducing control variables for regression analysis in models (1)-(3) was employed. It may be

observed from Table 5 that irrespective of the number of control variables added, the coefficient of SDG remained consistent and significant.

Table 5. Benchmark regression results

Variable	SDG2							
	Coef.	p value	Coef.	p value	Coef.	p value	Coef.	p value
Ecommerce	1.518	0.000	1.275	0.000	1.004	0.000	0.878	0.000
TO	-	-	0.005	0.000	0.004	0.000	0.003	0.000
GovEnv	-	-	-	-	1.380	0.000	1.468	0.000
WGI	-	-	-	-	-	-	0.298	0.036
R-Squared	0.935		0.943		0.955		0.955	
Adj R-squared	0.935		0.942		0.954		0.954	
SDG12								
Ecommerce	1.506	0.000	1.274	0.000	0.981	0.000	0.931	0.000
TO	-	-	0.005	0.000	0.003	0.000	0.003	0.001
GovEnv	-	-	-	-	1.488	0.000	1.523	0.000
WGI	-	-	-	-	-	-	0.119	0.443
R-Squared	0.926		0.932		0.946		0.946	
Adj R-squared	0.925		0.931		0.945		0.945	
SDG13								
Ecommerce	1.480	0.000	1.280	0.000	0.980	0.000	0.969	0.000
TO	-	-	0.004	0.000	0.002	0.006	0.002	0.008
GovEnv	-	-	-	-	1.525	0.000	1.533	0.000
WGI	-	-	-	-	-	-	0.027	0.863
R-Squared	0.925		0.930		0.945		0.945	
Adj R-squared	0.924		0.929		0.944		0.944	

Source: own elaboration

The empirical outcomes derived from PCSE (Table 6) show the associations of

e-commerce with SDG2, SDG12, and SDG13.

Table 6. The empirical results of PCSE (static estimation)

Variable	SDG2		SDG12		SDG13	
	Coef.	p value	Coef.	p value	Coef.	p value
Ecommerce	0.490	0.000	0.477	0.000	0.540	0.000
TO	0.006	0.000	0.007	0.000	0.006	0.000
GovEnv	0.835	0.000	0.770	0.000	0.869	0.000
WGI	1.149	0.000	1.130	0.000	0.958	0.000
R-Squared	0.914		0.894		0.897	
Observation	299		299		299	

Source: own elaboration

In the context of SDG2, the coefficient of 0.490 with a p value of 0.000 reveals a statistically significant and positive correlation between e-commerce and advancements in hunger reduction. This suggests that e-commerce practices potentially contribute to the enhancement of food distribution networks, facilitating access to nourishing sustenance. At the same time, concerning SDG12, the coefficient of 0.477 with a p value of 0.000 reveals a substantial and positive link between e-commerce and responsible consumption and production. This implies that while e-commerce may offer convenience and accessibility, it could concurrently foster sustainable consumption behaviours. Likewise, for SDG13, the coefficient of 0.540 with a p value of 0.000 establishes a noteworthy and positive connection between e-commerce and climate action. This hints at the potential influence of e-commerce strategies on initiatives aimed at mitigating carbon emissions and advancing environmental sustainability. The positive coefficients exhibited by TO, GovEnv, and WGI across all three SDGs, coupled with their low p values, underline their constructive associations with

progress toward the respective SDGs. This implies that increased trade openness, robust governance and environmental regulations, and favourable governance indicators collectively contribute to the advancement of these sustainability objectives. The substantial R-squared values (0.914, 0.894, and 0.897) confirm that a significant proportion of the variability in the dependent variables (SDG2, SDG12, and SDG13) could be elucidated by the independent variables featured in the model.

The results of Table 7 indicate that in the context of the European Union, the variables of e-commerce, trade openness, government expenditure on environmental protection, and government efficiency are positively associated with the achievement of SDG2 (Zero Hunger), SDG12 (Responsible Consumption and Production), and SDG13 (Climate Action). The lagged value of each SDG is also important in explaining its current value. Additionally, the Arellano-Bond tests for autocorrelation and the Hansen test for overidentification suggest that the assumptions of the model and the instruments are valid.

Table 7. Results of system GMM (Dynamic Estimation)

Variable	SDG2		SDG12		SDG13	
	Coef.	p value	Coef.	p value	Coef.	p value
L1.SDG	0.169	0.062	0.915	0.000	0.865	0.000
Ecommerce	0.012	0.000	0.002	0.000	0.001	0.022
TO	0.027	0.000	0.009	0.000	0.025	0.000
GovEnv	0.017	0.000	0.003	0.000	0.007	0.001
WGI	0.011	0.000	0.016	0.000	0.022	0.007
Arellano–Bond test for AR(1)	-1.91	0.056	-1.82	0.069	-2.45	0.014
Arellano–Bond test for AR(2)	1.25	0.212	1.06	0.290	1.62	0.105
Hansen test of overid restrictions	11.82	0.223	10.38	0.407	17.15	0.104
Group	23		23		23	
Instruments	15		16		17	

Source: own elaboration

The results for SDG2 demonstrate that e-commerce, trade openness, government expenditure on environmental protection, and government efficiency all exhibit positive and statistically significant coefficients (p value = 0.000), indicating a significant positive relationship with the SDG2 index score. This implies that an increase in e-commerce activity, greater trade openness, more government investment in environmental protection, and more efficient governance are associated with improved performance in terms of food security and sustainable agriculture. Additionally, the lagged value of SDG2 has a positive effect on its current value, although with a marginally significant statistical level (p value = 0.062), suggesting that past achievements in SDG2 might influence its current attainment. The emphasis placed by the EU on fostering e-commerce and trade openness, along with policies promoting environmental protection and efficient governance, can contribute to improving access to nutritious food and sustainable farming practices within the region.

