

Corruption's Effect on Shaping Eco-Innovation, Circular Economy, and Human Development

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Abstract

Considering that an economic vision oriented solely on profit-making fails to ensure corporate competitiveness along with sustainable development, a transition to a systemic approach of economic, social, and environmental dimensions became imperative. To support human development, the EU countries have not fully succeeded in transitioning to a circular economy and capitalising on the advantages of eco-innovation. This study aims to reveal corruption's impact on shaping eco-innovation, circular economy, and human development, considering a comprehensive panel data set of 270 values covering the 2013–2022 period for the EU-27 countries. Carrying out three-perspective research and a mixed-methods approach applying Principal Component Analysis (PCA) followed by the Structural Equation Model (SEM), this study provides valuable outcomes regarding the baneful corruption effect on human development within EU-27 countries, mediated through eco-innovation and circular economy. Thus, corruption hinders eco-innovation, which, in turn, inhibits countries' performance in transitioning to the circular economy. Finally, corruption indirectly hampers human development through its straight action on eco-innovation and its collateral effect on the circular economy. Research findings highlight that to support human development in the EU-27 countries, sustained anti-corruption measures must strengthen the competitive advantages achieved by switching towards eco-innovations and the circular economy. The study's complexity ensures powerful arguments supporting the findings' relevance and originality. It contributes to a comprehensive understanding of the mediated impact of corruption on human development within EU-27 countries, complementing the literature and offering valuable insights and strategies for policymakers and business leaders in sustainable development.

Keywords: *corruption, eco-innovation, circular economy, competitiveness, human development*

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1 INTRODUCTION

Innovation is key to global competitiveness, but in the current framework, it may have some side effects (Cetin & Erkisi, 2023). Adopting innovative behaviours to ensure long-term viability is necessary but no longer sufficient. Given that some innovative corporate activities contribute to environmental degradation or have social and economic side effects, highlighting and harnessing innovation's positive potential to achieve corporate development and competitiveness, along with human development and sustainable development of countries, becomes imperative (Zhang, 2024). The increasingly intense concerns focused on environmental sustainability can also support economic and social sustainability.

Thus, companies' trajectory towards sustainable innovation is reconfiguring with the growing interest in sustainable development. The critical issue is no longer enhancing corporate innovation but spotting and boosting innovative approaches that foster sustainable development and competitiveness, and simultaneously discouraging harmful innovations (Stankevičienė et al., 2025). Sustainable innovation aims to increase companies' competitiveness and stimulate sustainable economic growth while ensuring human development by using recyclable materials, improving resource efficiency, and using renewable energy sources in the circular economy framework. The positive effect of innovation in the circular economy framework on economic, social and environmental sustainability is consistently argued (Stoenoiu & Jäntschi, 2024).

Along with the increasing concerns regarding sustainable development, eco-innovation has emerged as a category of sustainable innovation. The concept of eco-innovation has emerged both as an opportunity for corporate development and from the need to balance the requirements of increasing corporate competitiveness and ensuring environmental sustainability, sustainable economic growth, and human development (Carvalho et al., 2018; Ostraszewska & Tylec, 2019; European Commission, 2024a).

Unfortunately, companies struggle to move towards sustainable business models based on eco-innovation and the circular economy to increase the company's competitiveness, while ensuring economic, social and environmental sustainability is hindered by corruption, affecting all countries, but with variable intensities.

In the framework described by the increasing importance of eco-innovation and the circular economy for human development, and on the other hand, by the spread of corruption and its devastating impact at an economic, social, and environmental level, the following research question emerges: How may the progress of human development, achieved through eco-innovation and circular economy, be mitigated by corruption?

Considering European countries' concern for competitiveness and sustainable business models, improving corporate performance, and simultaneously ensuring environmental sustainability, human development, and sustainable economic growth, this paper intends to make a robust case for the answer to the previously mentioned emerging research question. It aims to highlight the impact of corruption on eco-innovation, circular economy and human development within the EU-27 countries.

To assess the impact of corruption on eco-innovation and circular economy, and, finally, on the level of human development in the EU-27 countries, the following research hypotheses were stated:

H1: Corruption significantly affects all the eco-innovation dimensions.

H2: Corruption considerably influences the circular economy.

H3: The eco-innovation dimensions have a relevant impact on the circular economy.

H4: The eco-innovation and circular economy components have a consistent effect on the dimensions of human development.

In the context of rising sustainability concerns in the EU-27 countries, this research addresses the gap in the literature by outlining a comprehensive framework on how progress in increasing

the human development level based on eco-innovation and the transition to the circular economy may be mitigated by the negative impact of corruption.

In an original approach, this research study contributes to filling this gap by providing valuable insights into the impact of corruption on human development, mediated by two concepts that recently emerged with the rise of sustainability concerns: eco-innovation and circular economy.

The novel three-perspective research approach reveals the complexity, outcome relevance and originality of this study: the immediate impact of corruption on eco-innovation, the influence of eco-innovation on the circular economy, and finally, the mediated influence of corruption on the human development level through its direct action on eco-innovation and the collateral effect on the circular economy.

The research's depth highlights its novelty and originality. Thus, it focuses on the influence of corruption on eco-innovation and the circular economy components, which ultimately affect human development dimensions.

The research results provide powerful arguments regarding the mediated baneful effect of corruption on the human development level within the EU-27 countries through its direct hindering of eco-innovation and its intermediate hampering effect on the circular economy.

These results prove that the improvement of eco-innovation performance and the increase in the transition toward the circular economy must be strengthened by anti-corruption measures to increase the human development level in the EU-27 countries.

The article also presents limitations that mainly arise from the lack of grouping the analysed countries according to specific criteria, considering the lack of homogeneity within the EU-27 countries, but without diminishing the results' relevance.

The article structure is as follows: The next section outlines the theoretical background. The third section exposes the paper's purpose, the database, and the research methodology. The fourth section highlights the empirical results and discussion. The last section presents the research conclusions, implications, limitations and further research.

2 THEORETICAL BACKGROUND

2.1 Eco-innovation and circular economy - prerequisites for human development

In the new framework, the need for strong and, at the same time, socially and environmentally sustainable economic growth becomes evident. Even though the linear economy model fulfilled all requirements for producers and consumers by the end of the twentieth century, it can no longer ensure long-term competitiveness and growth due to extensive changes: the business environment has undergone significant transformations, the available resources have decreased, and companies' activity negatively affects the natural environment and human health to a certain extent.

