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DOES VULNERABILITY TO CORRUPTION AND GLOBAL CHALLENGES AFFECT SUSTAINABILITY IN LEAST DEVELOPED COUNTRIES?

Abstract. *The Human development index is widely seen as reliable and significant measurement of the various countries' levels of social and economic development. The aim of this study is to examine the impact of corruption on human development in a significant number of Least Developed Countries LDCs, for the period ranging from 2003 to 2019. There is a wide range of literature examining the effects of corruption on economic development, but less literature, especially empirical ones, focuses on the impact of corruption on human development. This study contributes to the literature on investigating the determining factors of human development by adding the control of corruption* (*Worldwide Governance Indicators (WGI)) as a proxy of the institutional variables influencing human development besides three other control variables: External debt - economic factor, Global Adaptation Index (the Notre Dame GAI) – country's readiness to improve resilience, and CO_2 emissions – environmental factor.*

Keywords*: Human Development Index (HDI), corruption, LDCs, resilience, external debt, Global Adaptation Index (the Notre Dame GAI)*

JEL Classification : F21, I25, P45

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1. Introduction

The Human development index is widely seen as reliable and significant measurement of the various countries' levels of social and economic development. The United Nations Research Institute for Social Development conducted one of the earliest studies in 1966, focusing on a "level of living index" across 20 countries. Subsequently, in 1972, they published a "Development Index" that incorporated nine economic and nine social variables. The United Nations Economic and Social Council rated 140 nations in 1975 based on the summation of two social and five economic indices. In 1987, Camp and Speidel introduced the International Human Suffering Index, which considered eleven criteria to measure social well-being. However, a significant shift occurred in 1990 when the United Nations Development Program (UNDP) published its first annual Human Development Report and introduced the HDI, marking a transformative moment in the field of development theory, measurement, and policy.

The HDI, created by Mahbub ul Haq and Amartya Sen, encompasses three fundamental human capabilities: health, education, and a decent standard of living. It classifies societies into categories such as very high, high, medium, or low human development based on progress in these areas. The HDI aligns with Amartya Sen's "capabilities" approach, prioritising outcomes over means, such as per capita income.

Despite criticism, the HDI serves as a valuable tool for global development planning. It often complements GDP and influences a country's economic and public policies. Nevertheless, it has limitations, such as its slow response to policy changes and its focus on long-term changes, potentially missing recent developments.

Critics argue that the HDI overlooks disparities in human development among nations and does not account for factors such as pollution, access to safe drinking water, or the potential for war. To address these concerns, the Inequality-adjusted Human Development Index (IHDI) was introduced by the UNDP.

In 2020, a National Sustainable Development Index (NSDI) was proposed to improve the HDI by considering sustainability factors, providing policymakers with a more comprehensive perspective. Additionally, there are other indices such as the Human Sustainable Development Index (HSDI) and the Human Green Development Index (HGDI), which incorporate environmental indicators. The HGDI, for instance, includes measurements such as CO_2 emissions, forest area, and more.

The aim of this study is to examine the impact of corruption on human development in a significant number of Least Developed Countries LDCs, for the period ranging from 2003 to 2019. This study contributes to the field in several ways. Firstly, it utilizes various Generalised Method of Moments (GMM) models to assess dynamic panel data from 22 Less Developed Countries (LDCs), effectively addressing issues of simultaneity bias and reverse causality. The approach involves evaluating a country's progress in terms of per capita national GDP using the Human Development Index (HDI), which assesses three key aspects of human development: longevity, access to information, and quality of life.

The rest of the paper is structured as follows: the second part includes the most relevant studies in the field, the third part refers to data and methodology applied. The fourth section indicates the obtained results, the conclusions ending the paper.

2. Literature review / State of the art

2.1. HDI & Control of Corruption

Researchers began focusing on corruption issues in the latter part of the 20th century. Corruption takes various forms, such as bribes, unofficial payments, or campaign donations exchanged for political favors or illegal conflicts of interest by public officials.

The impact of corruption on the business sector remains a subject of debate. Two contrasting concepts, "greasing the wheels" and "sanding the wheels," explore how corruption affects productivity in contexts with weak institutional support. "Greasing the wheels" suggests that corruption enhances efficiency in such settings, while "sanding the wheels" argues that it hampers efficiency. The "sanding the wheels" hypothesis suggests that corruption impedes the growth and expansion of companies. For example, Mauro (1995) contends that corruption raises operating costs, breeds uncertainty, and discourages investment. Other studies (Zhuo et al., 2021) demonstrate a positive correlation between corruption levels (measured by the CPI) and human development (measured by the HDI). This implies a negative impact of corruption on human development, with higher corruption levels associated with lower levels of well-being. In contrast, the "greasing the wheels" hypothesis suggests that corruption can improve operating conditions, boost economic investment, and enhance business competitiveness. Thus, corruption may have positive effects on human development.