In the context of SDG12 (responsible consumption and production), the notable positive coefficients associated with

e-commerce, trade openness, government expenditure on environmental protection, and government efficiency underscore their potential to serve as driving forces behind the promotion of responsible consumption and production patterns within the European Union. The statistical significance of these coefficients (p value = 0.000) strengthens the credibility of this relationship. The positive coefficient for the lagged value of SDG12 further indicates the lasting impact of past achievements on current outcomes. These findings hold particular significance for EU development policies. First, the positive link between e-commerce and SDG12 implies that the EU's efforts to foster sustainable e-commerce practices, such as encouraging online platforms that prioritise eco-friendly products and packaging, can lead to more responsible consumer choices and reduced environmental impact. Second, the positive association with trade openness suggests that EU trade policies which emphasise sustainability considerations can encourage responsible production practices both domestically and abroad. This alignment with trade openness can facilitate the exchange of sustainable goods and

services, contributing to the goals of SDG12. Moreover, the positive relationship between government expenditure on environmental protection and SDG12 highlights the pivotal role of governmental support in advancing responsible consumption and production practices. The EU commitment to investing in initiatives that promote sustainable production methods, encourage recycling and waste reduction, and facilitate the circular economy aligns directly with the objectives of SDG12. Additionally, the positive coefficient for government efficiency underscores the importance of effective governance in driving responsible consumption and production. Policies that streamline regulatory processes, promote transparency, and ensure efficient resource allocation can facilitate the adoption of sustainable practices by businesses and consumers alike. Furthermore, the highly significant positive effect of the lagged value of SDG12 emphasises the lasting impact of previous achievements in promoting responsible consumption and production within the EU. This suggests that the EU's historical dedication to sustainable practices has laid the foundation for ongoing progress in this area.

Within the framework of SDG13 (Climate Action), the positive coefficients observed for e-commerce, trade openness, government expenditure on environmental protection, and government efficiency, all of which are statistically significant at p value = 0.000, underscore their crucial roles in advancing climate mitigation and resilience objectives within the European Union. These findings align seamlessly with the essence of SDG13, which seeks to combat the adverse impacts of climate change. The results substantiate the instrumental role played by the EU in curbing the far-reaching effects of climate change through strategic policies that effectively balance economic growth with environmental stewardship. By prioritising sustainable e-commerce practices, fostering eco-friendly trade policies,

investing significantly in environmental protection initiatives, and ensuring efficient governance, the EU can effectively contribute to the reduction of greenhouse gas emissions, enhance the resilience of its communities and ecosystems, and pave the way for a more sustainable future.

4. Discussion

The empirical results confirm the research hypotheses regarding the effect of e-commerce on attaining SDG2: Zero Hunger (Hypothesis 1), SDG12: Responsible Consumption and Production (Hypothesis 2), and SDG13: Climate Action (Hypothesis 3).

The results reveal a robust link between e-commerce, trade openness, government environmental spending, and governance efficiency, all contributing to improved food security and sustainable agriculture. The highly significant coefficients (p value = 0.000) underscore their crucial roles in achieving SDG2, which is also confirmed in the research (Reardon et al., 2021; Carpio et al., 2013; Guo et al., 2021). This highlights the potential of the EU in terms of utilising e-commerce and trade openness to enhance food distribution networks, facilitating access to nutritious food and sustainable farming practices (Reardon et al., 2021; Carpio et al., 2013; Guo et al., 2021). The positive connection between e-commerce and SDG12 indicates that encouraging sustainable online platforms and eco-friendly packaging steer environmentally conscious consumer behaviour. The link between trade openness and SDG12 supports the hypothesis that EU trade policies stimulate responsible production both domestically and internationally (Dau et al., 2021; Jakob, 2021). The positive relationship with government environmental spending underscores the role of governmental support in promoting responsible practices, while the governance efficiency coefficient highlights the role of effective governance. The notable effect of the lagged

value of SDG12 further underscores the EU's historical dedication to responsible consumption and production, fostering continued progress. As in past studies (Zhang et al., 2022; Rao et al., 2023), our empirical findings also show positive coefficients for e-commerce, trade openness, government environmental spending, and governance efficiency for SDG13. These outcomes resonate with the essence of SDG13, affirming the EU's commitment to balancing economic growth and environmental stewardship. By prioritising sustainable e-commerce, advocating eco-friendly trade policies, investing in environmental protection, and ensuring efficient governance, the EU could significantly contribute to reducing greenhouse gas emissions, bolstering community and ecosystem resilience, and shaping a sustainable future.