A systemic change focusing on switching to the circular economy and adopting eco-innovations may allow corporate development and competitiveness, sustainable economic growth, and human development while ensuring the sustainability of the natural environment (Nuta et al., 2025; Rudolf & Schmidt, 2025). Therefore, a paradigm shift in corporate behaviours is noticed

alongside the switch from the linear toward the circular economy model: the transition from decision-making processes strictly focused on a profit-making approach to a systemic approach from the economic, social, and environmental dimensions perspective.

The switch towards sustainable business models to boost the transition to the circular economy in the new framework generated broad concerns (Najmaei & Sadeghinejad, 2023). There is a threshold level of technological development beyond which corporate innovation negatively affects environmental sustainability, which is more evident in highly innovative countries. This points out the relevance of eco-innovation as a category of sustainable innovation in companies for corporate development and competitiveness while ensuring environmental sustainability, human development, and sustainable economic growth (Machado et al., 2024; Kral & Janoskova, 2021).

Eco-innovations may ensure EU countries' sustainable economic growth and speed their transition to a circular economy (Arilla-Llorente et al., 2024; Peyravi et al., 2024). They have a critical role in supporting the transition of the EU economy to achieve the European Green Deal Objectives, with the EU-developed economies being less affected by this green transition (Neagu et al., 2024). Moreover, eco-innovation shapes environmentally friendly behaviour for producers and consumers, enabling switching toward the circular economy (Stankevičienė & Nikanorova, 2020).

European companies' switching towards sustainable business models by focusing on developing and implementing eco-innovations is key to the circular economy. Eco-innovation is considered the most effective way of strengthening the circular economy, and this becomes more stringent as economic growth increases (Chen et al., 2024). To move towards a circular economy and sustainable development, European countries must outline a strong national government framework supporting eco-innovation (Triguero et al., 2022; Obobisa, 2024). The complex relationship between eco-innovation and the circular economy is symbiotic. Eco-innovation may boost the circular economy by focusing on gaining competitiveness and stimulating economic growth while improving the quality of life and increasing environmental protection. However, a circular economy may increase companies' competitiveness by focusing on eco-innovation to develop new, more sustainable business models (Ghormare et al., 2024).

The circular economy is an emerging topic of increasing interest for researchers, practitioners, and policy decision-makers, with emphasis on the concept's definition and unveiling the drivers and barriers for the transition to the circular economy (Försterling et al., 2023). It is supported by new, sustainable business models and responsible consumers, involves micro- and macro-level action and focuses on achieving sustainable development through economic, social, and environmental sustainability (Kirchherr et al., 2017).

Although most European countries' circular economy performance has improved, there is still a high degree of heterogeneity in their transition towards a circular economy and sustainability, outlining a “four-speed Europe” regarding their circular economy performance. Moreover, the number of countries within the low circular economy performance group has increased. The EU countries with the highest development levels are leading in the faster implementation of circular economy and sustainability practices (Marino & Pariso, 2020; Mazur-Wierzbicka, 2021; Pintilie, 2021; Claudio-Quiroga & Poza, 2024). The EU countries' path towards the circular economy has been unbalanced; the European gap in circularity increases in terms of sustainability while narrowing concerning productivity (Lehmann et al., 2023). Thus, the need

for an integrated and balanced approach for the EU countries to accelerate the transition to a circular economy, embodied in an EU circular economy strategy, is emphasised (Castillo-Díaz et al., 2024; Apetrei Kalveram et al., 2024).

Environmental sustainability is a prerequisite for human development (UNDP, 2024a). There is a strong positive relationship between environmental sustainability and human development in countries with low corruption (Casagrande & Alve, 2017; Lai & Chen, 2020). Otherwise, there is a positive correlation between human development levels and decreased environmental sustainability in less developed countries and with more widespread corruption (Rahman & Sultana, 2024).

The “Human Development Index” (HDI) is the most relevant indicator for assessing human development. It is a metric for evaluating countries' economic and social development levels, with the degree of human development correlated with the economic development level (Rahman & Sultana, 2024). As the HDI recorded an unprecedented decrease in 2020 - 2021, human development evolution changed downwards, threatening a perpetual decrease. Thus, post-pandemic recovery will be challenging and unequal from the countries' development level perspective, making it much more difficult for less developed countries (UNDP, 2024a).

2.2 Corruption - a widespread multi-faceted phenomenon

Beyond the favourable outcome of eco-innovation adoption and the transition to the circular economy on corporate development, environmental sustainability, human development, competitiveness of countries and sustainable economic development globally, there are factors with a strong, widespread inhibiting effect, such as corruption.

Corruption is a widespread, multi-faceted phenomenon in all countries, regardless of their development level or geographical location, but on different scales, with significant implications: political, social, economic, and environmental (Transparency International, 2024). It hinders corporate innovation activity, especially eco-innovations, and hampers corporate evolution, human development, and the countries' sustainable growth (Amin & Motta, 2023; Quan et al., 2023).

It refers to the abusive use of public power to obtain private advantages. It can take different forms (Svensson, 2005) that hinder economic and human development, inhibit innovation, have negative social effects, and affect the business environment (Muramatsu & Bianchi, 2021). The different forms of corruption are intensively debated in the literature, along with the various forms of corruption prevention. Thus, corruption negatively affects corporate innovation that supports green transition and sustainable growth, known as eco-innovations or green innovations (Quan et al., 2023).

Moreover, anti-corruption measures may boost eco-innovations, and the positive impact of anti-corruption on eco-innovations is higher as the companies' political connections are more intense (Wu et al., 2022).

Considering completely different data sources, specific time spans, and corruption metrics shaped very different perspectives on the impact of corruption on countries' economic development. Thus, over time, the corruption approach in different frameworks has generated entirely different outlooks, ranging from theories supporting the negative or even destructive impact of corruption on countries' development level (“sanding the wheels theory”) to theories

arguing the positive influence of corruption on economic outcomes (“greasing the wheels theory”) (Bogetić & Naeher, 2024).

The negative impact of corruption manifests itself over different development dimensions at the micro and macro levels: human development, corporate development, and countries' competitiveness and economic development. Corruption is prevalent in emerging and developing countries, hurting companies and economies. Thus, corruption hinders innovations, companies' development, and these countries' economic growth and development levels (Pirtea et al., 2019).