For instance, Lui (1985) argued that corruption can expedite processes in slow-moving governments and have a positive impact on economies with weak property rights and protection. Corruption can also expand economic activity by allowing private citizens to bypass unfavourable regulations through bribery (Houston, 2007). In most developing countries, where governance quality is poor, corruption may improve bureaucratic efficiency, enable businesses to navigate ineffective regulations, and increase investment efficiency (Johnson et al., 1999).

The control of corruption has a positive and significant effect on economic growth, indicating that increased control of corruption implies an increase in the countries' economy. Overall, anti-corruption initiatives lead to economic growth and better governance.

In summary, relying on the findings from the studies outlined earlier, we suggest and then test through empirical testing the following hypothesis:

Hypothesis (H_1) - ***Control of Corruption is influencing HDI in LDC***

2.2. HDI & External debt

The ramifications of external debt on spending in social sectors, particularly health and education, have been scrutinised by scholars. Zaghdoudi's work demonstrates that research on living standards has been a focal point for studies conducted by researchers, the diverse studies have yielded varying conclusions about whether external debt positively or negatively affects human development or has no significant influence.

For example, Rojas-Suarez' (2015) study investigates the direct outcomes of external debt and foreign direct investment on human development as measured by HDI. However, this study employs a linear regression model, limiting its ability to identify threshold effects or reductions in HDI beyond specific debt thresholds.

In contrast, in 2018, Zaghdoudi used a panel dataset containing information from 95 developing nations collected between 2002 and 2015 to explore the relationship between external debt and the human development index between developing countries. By employing a Panel Smooth Threshold Regression (PSTR) model, this research reveals that this relationship is non-linear, indicating that there is an optimal external debt threshold at 41.7775%. Up to this threshold, external debt has a positive impact on human development (Zaghdoudi, 2018). Furthermore, in 2020, Osoro conducted a study to ascertain the optimal threshold for external debt that enhances HDI. This study employs regression analysis and examines annual data series from Kenya spanning from 1970 to 2018, ultimately identifying an optimal external debt threshold of 45% for optimising HDI (Osoro, 2020).

In summary, based on the outcomes of the aforementioned studies, the hypothesis (H_2) posits that external debt influences HDI in Less Developed Countries (LDCs).

Hypothesis (H_2) – ***External debt is influencing HDI in LDC***

2.3. HDI & Global Adaptation Index

According to the Intergovernmental Panel on Climate Change (IPCC) Glossary from 2014, adaptation is the process of adjusting to a changing climate. This procedure includes a number of costs and calls for financial commitment from both the public and private sectors (Sutton et al., 2011). An open-source, free index called the Notre Dame-Global Adaptation Index (ND-GAIN) Country Index illustrates a nation's current susceptibility to climate change. Additionally, it evaluates whether a nation is prepared to use both public and private investment for adaptive measures (Chen et al., 2015).

ND-GAIN combines over 74 factors to provide 45 main indicators that analyse the capability and vulnerability of 192 UN member states between 1995 and the present (Due to data availability, ND-GAIN measures vulnerability of 182 countries and availability of 184 countries). The country-level rankings and supporting data from ND-GAIN are used by corporate, NGO, government, and development decision-makers to make strategic operational and reputational decisions on supply chains, capital projects, policy changes, and community activities.

Recently, according to ND-GAIN, adaptation readiness is the capacity "to utilise investments for adaptation measures effectively as a result of a safe and effective business environment". Economic, governmental, and societal factors are used to evaluate adaptation capacity. These interpretations and definitions are in line with the IPCC's assertions that adaptable capacity and adaptation capability strongly complement each other.

In conclusion, considering the results of the aforementioned studies, we formulate and conduct empirical testing on the following hypothesis:

Hypothesis (H_3) – ***The LDCs vulnerability to global challenges in combination with them readiness to improve resilience influences HDI***

2.4. HDI & CO2 emissions

In the thirtieth centenary version of the statement, the HDI comprises two more features such as a nation's CO_2 emissions and its physical footprint, together with the former 3—living standards, education, and the nation's health. The Inter-Governmental Panel on Climate Change (IPCC) declared in 2013 that CO_2 emissions are the biggest source of global warming. The "Kyoto Protocol," which was signed by more than 100 nations in 1997, set a goal of lowering CO_2 emissions in order to protect developed economies from the harmful impacts of global warming (Javaid et al., 2022).