Conclusions

The paper investigated the intricate relationship between e-commerce and sustainable development within the European Union. The study utilised a novel approach, blending existing research insights and the construction of tailored econometric models to comprehensively assess the specific influence of e-commerce on SDG2, SDG12, and SDG13 by adopting a combined methodology of the panel-corrected standard error and the system generalised method of moments. By investigating the potential positive and negative consequences of e-commerce, the study contributes to a nuanced understanding of how this dynamic sector either aligns with or deviates from the objectives of sustainable development. Furthermore, the adoption of advanced econometric models bolsters the robustness of the findings, enhancing the credibility of our conclusions. Considering the empirical results, the following policy implications can be outlined:

It may be worth encouraging international trade agreements that integrate sustainable e-commerce practices, thus fostering

cross-border collaborations that not only facilitate economic growth but also prioritise responsible production, consumption, and delivery methods. By aligning these practices with SDG12, which emphasises responsible consumption and production, such agreements create a global framework for e-commerce operations that are mindful of their environmental impact. This approach would not only bolster economic activity but also propel the sustainable development agenda forward by ensuring that the benefits of e-commerce are harnessed without compromising the well-being of the planet (Letunovska et al., 2022; Kwilinski et al., 2022; Oláh et al., 2023).

The implementation of stringent environmental standards for packaging and shipping methods within the e-commerce sector constitutes a crucial step toward achieving sustainable development. By mandating the use of eco-friendly materials and energy-efficient delivery practices, these regulations demonstrate a commitment to both SDG12 and SDG13. Such standards not only minimise the environmental footprint of e-commerce operations but also foster a culture of sustainability within the industry. This comprehensive approach ensures that the convenience of online shopping is harmonised with the broader goals of environmental preservation and the responsible utilisation of resources, paving the way for a more sustainable future (Miśkiewicz et al., 2022; Kwilinski et al., 2023; Melnyk et al., 2021; 2022).

Developing comprehensive regulations that hold e-commerce platforms accountable for the entire lifecycle of products is an essential stride toward embracing the principles of a circular economy. By extending their responsibilities to encompass post-consumer waste management, these regulations powerfully address SDG12. By advocating for sustainable practices that prioritise not just the initial sale but also the entire lifecycle of products, these measures not only contribute to environmental conservation but also

ensure that the e-commerce sector aligns with the broader SDGs. This approach not only enhances transparency but also encourages innovation in product design, resource utilisation, and waste reduction, ultimately fostering a more resilient and sustainable economic ecosystem.

Rolling out comprehensive digital literacy programmes represents a pivotal strategy in educating and empowering consumers to navigate the intricate landscape of online shopping with an environmental lens (Kwilinski et al., 2020; Trzeciak et al., 2022; Dzwigol, 2022a; 2022b; 2023). By imparting knowledge about the profound environmental repercussions of their choices, these programmes equip consumers with the tools to make informed decisions that are harmoniously aligned with responsible consumption and production. Empowered with this awareness, consumers proactively opt for eco-friendly products, evaluate the sustainability credentials of e-commerce platforms, and ultimately steer the industry toward practices that prioritise environmental integrity. This virtuous cycle of education and action not only elevates individual consumer agency but also lays the groundwork for collective efforts to drive the e-commerce sector toward a more sustainable trajectory.

To advance SDGs within the European Union, it is imperative to foster strategic partnerships among e-commerce platforms, governmental bodies, and environmental organisations. Such collaborations stand as catalysts for innovation and knowledge sharing, enabling the exchange of best practices that endorse sustainable operations. By collectively developing voluntary industry standards for e-commerce that are environmentally conscious, these partnerships are poised to drive positive change and positively impact SDG2, SDG12, and SDG13.

Establishing uniform regulations and standards across EU member states is crucial to cultivating a unified and conducive environment in which sustainable

e-commerce practices could flourish. This initiative, aimed at mitigating fragmentation caused by varying regulations, paves the way for a consistent framework that incentivises conscientious operations throughout the industry. Consequently, this endeavour fortifies the advancement of SDG2, SDG12, and SDG13, benefiting from a harmonious regulatory milieu that nurtures sustainability while concurrently enhancing economic growth and environmental conservation.

While this study offers valuable insights into the intricate relationship between e-commerce and SDGs within EU countries, it is important to acknowledge certain limitations that warrant consideration. First, the scope of this research primarily focuses on three specific SDGs, namely, SDG2: Zero Hunger, SDG12: Responsible Consumption and Production, and SDG13: Climate Action. While these goals are undoubtedly significant, the exclusion of other relevant SDGs might limit the comprehensive assessment of the broader impact of e-commerce on sustainable development in the EU. The study does not delve into the perspectives and experiences of key stakeholders such as consumers, businesses, and policymakers, which could provide nuanced insights into the challenges and opportunities encountered in the real-world implementation of e-commerce strategies. Furthermore, variations in socioeconomic factors, regulatory environments, and cultural dynamics across different EU regions might influence the transferability of findings to other global contexts, thus limiting the generalisability of the study's conclusions beyond the EU.

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