The dark side of multiple forms of corruption in the different eco-innovation facets has been intensely studied, especially in developing countries that are more affected by corruption. Thus, local political corruption has a significant adverse effect on corporate green innovation, pointing out the negative impact of corruption on eco-innovation (Quan et al., 2023). Moreover, anti-corruption campaigns enhance corporate green innovations by reducing political corruption (Wu et al., 2022).

Effective corruption control is imperative for environmental sustainability, and countries that ensure a low level of corruption achieve high environmental sustainability (Aydin et al., 2024). Reducing corruption, changing the economic growth model by shifting toward a circular economy, and reshaping innovation trajectories to eco-innovation, as part of general improvements in national ESG performance, can shape a national governance framework oriented towards sustainable development that significantly supports eco-innovation (Pirtea et al., 2024; Long et al., 2023; Le Thanh et al., 2022).

The greasing-the-wheels hypothesis highlights that in specific contexts, corruption may positively affect the development level in less developed countries. Although corruption in any form harms the company's development, some arguments support that, under certain conditions, corruption may positively affect the company's behaviour and outcomes. Thus, greasing bribes strongly impacts corporate decisions to implement eco-innovation in developing countries with a low-developed institutional framework (Ha et al., 2021). It is argued that there is a more substantial impact in the case of large companies without homogeneity in terms of the influence of different forms of corruption on companies' decisions regarding pursuing eco-innovation. However, encouraging corruption in developing countries as an argument for minimal economic growth and human development is expected to have a devastating impact, both from a social and economic point of view (Bouteraa et al., 2024).

Corruption has a braking effect on countries' transition towards the circular economy. Corruption and governance quality negatively impact the transition to green innovation (Ziya et al., 2024). Eco-innovations find a nurturing development environment in countries with high institutional quality and low corruption levels (Ibrahimi et al., 2025).

As observed, the previous studies' outcomes mentioned above aimed either to argue the eco-innovation influence on human development level or the European countries' progress towards circular economy or the negative impact of corruption on sustainable economic growth and human development level, but without allowing a deep understanding on how corruption may hinder progress in increasing the human development level, previously affecting eco-innovation and the EU-27 countries transition to the circular economy.

3 DATA AND METHODOLOGY

Pursuing to reveal the effect of corruption on eco-innovation and the circular economy and, finally, on the human development level within the EU-27 countries, the research conducted in this paper considers corruption, eco-innovation, circular economy, and human development as key indicators. Three of the indicators integrated into the model are explained based on indices that are widely referred to in the literature: the “Corruption Perception Index” (CPI), the “Eco-Innovation Index” (EIIndex) and the “Human Development Index” (HDI). The authors built the fourth composite indicator, related to the circular economy (CEc), based on five variables, as will be presented below.

The “Corruption Perception Index” (CPI) is used as a proxy for corruption in 180 countries and territories worldwide (Transparency International, 2024). The index values range from 0 to 100. A high score of CPI means a low degree of corruption in a country, while a low score shows a high degree of corruption. In this study, seven of its relevant components at the European Union level are considered, as presented in Tab. 1:

Tab. 1 – The seven components of the Corruption Perception Index (CPI) considered in the study. Source: Transparency International

Corruption Perception Index components	Abbreviation
“Bertelsmann Foundation Sustainable Governance	BFSGI
“Economist Intelligence Unit Country Ratings”	EIU
“Global Insights Country Risk Ratings”	GICRR
“IMD World Competitiveness Yearbook”	IMD
“PRS International Country Risk Guide”	ICRG
“World Economic Forum EOS”	WEF
“World Justice Project Rule of Law Index”	WJP

In the very few cases where data on a country's score was missing in a specific year, they have been replaced with the previous value for that country.

The “Eco-Innovation Index” (EIIndex) is a relevant composite indicator measuring the environmental innovation performance of the EU countries. The Eco-Innovation Index comprises 12 variables structured on five dimensions (European Commission, 2024a), as presented in Tab. 2:

Tab. 2 – The Eco-Innovation Index (EIIndex) dimensions considered in the study. Source: European Commission

Eco-Innovation Index dimensions	Abbreviation
“Eco-Innovation Inputs”	EII
“Eco-Innovation Activities”	EIA
“Eco-Innovation Outputs”	EIO
“Eco-Innovation Resource Efficiency Outcomes”	REO
“Eco-Innovation Socio-Economic Outcomes”	SEO

The European Commission database comprises normalised values of the Eco-Innovation Index and its five dimensions.

The Circular Economy Indicator (CEc) was composed by the authors based on five variables provided by Eurostat (European Commission, 2024b), as presented in Tab. 3:

Tab. 3 – The Circular Economy Indicator (CEc) variables considered in the study. Source: European Commission

Circular Economy Indicator variables	Abbreviation
“Consumption footprint”	CF
“Greenhouse gases emissions from production	GGE
“Material import dependency”	MID
“Material footprint”	MF
“Generation of municipal waste per capita”	GMWpc

The variables in Tab. 3 are essential in achieving the main objectives of the new circular economy action plan adopted in 2020 at the EU level. As one of the main bases of the European Green Deal, it is crucial to achieving the EU climate neutrality objective in the following decades.

Considering these five variables' specificity, the higher the Circular Economy Indicator values, the lower the circular economy performance of the EU-27 countries. Reducing these variable values means improving the circular economy performance.

Although previous research highlighted the advantages of the circular economy's comprehensive multidimensional approach, most studies failed to capture relevant aspects of the circular economy due to their high degree of complexity (Ahmed et al., 2022).

Given the limits of circular economy data availability, a compromise is needed in choosing the number of variables related to the circular economy, the time, and the number of countries analysed (Lehmann et al., 2023). To cover all 27 EU countries for a longer and more recent time span compared to other studies, the circular economy-related dimensions were expressed synthetically through fewer variables, selecting only the most relevant ones. Thus, the five previously mentioned variables were used in this study, targeting two circular economy-related dimensions: global sustainability and resilience and, respectively, production and consumption.