The theoretical underpinnings suggest that CO_2 emissions pose great risks to the prosperity of humans on this planet (Hasanov et al., 2021). Academics believe that fundamental human needs such as health, food security, and economic development could be hindered as CO_2 emissions rise. They recommend that countries around the world take actions to reduce their CO_2 emissions by engaging in activities that are friendly to the environment.

The empirical out-come suggests that an increase in CO_2 emissions has a negative impact on HDI. In 2016, by covering the time span from 1992 to 2011, Bedir and Yilmaz explore the unidirectional causality between CO_2 emissions and HDI in the context of nine OECD countries. They argue that if policymakers want to dampen the negative consequences of CO_2 emissions on HDI, they must ensure the efficient use of energy (Bedir & Yilmaz, 2016). Likewise, Asongu et al. (2019) assert that Information Communication Technologies (ICT) diminish the negative effects of CO_2 emissions on HDI (Asongu et al., 2017). Moreover, Boogaard et al. (2017) shown that environmental degradation negatively affects life expectancy and human health (Boogaard et al., 2017).

Asongu (2017) investigated how CO_2 emissions impact HDI. The study divides the world into categories based on a variety of essential traits, including political stability, income level, geographic location, legal status, and religious affiliation. The empirical findings indicate that CO_2 emissions are harmful to people's health and welfare and negatively impact the HDI in each of these situations (Asongu et al., 2018). Also, Asongu and Odhiambo examined how CO_2 emissions affect the HDI in 44 sub-Saharan African countries in the period 2000–2012, resulting CO_2 emissions have a negative impact on HDI (Asongu & Odhiambo, 2019).

Mohmmed et al. (2019) reveal that causality does exist between CO_2 emission and HDI by using the data of ten top CO_2 emitting countries (USA, Russia, Saudi Arabia, Iran, Japan, South Korea, Germany, China, Canada, and India). Taking a sample of several nations as an example, Yumashev et al., (2020) analysed the effect of population energy consumption quality and volume on the HDI. Using the 3SLS method, they proved that there is a connection between the quantity of energy used, the HDI, and the environment - CO_2 emissions into the atmosphere.

Finally, the recent study by Yu and Qayyum, in 2022, a cross-country panel data consisting of 158 economies during the period between 2004 and 2017, shows the long-run dynamics between CO_2 emission, and HDI by constructing a variable PVAR model. The impacts of HDI on carbon emission are positive (HDI enhancement can increase carbon emission), but also negative (increasing HDI can restrain more carbon

emission) (Yu & Qayyum, 2022). Nowadays, the term CO_2 emissions widely appear in the economic literature associated with the environmental quality across the globe and ecological footprint.

In summary, given the findings from the studies mentioned earlier, we propose and then empirically examine the following hypothesis.

Hypothesis (H_4) – ***The LDCs vulnerability to climate change influences HDI***

3. Data and methodology

3.1. Data

To study the way in which corruption and global challenges affect sustainability, annual data of 22 Least Developed Countries (LDC), between 2003 and 2019, were analysed based on data availability. The countries included in the sample are former British Commonwealth colonies (Bangladesh, Rwanda, Uganda, and Tanzania); others were French or Portuguese colonies (Benin, Burundi, Comoros, Guinea, Mozambique, Madagascar, Mali, Mauritania, the Democratic Republic of the Congo, Togo and Senegal), Angola, Bangladesh, and Nepal are in the process of graduating from LDC status and Comoros, Cambodia, Senegal met the graduation thresholds for the first time in 2021.

Human Development Index (HDI) was chosen as a composite indicator of human development, inextricably linked to sustainability, because the HDI captures the sustainable dimension of human development (Neumayer, 2001). Corruption was analysed by a proxy variable, *control of corruption*, while global challenges addressed in this paper are represented by the following variables that are considered to influence human development process, as the literature studied in this paper revealed: a macroeconomic indicator that highlights the degree of external indebtedness of a state (*external debt*); an index of the ability to adapt to climate changes that support life and the willingness to invest in adaptation (*Global Adaptation Index*); an indicator of environmental degradation (represented by *CO2 emissions*).

Table 1 presents the description of the variables and data sources.