The “Human Development Index” (HDI) is a concise measure of average achievement in the dimensions considered essential to global human development: health, education, and standard of living (UNDP, 2024b). It is built on these three pillars based on four variables, presented in Tab. 4:

Tab. 4 – The Human Development Index (HDI) variables considered in the study. Source: United Nations Development Programme (UNDP)

Human Development Index variables	Abbreviation
“Life expectancy at birth”	LE
“Expected years of schooling”	EYS
“Mean years of schooling”	MYS
“Gross national income per capita”	GNIpc

This research study is conducted in two stages. In the first stage, to highlight the greatest contributions of variables in determining the influences exerted within each composite indicator, a Principal Component Analysis (PCA) was performed for each structural indicator included in the analysis: the Corruption Perception Index, the Eco-Innovation Index, the Circular Economy Indicator, and the Human Development Index. PCA is an important and versatile framework that offers an overview of complex multivariate datasets (Greenacre et al., 2022). Thus, the PCA defines new axes based on the variable’s variation: the first principal component describes the most important variation, the second principal component explains the second most important variation, and so on. This method can reveal relationships between variables, detect findings, and generate new hypotheses. The principal component analysis describes a way of data analysis in the case of complex data sets. The main feature of this technique is represented by the possibility of data reduction while retaining most of the variation in the analysed dataset. The main directions resulting from this data set reduction are called principal components, for which the variation in data is maximum. These principal components represent the results of mathematical principles which transform several possibly correlated variables into a more homogeneous dataset.

Further, in the second research stage, a Structural Equation Model (SEM) with latent, measured, endogenous, and exogenous variables was developed to emphasise the effect of corruption on eco-innovation, circular economy, and, ultimately, human development.

The study was conducted on a comprehensive database of 270 observations related to the EU-27 countries, structured as panel data covering 10 years between 2013 and 2022. The database was configured by selecting the relevant indicators and their variables to ensure an appropriate sample size and high data homogeneity. The data were provided by Transparency International for the Corruption Perception Index (Transparency International, 2024), by the European Commission for the Eco-Innovation Index dimensions (European Commission, 2024a) and the Circular Economy Indicator (European Commission, 2024b) and by the United Nations Development Programme for the Human Development Index (UNDP, 2024b). The data relating to these indices were available for different periods, and the relevant time span that could be considered in the study covers the interval between 2013 and 2022. Stata 17 was used for data processing and model development, using Principal Component Analysis followed by the Structural Equation Model (SEM), with the Maximum Likelihood (ML) estimation method and the Observed Information Matrix (OIM) as the Standard Error type.

Following the research hypotheses, Fig. 1 expresses the conceptual model in which corruption has an essential effect on eco-innovation and circular economy indicators, which, in turn, significantly impact human development.

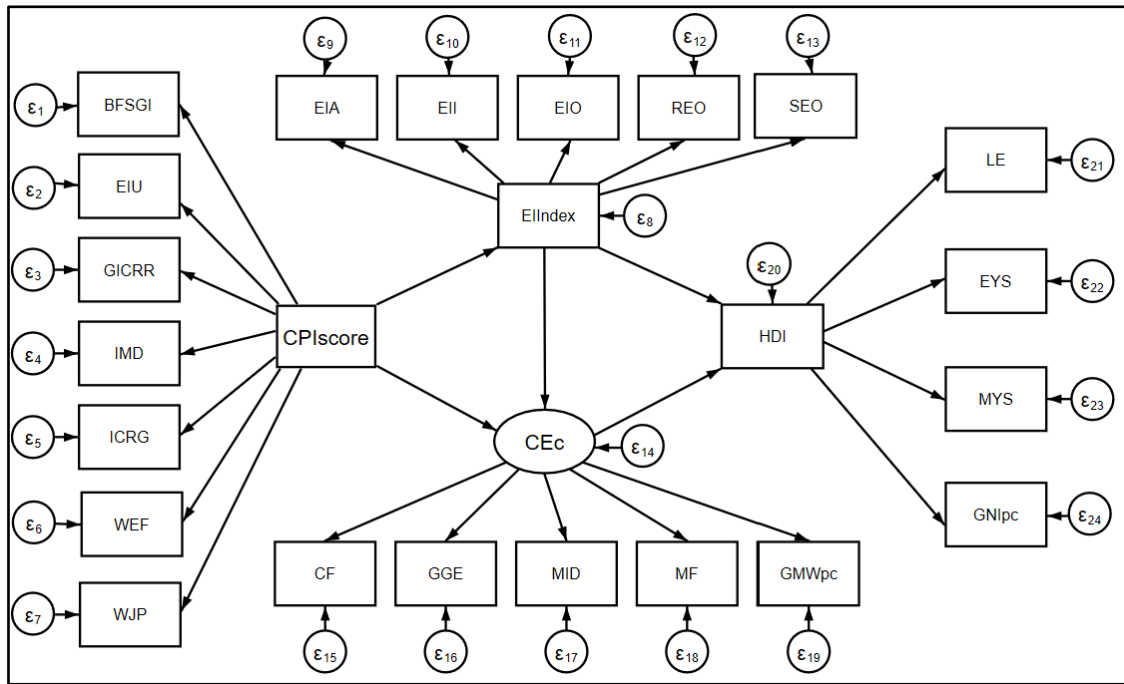


Fig. 1 – The conceptual model of the impact of corruption on eco-innovation, circular economy, and human development. Source: own design

Starting from this conceptual model, the following section explains the outcomes obtained by performing the Principal Components Analysis (PCA) and, respectively, the Structural Equation Model (SEM).

4 RESULTS AND DISCUSSION

In the study's first stage, a Principal Component Analysis (PCA) was conducted to analyse the principal components of the sets of variables composing the structural indicators that explain the greatest variance. In this regard, a PCA was performed for each structural indicator included in the analysis: the Corruption Perception Index, the Eco-Innovation Index, the Circular Economy Indicator, and the Human Development Index.

Thus, Tab. 5 presents the Principal Component Analysis results for the variables composing the Corruption Perception Index:

Tab. 5 – Principal Components Analysis of Corruption Perception Index (CPI). Source: own calculations. Computed using ordinary (un-centered) correlations, extracting 7 of 7 possible components.

Variables: BFSGI, EIU, GICRR, IMD, ICRG, WEF, WJP		Number of obs = 270		
Principal components/correlation		Number of comp. = 7		
Rotation: (unrotated = principal)		Trace = 7		
		Rho = 1.0000		
Component	Eigenvalue	Difference	Proportion	Cumulative
Comp 1	5.917	5.513	0.845	0.845
Comp 2	.4030	.1884	0.057	0.902
Comp 3	.2146	.0150	0.030	0.933
Comp 4	.1996	.0942	0.028	0.962
Comp 5	.1053	.0161	0.015	0.977

Comp 6	.0891	.0181	0.012	0.989
Comp 7	.0710	.	0.010	1.000
Principal components (Eigenvectors)			PC1 (Correlation Coefficients)	
BFSGI			0.358	
EIU			0.357	
GICRR			0.372	
IMD			0.393	
ICRG			0.390	
WEF			0.381	
WJP			0.389	

Tab. 5's first section shows that the first principal component of the set of tested variables describes 84.5% of the total variation of the group, while the second principal component defines 5.7% of this variation. Thus, the first two principal components describe over 90% of the variation of the group of variables, sufficient to construct a synthetic informational indicator based on the explanatory variables considered.

The second section indicates a linear combination of the coefficients within the first principal component, with eigenvalues between 0.357 and 0.390, showing a high homogeneity of these coefficients. Thus, the data highlights a high degree of homogeneity of the CPI based on the seven variables composing it. That means all the CPI dimensions act synergistically, giving this indicator a high relevance in reflecting the corruption in the EU countries.

Further, Tab. 6 presents the PCA results for the variables composing the EIIndex.

Tab. 6 – Principal Components Analysis of Eco-innovation Index (EIIndex). Source: own calculations. Computed using ordinary (un-centered) correlations, extracting 5 of 5 possible components.

Variables: EIA, EII, EIO, REO, SEO		Number of obs = 270		
Principal components/correlation		Number of comp. = 5		
Rotation: (unrotated = principal)		Trace = 5		
		Rho = 1.0000		
Component	Eigenvalue	Difference	Proportion	Cumulative
Comp 1	2.109	.7696	0.422	0.422
Comp 2	1.340	.4880	0.268	0.690
Comp 3	.8521	.3629	0.170	0.860
Comp 4	.4892	.2805	0.098	0.958
Comp 5	.2086	.	0.042	1.000
Principal components (Eigenvectors)		PC1 (Correlation Coefficients)		
EIA		0.054		
EII		0.579		
EIO		0.636		
REO		0.105		
SEO		0.494		

The results show that the first principal component of the tested variables describes only 42.2% of the group's total variation. In comparison, the second principal component defines 26.8% of this variation. Thus, the first two principal components describe 69% of the group's variation.

In the Tab. 6's second section, a linear combination of the coefficients within the first principal component, with diverse eigenvalues between 0.054 and 0.636, shows a relatively high degree of heterogeneity. The relevant components for the EIIndex are the EIO, EII, and SEO. In contrast, small correlation coefficients indicate that REO and EIA have low relevance. Thus, the structural indicator EIIndex is highly homogeneous based only on three of the five dimensions, evidencing that REO and EIA are not sufficiently integrated into sustainable development policies based on eco-innovation at the EU level.

Next, Tab. 7 presents the PCA results for the variables composing the Circular Economy Indicator.

Tab. 7 – Principal Components Analysis of Circular Economy Indicator (CEc). Source: own calculations. Computed using ordinary (un-centered) correlations, extracting 5 of 5 possible components.

Variables: CF, GGE, MID, MF, GMWpc		Number of obs = 270		
Principal components/correlation		Number of comp. = 5		
Rotation: (unrotated = principal)		Trace = 5		
		Rho = 1.0000		
Component	Eigenvalue	Difference	Proportion	Cumulative
Comp 1	1.887	.4795	0.377	0.377
Comp 2	1.408	.6121	0.281	0.659
Comp 3	.7960	.2642	0.159	0.818
Comp 4	.5318	.1558	0.106	0.924
Comp 5	.3759	.	0.075	1.000
Principal components (Eigenvectors)		PC1 (Correlation Coefficients)		
CF		0.429		
GGE		0.409		
MID		0.519		
MF		0.126		
GMWpc		0.602		

The first principal component of the set of tested variables describes only 37.7% of the total variation of the group, while the second principal component defines 28.1% of this variation. Thus, the first two principal components describe around 66% of the variation of the group of variables.

In the Tab. 7's second section, a linear combination of the coefficients within the first principal component, with diverse eigenvalues between 0.126 and 0.602, is observed, reflecting a certain degree of heterogeneity. The relevant components for constructing the CEc are the GMWpc, MID, CF, and GCE. In contrast, the MF has a low relevance and correlation coefficient.

The CEc structural indicator is highly homogeneous based on four of the five considered variables. The MF component is less relevant in ensuring sustainable development based on the circular economy at the EU level. This indicator is based on the demand for extractive materials regarding raw material equivalents needed to obtain products consumed in the EU. Thus, this indicator, which provides an insight into the quantity and type of materials necessary to satisfy the product demand, is not yet linked to EU long-term circular economy policies.

Finally, Tab. 8 presents the PCA results for the variables composing the HDI.

Tab. 8 – Principal Components Analysis of Human Development Index (HDI). Source: own calculations. Computed using ordinary (un-centered) correlations, extracting 4 of 4 possible components.

Variables: LE, EYS, MYS, GNIpc		Number of obs = 270		
Principal components/correlation		Number of comp. = 4		
Rotation: (unrotated = principal)		Trace = 4		
		Rho = 1.0000		
Component	Eigenvalue	Difference	Proportion	Cumulative
Comp 1	1.539	.4421	0.384	0.384
Comp 2	1.097	.2816	0.274	0.659
Comp 3	.8154	.2673	0.203	0.863
Comp 4	.5481	.	0.137	1.000
Principal components (Eigenvectors)		PC1 (Correlation Coefficients)		
LE		0.559		
EYS		0.472		
MYS		0.225		
GNIpc		0.642		

Tab. 8 shows that the first principal component describes less than half of the variation of the group of variables, 38.4%, and the second principal component defines 27.4% of the variation. In this situation, the first two principal components describe 65.9% of the variation of the group of variables.

A linear combination of the coefficients within the first principal component is observed, with diverse eigenvalues between 0.225 and 0.642, showing a certain degree of heterogeneity. The relevant components for the HDI are the GNIpc, LE, and EYS, while MYS is less relevant, with a smaller correlation coefficient. Three of the four variables composing the structural indicator HDI show high homogeneity. The components related to the standard of living and health are highly relevant to HDI. In contrast, the education component is significantly represented only by expected years of schooling for children. The component given by mean years of education for adults is less relevant, which means that this indicator is not significantly correlated with the other components of the HDI.