Table 1. Variable and source of data

Variables	Symbol / measure	Description (defined by the issuer)	Data source
Dependent variable			
HUMAN DEVELOPMENT INDEX	HDI / index	"HDI represents a summary measure of achievements in three dimensions of human development: long and healthy life, knowledge and decent standard of living."	The Human Development Report of the United Nations Development Programme (https://hdr.undp.org)
Independent variable			
CONTROL OF CORRUPTION	Control of corruption / index	"It captures perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as "capture" of the state by elites and private interests."	The World Bank - Worldwide Governance Indicators (http://info.worldbank.org/governance/wgi/)

Variables	Symbol / measure	Description (defined by the issuer)	Data source
EXTERNAL DEBT	External debt / % of GNI (Gross National Income)	"It is the sum of public, publicly guaranteed, and private nonguaranteed long-term debt, use of IMF credit, and short-term debt as a share of GNI."	United Nations Statistics Division, National Accounts Main Aggregates Database (https://unstats.un.org/unsd/nationalaccount/data.asp) via The World Bank, World Development Indicators Database
GLOBAL ADAPTATION INDEX	Global Adaptation index / index	"GA index is based on 45 indicators capturing climate change vulnerability in life-supporting sectors and readiness to invest in adaptation. It is provided by University of Notre Dame, Notre Dame Global Adaption Initiative."	United Nations Statistics Division, National Accounts Main Aggregates Database (https://unstats.un.org/unsd/nationalaccount/data.asp)
CO_2 EMISSIONS	CO_2 emissions / metric tons per capita	"They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring."	The World Bank (https://data.worldbank.org/indicator/EN.ATM.CO2E.PC)

Source: Authors' processing.

The reason for introduction control variables in the studied model is that they influence human development process.

The basic summary statistics is presented in Table 2.

Table 2. Descriptive statistics

Variables	Obs.	Mean	Std. Dev.	Minimum	Maximum
HDI	374	0.45	0.057	0.351	0.527
Control of corruption	374	-0.818	0.294	-1.27	-0.34
External debt	374	43.153	23.605	17.974	87.551
Global Adaptation index	374	37.037	2.255	33.014	39.924
CO_2 emissions	374	0.253	0.18	0.056	0.609

Source: Authors' processing.

To increase the quality of the regression models, all variables were winsorised (95% winsorisation) to remove outliers.

Based on the Human Development Index, the countries were grouped into five clusters, which gather the countries with the lowest values of the indicator in the first cluster and the increasing results in the following:

- Cluster 1: Sierra Leone, Burundi, Mozambique, Mali, Niger
- Cluster 2: Guinea, Gambia, Democratic Republic of Congo, Haiti
- Cluster 3: Madagascar, Senegal, Togo, Benin
- Cluster 4: Mauritania, Rwanda, Uganda, Tanzania
- Cluster 5: Angola, Cambodia, Nepal, Bangladesh, Comoros (the island country does not appear on the map because it has a very small territory)

Also, the analysed countries were grouped into five clusters based on the Control corruption indicator (the worst corruption control results in the first cluster and a better corruption control in the following ones), as follows:

- Cluster 1: Cambodia, Democratic Republic of Congo, Uganda, Burundi, Haiti
- Cluster 2: Guinea, Madagascar, Angola, Bangladesh
- Cluster 3: Togo, Mozambique, Mauritania, Mali
- Cluster 4: Tanzania, Niger, Nepal, Sierra Leone
- Cluster 5: Gambia, Benin, Senegal, Rwanda, Comoros (the island country does not appear on the map because it has a very small territory)

3.2. Model specification

To discover the causal nexus between HDI and corruption, a panel data model was developed as follows:

$$HDI_{i,t} = \propto_0 + \propto_1 Control\ of\ corruption_{i,t} + u_{i,t} (1)$$

In line with the previous studied literature (section2), three indicators are used as control variables in the main regression specifications: the External debt, the Global Adaptation index, and the CO_2 emissions.

$$HDI_{i,t} = \propto_0 + \propto_1 Control\ of\ corruption_{i,t} + \propto_2 External\ debt_{i,t} + \propto_3 Global\ Adaptation\ index_{i,t} + \propto_4 CO2\ Emissions_{i,t} + u_{i,t} (2)$$

In Equations (1) and (2), *i* represents the country, *t*is the period and $u_{i,t}$ is the error term.

First, to maintain the data validity and the robustness of the regressed results of the study, the **basic classical linear regression model (CRLM) assumptions** must be misspecification and correct them.

- ***Assumption 1***: Unit root test, the stationarity of the data based on the first-generation unit root tests (Levin-Lin-Chiu test, Fisher-type unit root test based on Phillips-Perron tests, Fisher-type unit root test based on Augmented Dickey-Fuller tests);
- ***Assumption 2***: The multicollinearity between variables, through the correlation matrix and the Variance Inflation Factor (VIF-test);
- ***Assumption 3***: The homoscedasticity test in the data based on the Breusch-Pagan test and the White test;
- ***Assumption 4***: The autocorrelation test, to verify the serial correlation in the proposed linear panel-data using Wooldridge test;
- ***Assumption 5***: The co-integration tests based on Kao and Pedroni tests, to study if it is a long-term equilibrium among variables;
- ***Assumption 6***: The normality test, to check if the errors of prediction are normally distributed, based on the Skewness/Kurtosis tests for normality.