Furthermore, the second stage of the research involves developing a Structural Equation Model (SEM). The results are presented according to the established research hypotheses. The empirical SEM model is built on the variables and equations presented in Tab. 9.

Tab. 9 – The variables and equations of the Structural Equation Model. Source: own design

Structural equation model (SEM)
Number of observations = 270
Estimation method = maximum likelihood (ML), $p = 0.95$
Log-likelihood = -25524.657
Endogenous variables
Observed: BFSGI EIU GICRR IMD ICRG WEF WJP EIIndex EIA EII EIO REO
SEO HDI LE EYS MYS GNIpc
Measurement: CF GGE MID MF GMWpc
Latent: CEC

Exogenous variables

Observed: CPIscore

Equations: sem (CPIscore -> BFSGI), (CPIscore -> EIU), (CPIscore -> GICRR), (CPIscore -> IMD), (CPIscore -> ICRG), (CPIscore -> WEF), (CPIscore -> WJP), (CPIscore -> EIIndex), (EIIndex -> EIA), (EIIndex -> EII), (EIIndex -> EIO), (EIIndex -> REO), (EIIndex -> SEO), (EIIndex -> CEC), (EIIndex -> HDI), (CEC -> CF), (CEC -> GGE), (CEC -> MID), (CEC -> MF), (CEC -> GMWpc), (CEC -> HDI), (HDI -> LE), (HDI -> EYS), (HDI -> MYS), (HDI -> GNlpc), latent (CEC) nocapslatent

Several methods were used to test the model, such as the OIM (Observed Information Matrix) and the EIM (Expected Information Matrix). The structural equation model was tested for 0.95 and 0.99 probabilities. The results were similar regardless of the chosen method and probability, supporting the model's robustness.

Therefore, Fig. 2 and the following tables will present the results related to the 0.95 probability. Based on the structure in Tab. 9 and the conceptual model, the empirical Structural Equation Model is presented in Fig. 2.

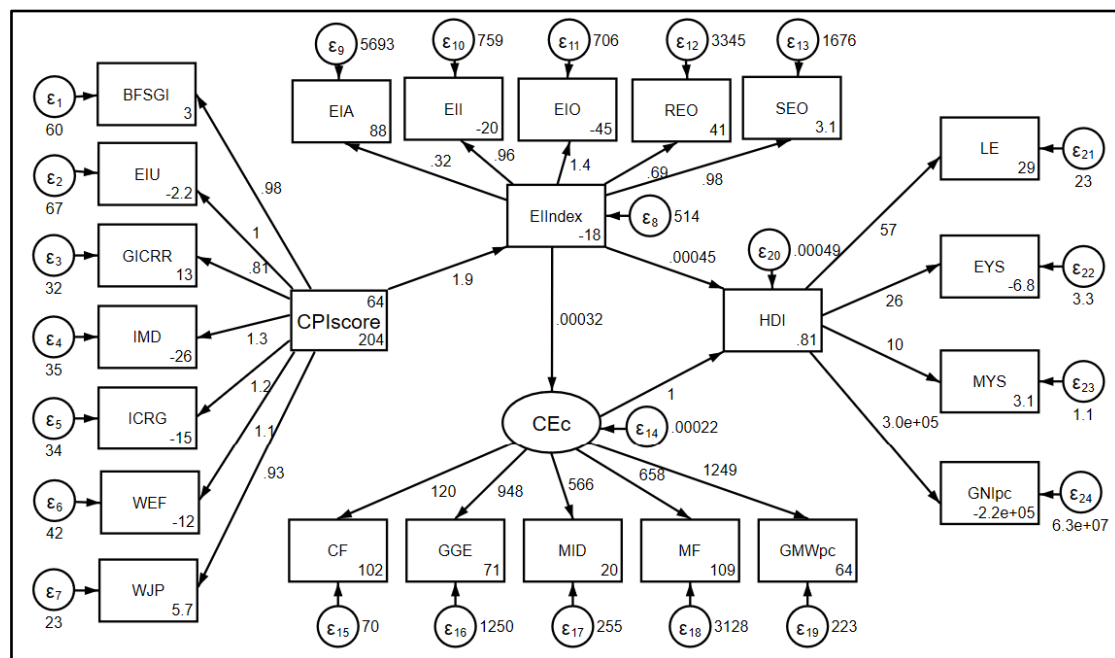


Fig. 2 – The empirical Structural Equation Model results illustrating corruption's impact on eco-innovation, circular economy, and human development. Source: own calculations

The empirical SEM has proven statistically significant results for H1, H3, and H4 research hypotheses. Hypothesis H2, which assumed a considerable impact of corruption (CPI score) on the circular economy (CEC), was not validated. The model that includes hypothesis H2 was not concave and did not yield relevant results. There are insufficient relevant elements for SEM to determine a significant direct relationship between corruption and the circular economy. This is undoubtedly due primarily to the lack of homogeneity in applying measures regarding the complex phenomenon of the circular economy. Even if the EU countries have progressed in transitioning to a circular economy, there are still significant disparities (Ghormare et al., 2024; Claudio-Quiroga & Poza, 2024). There is a substantial gap between the EU countries in

implementing circular economy policies, leading to inconsistency of data and difficulty in highlighting the direct influence of corruption on the circular economy.

The first research hypothesis (H1), assuming a significant impact of corruption on eco-innovation dimensions, is confirmed by the SEM model, as seen in Tab. 10 for a probability of 0.95.

Tab. 10 – The results for the hypothesis H1 of the Structural Equation Model. Source: own calculations

Variables	Coef.	OIM Std. Err.	z	P> z	[95% Confidence Interval]
EIIndex					
CPI	1.897	.0966	19.64	0.000	1.7084 2.087
_const.	-18.18	6.322	-2.88	0.004	-30.57 -5.787
EIA					
EIIndex	.3194	.1299	2.46	0.014	.0646 .5742
_const.	87.87	14.155	6.21	0.000	60.13 115.6
EII					
EIIndex	.9558	.0474	20.14	0.000	.8628 1.048
_const.	-19.74	5.167	-3.82	0.000	-29.87 -9.617
EIO					
EIIndex	1.399	.0457	30.58	0.000	1.309 1.489
_const.	-44.68	4.983	-8.97	0.000	-54.45 -34.92
REO					
EIIndex	.6884	.0996	6.91	0.000	.4931 .8837
_const.	41.37	10.85	3.81	0.000	20.10 62.63
SEO					
EIIndex	.9778	.0705	13.87	0.000	.8396 1.116
_const.	3.126	7.679	0.41	0.684	-11.92 18.17

The overall influence of CPI on EIIndex is significantly positive, with a regression coefficient of 1.897. Considering that a high CPI value expresses a low level of country corruption, a positive correlation between CPI and EIIndex shows that as a country's corruption level decreases, its eco-innovation performance will increase. The estimated coefficient value is statistically relevant, with a high z-value of 19.64 and the probability $P > |z| = 0.000$. These values emphasise that the low corruption level in EU countries has a significantly positive impact on eco-innovation as a global index and aligns with evidence from Ibrahimi et al. (2025), strengthening the proof that countries with low corruption levels are more likely to develop sustainable innovations.

Regarding the structural influence on the EIIndex components, it is observed that all the regression coefficient values are positive, showing that the decrease in corruption has a significant positive effect on all eco-innovation dimensions in the EU countries. However, there are substantial differences regarding the intensity of this influence on the different dimensions of the EIIndex. Thus, with a regression coefficient of 1.399, the most significant positive impact is observed in the case of EIO, followed by SEO at 0.9778, EII at 0.9558, REO at 0.6884, and EIA at only 0.3194. All the estimated regression coefficient values are statistically relevant, with high z-values and very low probabilities $P > |z|$.

Thus, the principal component analysis conclusions are confirmed, reinforcing that REO and EIA are the least integrated eco-innovation dimensions at the EU countries' level. These are the eco-innovation dimensions on which EU countries must substantially focus in the future to make them more relevant in supporting sustainable development based on eco-innovation.

As already discussed, the SEM did not validate hypothesis H2.

Hypothesis H3 assumes a significant influence of eco-innovation on the circular economy variables. The results based on SEM are presented in Tab. 11.

Tab. 11 – The results for the hypothesis H3 of the Structural Equation Model. Source: own calculations

Variables	Coef.	OIM Std. Err.	z	P> z	[95% Conf. Interval]	
CEc						
EIIndex	.00032	.00006	4.96	0.000	.00019	.00044
CF						
CEc	120.42	41.50	2.90	0.004	39.072	201.78
const.	101.53	1.189	85.39	0.000	99.208	103.86
GCE						
CEc	948.18	179.32	5.29	0.000	596.70	1299.6
const.	71.466	6.058	11.80	0.000	59.592	83.341
MID						
CEc	566.30	101.30	5.59	0.000	367.74	764.86
const.	20.392	2.825	7.22	0.000	14.854	25.931
MF						
CEc	657.66	229.33	2.87	0.004	208.17	1107.1
const.	109.25	8.838	12.36	0.000	91.935	126.58
GMWpc						
CEc	1248.5	229.86	5.43	0.000	798.04	1699.1
const.	64.078	4.465	14.35	0.000	55.327	72.830

The EIIndex has a very slight positive effect on the CEC, with a regression coefficient of only 0.00032. As mentioned in the previous section, considering the CEC components, namely consumption footprint, greenhouse gas emissions from production activities, material import dependency, material footprint, and generation of municipal waste per capita, there should be a negative correlation between EIIndex and CEC. An eco-innovation increase must lead to a decrease in all these CEC dimensions.

The fact that there is still a positive regression coefficient, even if very small, shows that even at the EU countries' level, the influence of eco-innovation does not lead to a decrease in the variables considered and, thus, to an increase in the degree of circular economy implementation. This may be explained through the significant disparity lens in the progress of the EU countries in adopting sustainability and circular economy practices. This is consistent with the previous research outcomes on the different paces of the European countries in their transition to the circular economy, as well as on the disparities within the EU-27 regarding the countries' circularity performance (Marino & Pariso, 2020; Mazur-Wierzbicka, 2021; Pintilie, 2021; Claudio-Quiroga & Poza, 2024; Lehmann et al., 2023).

Observing the other regression coefficients in Tab. 11, the highest values are for generating municipal waste per capita and greenhouse gases emissions from production activities. These

are the two dimensions where EU countries must considerably accelerate their reduction process, followed by material footprint and material import dependency. Eurostat data regarding the variables composing the CEC (European Commission, 2024b) show that highly developed European countries have significantly advanced in the case of some variables, such as reducing greenhouse gases emissions from production activities or material footprint. Regarding material import dependency and the generation of municipal waste per capita, highly developed countries still have difficulties reducing them. Only a few EU countries have reduced their consumption footprint, while most have recently increased it. This high heterogeneity between EU countries in adopting sustainability and circularity practices is intensely debated and argued in the current literature (Marković et al., 2023), claiming the need for a balanced approach at the European level. Detailed studies are lacking in the contribution of eco-innovation activities to circular economy practices (Peyravi et al., 2024), and our research outcomes aim to fill this gap in the broader context.

Tab. 12 presents the model results for hypothesis H4, which assumes that eco-innovation and the circular economy strongly impact human development dimensions.

Tab.12 – The results for the hypothesis H4 of the Structural Equation Model. Source: own calculations

Variables	Coef.	OIM Std. Err.	z	P> z	[95% Conf. Interval]
HDI					
EIIndex	.00045	.00007	6.41	0.000	.0003 .0005
CEC	1.0000	(constrained)			
const.	.81258	.00497	163.2	0.000	.8028 .8223
LE					
HDI	56.972	7.5995	7.50	0.000	42.077 71.867
const.	28.685	6.7851	4.23	0.000	15.387 41.984
EYS					
HDI	26.190	2.9135	8.99	0.000	20.480 31.901
const.	-6.8185	2.6013	-2.62	0.009	-11.917 -1.7201
MYS					
HDI	10.052	1.6470	6.10	0.000	6.8247 13.280
const.	3.1309	1.4705	2.13	0.033	2.2487 6.013
GNlpc					
HDI	296854.3	12666.7	23.44	0.000	272028 321680.6
const.	-223942.5	11309.2	-19.80	0.000	-246108 -201776.7

The EIIndex has a slight positive effect on the HDI, while the CEC has a constrained structural equation model effect equal to 1. The estimated coefficients' statistical significance is fair, with null probabilities and sufficiently high z-values in almost all cases. Considering the regression coefficient values and the z-values of statistical significance, it is observed that the effect of eco-innovation and the circular economy on the HDI components is most strongly reflected in the economic component, given by GNlpc. This also confirms and strengthens the conclusion from the principal component analysis, which, according to Tab. 8, is that the most relevant component within the HDI construct is GNlpc.