Second, the analysis of the relationship between the variables was carried out gradually based on several regression models, having a starting point the Ordinary Least Squares (OLS) regression model. Next, the comparison between the Fixed Effects (FE) and the Random Effects (RE) models, based on the Hausman test, led to the choice of the Random Effects model as appropriate. The relationship between the variables was also tested using some specific models of panel data, namely the Feasible Generalised Least Squares (FGLS), Pooled OLS with the Panels Corrected Standard Errors (PCSE), and the Pooled OLS with Driscoll-Kraay Standard Errors. Testing each of these methods was based on either certain violated assumption of classical regression models (e.g., heteroscedasticity, serial correlation, and normality), findings of the Pesaran cross-sectional dependence test or the Breusch-Pagan Lagrange multiplier test results (on the basis of which the Pooled OLS model was considered appropriate).

Some problems of econometrics occur from estimating Equation (2), regarding the fact that the variables could be endogenous and could be correlated with the error term. Also, the panel data contains a short observation length (T = 17) and a larger number of countries (N = 22). These aspects may cause OLS estimator inconsistent and biased, while Fixed Effects and Random Effects models cannot deal with endogenous variables, but the 2SLS estimator requires some appropriate instrumental variables which are out of independent variables in the model (Nguyen, 2021).

Third, based on the endogenous potential of the variables, the Two-Stage Least Squares (2SLS) and the Generalised Method of Moments (GMM) models were applied.

4. Results and discussion

Testing the basic classical linear regression model (CRLM) assumptions, as established in the previous subsection, involved the application of specific tests and their interpretation, as shown below.

Assumption 1. The preliminary investigation of the variables involves the studying of the stationarity of data (Table 3) through LLC Levin-Lin-Chu unit-root test, Fisher test based on Phillips-Perron approach that use nonparametric adjustment for short-term dynamics and the Augmented Dickey-Fuller tests, which take care of short-term dynamics in a parametric way.

Table 3. Unit root tests: 2003-2019 (22 Least Developed Countries)

Variables	Panel unit root tests		
	Levin-Lin-Chu	Phillips-Perron-Fisher chi-square	Augmented Dickey-Fuller-Fisher chi-square
	Statistic		
HDI	-8.1144***	83.9174***	117.1821***
Control of corruption	-1.8608**	74.2099***	54.4245
External debt	-6.8616***	53.7711	95.1152***
Global Adaptation index	-1.6001*	78.0499***	54.7370
CO_2 emissions	-1.6505**	42.1009	34.3914

Note: ***, ** and * denote significance at 1, 5 and 10 percent level respectively.
Source: Authors' processing.

The variables are stationary according to most of the results presented in Table 1. The null hypothesis of LLC test for stationarity is rejected for all variables, while based on the other two tests, and some of the variables contain unit roots (Control of corruption – ADF test, External debt – PP test, Global Adaptation index – ADF test and CO_2 emissions – PP and ADF tests).

Assumption 2. Next step was the studying the correlation between variables and the results suggest that the dependent and explanatory variables are not correlated, as it results from the correlation matrix, that shows low values of the correlation coefficients between the variables. In addition, the variance inflation factor (VIF) indicates the absence of multicollinearity, which eliminates the risk of spurious correlations from occurring. The mean of VIF is 1.28, which is below the threshold level, approximately5, according to the main approach in the area.

Assumption 3. Data testing also involved the heteroscedasticity analysis, based on the Breusch-Pagan test and the White test, which generated contradictory results. According to the results of the Breusch-Pagan test, the probability value of the chi-square statistic is greater than 0.05 and therefore the null hypothesis of constant variance cannot be rejected at 5% level of significance, which denotes no heteroscedasticity in the residuals. Contrary to these results, the output of the White test, the null hypothesis of constant variance, can be rejected at 5% level of significance, which suggests that there is heteroscedasticity in the residuals. Given the fact that the Breusch-Pagan test assumes that the heteroscedasticity is a linear function of the independent variables, while the White test involves a nonlinear effect on the error variance, the results of the last test are considered and the presumption of heteroscedasticity is accepted, so its correction is based on the running an OLS regression with option robust.

Assumption 4. To identify serial correlation in the idiosyncratic error term in the model, a modern test of Wooldridge was applied. The results suggest that the null hypothesis of no serial correlation is strongly rejected, and there is serial correlation in the idiosyncratic error term.

Assumption 5. To study if it is a long-term equilibrium among variables, two co-integration tests were applied, respectively Kao and Pedroni. The findings from the Kao test confirm the existence of a long-run cointegration relation between variables, all five statistical tests strongly confirm the cointegration. Also, the outcome of the Pedroni panel cointegration test indicates the same conclusion of the cointegration between the analysed variables.

Assumption 6. To test the normality of variables, Skewness and Kurtosis tests were carried out. Based on the results the null hypothesis of the normally distribution of the variables was rejected. Each variable violates the univariate normality assumption.

To obtain accurate regression results, after testing the data and interpreting the obtained results, based on the above assumptions specific to the classical regressions, the next stage involves the effective development of some regression models considered to be adequate to the data of the proposed model. The synthetic

results of classical assumption testing of linear regression show the stationarity of data, the absence of multicollinearity, the heteroscedasticity in the residuals, the serial correlations, the cointegration relations between variables and the normality of data.

To explore the relationship between the variables that cover some major issue - economic, environmental and climate change adaptation – and human development, we initially develop an Ordinary Least Squares model (OLS) with robust option, followed by Fixed Effects (FE) model and Random Effects (RE) model (Table 4).

Table 4. Ordinary Least Squares (OLS) robust, Fixed Effects (FE) and Random Effects (RE) models

	(Model 1)	***(Model 2)***	***(Model 3)***
HDI	**Ordinary Least Squares (OLS)**	**Fixed Effects (FE)**	**Random Effects (RE) (*p = 0.0941 Hausman)***
Control of corruption	-0.04472***	-0.01477	-0.01651*
	(0.00765)	(0.00913)	(0.00883)
External debt	-0.00118***	-0.00091***	-0.00093***
	(0.00008)	(0.00006)	(0.00006)
Global Adaptation index	0.01011***	0.00484***	0.00506***
	(0.00106)	(0.00145)	(0.00137)
CO_2 emissions	0.10187***	0.20264***	0.18914***
	(0.01146)	(0.01856)	(0.01718)
Constant	0.06394	0.24660***	0.24094***
	(0.04209)	(0.05752)	(0.05458)
Obs	374	within=0.5835	within=0.5829
R^2	0.5383	between=0.4287	between=0.4399
		overall=0.4680	overall=0.4780

Note: Standard errors in parentheses; ***, ** and * denote significance at 1, 5 and 10 percent level respectively.
Source: Authors' processing.

In the OLS model, statistical significance was obtained for all the analysed variables (except the constant), at the level of 0.01%. An initial comparative examination of the statistical significance of the variables (and constants) of the Fixed Effects and Random Effects models shows that in the Random Effects model this was obtained, while in the Fixed Effects model, the control of corruption variable is not statistically significant. The application of the Hausman test, which shows the appropriateness of one of the two models, revealed that the Random Effects model is the appropriate one.

Table 5. Breusch-Pagan Lagrange multiplier test for Random Effects

Breusch-Pagan Lagrange multiplier test for Random Effects	
H_0: var(u) = 0	
chibar2	*1289.88*
Prob > chibar2	*0.0000*

Source: Authors' processing

Once identifying the Random Effects model as the most suitable up to this stage of development of the research of the regression models initially tested, the Breusch-Pagan Lagrange multiplier test for Random Effects was applied (Table 5), which supports the choice between random effect mode or a new regression model, namely Pooled OLS. The null of this test is that the variance of the random effect is zero and the findings shown that no Random Effect model is the most suitable. The results show that the Pooled OLS method is adequate for the panel.

Because the default assumption in the Random Effects model established above as suitable is that the cross-sectional units are independent, the testing of the cross-sectional independence hypothesis was carried out by using the Pesaran test. The null hypothesis of no cross-sectional dependence is strongly rejected, and the average absolute value of the residuals is high. In conditions of cross-sectional dependence, it is necessary to test the Panel Corrected Standard Errors model.

Based on the results obtained, the following regression models will be tested as a reaction to the results of the Breusch-Pagan Lagrange multiplier test, which adequately indicates ***Pooled OLS model*** and in the presence of heteroscedasticity (Assumption 3), serial correlation (Assumption 4), normality (Assumption 6) and cross-sectional dependence:

- Feasible Generalised Least Squares (FGLS);
- Pooled OLS with Panel Corrected Standard Errors (PCSE);
- Pooled OLS with Driscoll–Kraay Standard Errors.

These mentioned regression models try to treat the problems of heteroscedasticity of the data, but they are suitable for a certain type of panel's time dimension. The following two tested methods – Pooled OLS with PCSE Panels Corrected Standard Errors and with Driscoll–Kraay Standard Errors – present the same type of outcomes, which are appropriate for the dimensions of the panel studied in this paper (Table 6). Besides being heteroskedasticity consistent, these Pooled OLS methods are also effective for cross-sectional dependence, respectively for serial correlation.