The following relevant influence is exerted on the HDI health component quantified by life expectancy at birth. Thus, over the analysed period of a decade, the main positive influences of eco-innovation and circular economy may be observed on the economic and health components.

Certainly, the effects observed on the health component are also influenced by the COVID-19 pandemic period since the analysed time horizon is 2013 - 2022. Life expectancy at birth has decreased globally, mainly in 2020 and 2021, affecting any analysis including this variable. However, the EU is one of the areas with the highest life expectancy values in the world, even if the pandemic has temporarily affected it.

Although statistically significant, the weakest influence on the education components of the HDI may be observed. Some more consistent influence may be detected in the case of the EYS component, which has a positive regression coefficient in the model results. The weakest result is observed in the case of the MYS component, although this is also positive and statistically relevant. One explanation is that the positive effects of eco-innovation and sustainable development based on circular economy practices are reflected in people's education over very long time horizons. Even though the analysed period of 10 years is quite long, the effects on the education of young generations, respectively adults, materialised over extended periods. The most serious difficulty lies in implementing the concepts and practices of eco-innovation and circular economy at the people's consciousness level. Thus, these concepts must be defined and explained, especially to young people, who will have to gradually assimilate the ideas of sustainable development based on eco-innovation and the circularity of the economy over time. This result reinforces previous study outcomes (Burlea-Schiopoiu et al., 2021), highlighting the need for sustainability policies at the European countries' level, contributing to capitalising on the young generation's pro-environmental and ethical values orientation to shape their responsible behaviours, especially in crisis periods. Economic growth may lead to sustainable human development as long as sustainability policies are promoted, correlated with a focus on investments to ensure increased education levels, improved health conditions, and employment skills (Sapena et al., 2018).

Thus, although prior research has analysed the causal relationship between corruption and human development (Castillo et al., 2024), this study broadens the research framework of this relationship by also addressing eco-innovation and the circular economy.

5 CONCLUSION

The study's results outline, in an original approach, a comprehensive picture of how corruption in the EU-27 countries hinders human development in a mediated way through two recent concepts related to sustainability: eco-innovation and circular economy.

Corruption's negative impact on human development in EU-27 countries is mediated by directly hampering eco-innovation, which, in turn, inhibits performance in the transition to the circular economy, and eco-innovation and the circular economy support human development, reinforcing recent research results (Nuta et al., 2025; Rudolf & Schmidt, 2025).

The complexity and depth of the research provide powerful arguments supporting the outcomes' relevance and originality and complement existing literature. Thus, the study follows a three-perspective approach: the immediate impact of corruption on eco-innovation, the influence of eco-innovation on the circular economy, and finally, the intermediate influence of corruption on the human development level through its direct action on eco-innovation and the collateral effect on the circular economy.

Globally, the EU-27 countries have not yet reached the “green revolution” stage, which would allow them to fully capitalise on the benefits of eco-innovation and sustainability practices to

improve competitiveness. Even if some countries have made significant progress in this direction, most are still at an early stage of the transition to the circular economy. To support human development in the EU-27 countries, the advances in switching towards eco-innovation and the circular economy must be strengthened through sustained anti-corruption measures, with an emphasis on less developed countries.

This study's results fill a gap by advancing knowledge in understanding how corruption's negative impact may mitigate the progress in increasing the human development level based on eco-innovation and the transition to the circular economy in EU-27 countries. It unveils the causal relationships between variables and goes down to their dimensions.

The research's results, based on an extensive sample and the latest data on the sustainability progress of the EU-27 countries, may be very relevant for decision-makers concerned with the baneful influence of corruption, which is widespread in the economic, social, and environmental fields, on eco-innovations, circular economy practices, and, finally, on human development. The study's output is even more significant as decision-makers focus on finding solutions after the unprecedented decrease in worldwide human development levels in 2020-2021.

Given the global increase in concerns about competitiveness and sustainability, the research outcomes have strong policy implications, with positive results for the EU-27 countries. They provide valuable arguments and information for policy decision-making and strategic planning in sustainable development and anti-corruption measures. Thus, to sustain the progress of human development based on eco-innovation and the circular economy in the European Union countries, it is recommended that policymakers undertake a concrete, integrated and balanced action plan that aims at both anti-corruption measures and speeding up the transition to the circular economy and sustainable competitiveness.

The research implications emerge from approaching the mediated impact of corruption on human development in EU countries from three perspectives: corruption on eco-innovation, eco-innovation on circular economy, and corruption on the human development level (through eco-innovation and circular economy). Previous studies provide relevant results from at most two perspectives without outlining a comprehensive image of how corruption may hinder human development in EU-27 countries (Peyravi et al., 2024; Bouteraa et al., 2024; Ibrahimi et al., 2025). Also, the study's results may open new research directions in this field.

Furthermore, there are methodological implications arising from the fact that this research's outcomes expand the literature, bringing strong arguments in support of the mediated influence of corruption on human development in the EU-27 countries, using two quantitative analysis methods: Principal Component Analysis and the Structural Equation Model, allowing simultaneous consideration and testing within the same model of all four hypotheses stated.

Although the article outlines an overall picture of the EU-27 countries regarding how corruption mitigates the increase in the human development level in the context of sustainability and makes essential contributions to the literature expansion on the topic, one of its limits is that it does not differentiate the analysis into groups of countries according to the nature and intensity of the corruption impact, considering the significant discrepancies between the EU-27 countries based on their eco-innovative performances, their progress towards the circular economy, or the spread level of corruption.

Another limitation of this study comes from considering only the five most relevant variables for the circular economy within the model, covering two significant dimensions: global sustainability and resilience and, respectively, production and consumption. This restriction allowed a more significant expansion of the study for a higher relevance: coverage of all EU-27 countries for a more recent period, compared to similar studies, due to the limited availability of circular economy data.

The results of this study, complemented by considering the disparities between the groups of countries based on the criteria of eco-innovative performance, the countries' progress towards the circular economy, and the spread of corruption, may provide a framework for expanding the research question in future studies, both to the EU-27 countries level or extended at the regional or global level, or even up to the level of different sectors/industries.

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