Table 6. Feasible Generalised Least Squares, Pooled OLS with Panel Corrected Standard Errors, and Pooled OLS withDriscoll-Kraay Standard Errors models

	(Model 4)	***(Model 5)***	***(Model 6)***
HDI	**Feasible Generalised Least Squares (FGLS)**	**Pooled OLS with Panels Corrected Standard Errors (PCSE)**	**Pooled OLS with Driscoll–Kraay Standard Erors**
Control of corruption	-0.04294***	-0.04472***	-0.04472***
	(0.00103)	(0.00762)	(0.00762)
External debt	-0.00116***	-0.00118***	-0.00118***
	(0.00001)	(0.00011)	(0.00011)
Global Adaptation index	0.01000***	0.01011***	0.01011***
	(0.00010)	(0.00083)	(0.00083)
CO_2 emissions	0.10160***	0.10188***	0.10188***
	(0.00194)	(0.00902)	(0.00902)
Constant	0.06890***	0.06394**	0.06394*
	(0.00377)	(0.03161)	(0.03161)
Obs	374	374	374
R^2		0.5383	0.5383

Note: Standard errors in parentheses; ***, ** and * denote significance at 1, 5 and 10 percent level respectively.

Source: Authors' processing.

The comparative analysis of the results of the tested regression models gradually shows that starting from the Ordinary Least Squares (OLS) model and continuing with regression models that consider the properties of the data (heteroscedasticity, serial correlation, normality, cross-sectional dependence) outcomes continue to be statistically significant in all the tested models. The Pooled OLS models (with Panel Corrected Standard Errors and with Driscoll–Kraay Standard Errors) prove to be the most suitable for the studied panel, up to this stage of research.

There is evidence of a negative correlation between the Control of corruption and the Human development index, which indicates that the decrease in the degree of corruption control contributes to the growth of the Human Development Index. These results are in line with previous research. The H1 hypothesis is confirmed.

Regarding the influence of External debt on the Human Development Index, it is characterised by a negative relationship, in the sense that the more indebted the country is, the lower the degree of human development. The H2 hypothesis is validated.

The state's degree of global adaptation to climate vulnerabilities that support life and the willingness to invest in adaptation contribute to the growth of the Human Development Index. The H3 hypothesis is confirmed.

The decrease in CO2 emissions contributes to the enhancement of the Human Development Index, which shows results in accordance with the literature (Wang et al., 2018) and leads to the validation of the H4 hypothesis.

The next stage of the study involved testing the link between variables using models in which regressors are endogenous: the Two-Stage Least Squares (2SLS), Limited-Information Maximum Likelihood (LIML), and Generalised Method of Moments (GMM). ***Two-Stage Least Squares (2SLS)*** model (Cumby et al., 1983) has the potential to correct serial correlation (Assumption 4), the ***Generalised Method of Moments (GMM)*** option uses a more general matrix that leads to obtaining an efficient estimator and under conditions of conditional heteroscedasticity, while the ***Limited-Information Maximum Likelihood (LIML)*** estimator may yield less bias and confidence intervals with better coverage rates than the 2SLS estimator. Two explanatory variables were considered endogenous, namely the Global Adaptation index and the CO_2 emissions.

To correct the endogeneity, some instruments (instrumental variables IVs) were used (Table 7).

Table 7. 2SLS models

HDI	***(Model 7)*** **2SLS**	***(Model 8)*** **2SLS- GMM**	***(Model 9)*** **2SLS – LIML**
Control of corruption	-0.17971*** (0.02467)	-0.18100*** (0.02537)	-0.17993*** (0.02471)
External debt	-0.00182*** (0.00020)	-0.00183*** (0.00022)	-0.00182*** (0.00020)
Global Adaptation index	0.04645*** (0.00551)	0.04668*** (0.00560)	0.04651*** (0.00552)
CO_2 emissions	-0.12433*** (0.04800)	-0.12658*** (0.04872)	-0.12476*** (0.04808)
Constant	-1.30741*** (0.20831)	-1.31610*** (0.20999)	-1.30964*** (0.20871)
N	374	374	374
Tests of endogeneity of variables – *p-value*	Durbin *0.0000* Wu-Hausman *0.0000*	GMM C statistic *0.0000*	Not applicable
Test of overidentifying restrictions – *p-value*	Sargan *0.7595* Basmann *0.7613*	Hansen *0.7606*	Anderson-Rubin *0.7596* Basmann *0.7616*
Test of weak instruments *Minimum eigenvalue statistic* *Shea's adj. partial R^2* *- CO_2 emissions* *- Global Adaptation index*	*21.6848 > critical values* *0.2498* *0.1509*	Not applicable *0.2498* *0.1509*	*21.6848 > critical values* *0.2498* *0.1509*

Note: Standard errors in parentheses; ***, ** and * denote significance at 1, 5 and 10 percent level respectively.

Source: Authors' processing.

The results of the Two-Stage Least Squares (2SLS), Generalised Method of Moments (GMM) and Limited-Information Maximum Likelihood (LIML) models are all statistically significant at the level of 1% (including the constant). The meaning of the evolution between variables, identified in the first regression models previously tested is preserved in the case of 2SLS models. A significant reduction of standard errors and an increase in the values of the correlation coefficients is recorded for the 2SLS type models.

A first postestimation test for endogeneity of the variables, based on the Durbin and Wu-Hausman method (Cameron & Trivedi, 2009) and GMM C statistic (Hayashi, 2000), assumes that the null hypothesis is that the mentioned variables are exogenous. In this case, the hypothesis is rejected, so the variables are endogenous (for the LIML method, the test of endogeneity is not applicable). Considering that instruments must be uncorrelated with the structural error term, the second postestimation test is a test of overidentifying restrictions. The test also analyses whether the equation is miscalculated and whether one or more of the variables that were excluded should have been included in the model. In this case, the null hypothesis could not be rejected and that none of the statistical tests are significant at the level of 5%, which shows that the model is correctly specified and that the instruments are valid. To obtain some statistics for the power of the instruments, a third postestimation test of weak instruments was made. The null hypothesis of weak instruments is rejected.

The reason for using the ***Difference and System Generalised Method of Moments (GMM)*** method (Table 8), as in the case of the 2SLS, is that of the suspicion that certain explanatory variables could be endogenous and given the normality of data.

Table 8. Difference and System GMM models

	(Model 10)	***(Model 11)***
HDI	**Difference GMM**	**System GMM**
L.HDI	0.87989***	0.88949***
	(0.01587)	(0.01832)
Control of corruption	-0.00478***	-0.00687***
	(0.00083)	(0.00057)
External debt	-0.00018***	-0.00016***
	(0.00002)	(0.00002)
Global Adaptation index	-0.00022	0.00125***
	(0.00014)	(0.00032)
CO_2 emissions	0.01767**	0.01942**
	(0.00731)	(0.00955)
N	330	352
Sargan	20.224	19.478
	(1.000)	(1.000)
AR1	0.021	0.011
AR2	0.112	0.121

Note: Standard errors in parentheses; ***, ** and * denote significance at 1, 5 and 10 percent level respectively.
Source: Authors' processing.

The results show a statistically significant relationship between dependent variable and its first lag and between dependent variable and the explanatory variables. The post-estimation test for no autocorrelation in first-differenced errors showed rejection of the null hypothesis of no serial correlation in the first-differenced errors at order 1 and no significant evidence of serial correlations in the first-differenced errors at order 2. The Sargan test of overidentifying restrictions did not lead to the rejection of the null hypothesis that overidentifying restrictions are valid.

5. Conclusions

This article examined the vulnerability to corruption and global challenges affect sustainability in the case of LDCs, an area insufficiently investigated in the literature. Out of the 46 Least Developed Countries (LDCs) designated by the UN General Assembly in this category and taking into account the 17-year period and data availability, our sample consisted of data for 22 LDCs. The sustainability was investigated through HDI, so when the regression model was run with control variables included, such as External Debt, Global Adaptation Index (the Ntre Dame GAI), and CO_2 emission, our findings revealed that indicate that negative correlation between the Control of corruption and the Human development index, which indicates that the decrease in the degree of corruption control contributes to the growth of the Human Development Index, regarding the influence of External debt on the Human Development Index, it is characterised by a negative relationship, in the sense that the more indebted the country is, the lower the degree of human development; state's degree of global adaptation to climate vulnerabilities that support life and the willingness to invest in adaptation contribute to the growth of the Human Development Index; decrease in CO_2 emissions contributes to the enhancement of the Human Development Index.

Based on our findings, we can draw the conclusion that policymakers in Least Developed Countries (LDCs) should prioritise the significance of a stable legislation with regard to the corruption, and anti-corruption attainment to enhance the demand of their countries for a more sustainable lifestyle and future. To achieve this, it is necessary to improve the quality and accessibility of educational programs through well-crafted public policies implemented by responsible institutions. Additionally, policymakers should place greater emphasis on factors that facilitate adjustments in the states' degree of global adaptation, considering the substantial and positive impact of the decrease in CO_2 emissions in achieving a more sustainable lifestyle necessary to stimulate economic development in LDCs.

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