Climate change, economic security, and macroeconomic stability: Insights from the EU

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Abstract. This research examines the impact of climate change risks on the macroeconomic situation and the security of the economic system in the EU-27 during the 2002-2020 period. By employing methodologies such as the Ordinary Least Squares and Principal Component Analysis, the study evaluates the interrelationship between Climate Change Risk (CCR), Macroeconomic Situation (MS), and Economic System Security (ESS). The research develops composite indicators to analyse these phenomena in detail, while results reveal significant variations in CCR, MS, and ESS among EU member states, indicating a heterogeneous response to climate risks and economic stability and highlighting the need for differentiated policy approaches. Our research contributes to understanding the impacts of climate change on economic structures by providing insights into policy formulation and strategic planning to strengthen economic resilience and emphasising the need for an interdisciplinary approach that connects climate variables with economic indicators. The strategic alignment at national levels supports global sustainability efforts and ensures a unified and effective response to climate risks within the European economic system.

1 Introduction

Climate change represents one of the pressing global issues of our time because it threatens natural ecosystems and poses a major challenge to global economic stability. Extreme weather events may significantly destroy infrastructure and disrupt global supply chains, leading to direct and indirect economic losses. Furthermore, climate change can irreversibly alter economic landscapes by affecting key sectors particularly sensitive to climatic conditions, such as agriculture, fisheries, or tourism [1].

At the international level, climate fluctuations can aggravate political and social tensions, leading to forced migration and even conflicts [2, 3]. Populations affected by drought are

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often forced to migrate, leading to overcrowding in urban areas or conflicts over limited resources in their regions. Accordingly, decision-makers should integrate climate risks into economic planning and national security strategies. More specifically, robust policies may promote adaptation and economic resilience, mitigating the direct effects of climate change and minimising indirect socio-economic impact by supporting macroeconomic stability and ensuring an effective response to these global challenges.

Our research makes important contributions to the field of climate change, economic security, and macroeconomic stability, by implementing innovative methodological approaches. Firstly, the paper provides an overview of the literature, examining specific articles published on these concepts and inter-relationships. This initial analysis, developed in the second section of the paper, serves as a reference point for understanding the evolution and trends in the study of the interrelationship between climate and the economy, highlighting the need for a new approach to respond to the increased dynamics and complexity of climate risk.

Our paper addresses an important topic of climate change because it underlines contemporary concerns about sustainability and economic stability. In a context where the impact of climate change on the environment and society is becoming increasingly visible and critical, our research aims to explore how these changes affect essential macroeconomic indicators. By analysing the impact of climate change on the economy, the paper makes a significant contribution to a vital field of study, providing valuable perspectives and recommendations for formulating effective policies, counteracting adverse effects and promoting adaptation to new climatic conditions. Our approach responds to the need to deeply understand the interaction between climate and economy but also offers pragmatic solutions for adaptability and mitigation of climate challenges and risks.

The third section presents a detailed empirical analysis of data from the EU-27 member states over the period 2002-2020. Our analysis employs advanced statistical and econometric methodologies to evaluate the interactions between Macroeconomic Situation (MS), economic system security (ESS), and Climate Change Risk (CCR). By means of composite indicators and regression analysis, the study emphasises trends and correlations that contribute to understanding the impact of climate change on national economies.

In the fourth section, the paper synthesises and interprets the results obtained. This section highlights the study's main findings, illustrating how macroeconomic variables directly affect climate change. It provides a solid foundation for formulating policy and strategic recommendations. The fifth section concludes and offers strategic recommendations for addressing the impact of macroeconomic stability on climate change risks.

2 Literature Review

The interaction between climate change, macroeconomic stability, and the security of the economic system represents an essential field of study with major implications for both contemporary economy and environmental policies. Climate change is a threat not only to the surrounding environment but also to economic stability, affecting essential macroeconomic variables such as GDP growth, inflation, and employment [1]. This leads to increased economic volatility and uncertainty. Additionally, the macroeconomic situation influences the capacity to respond and mitigate the effects of climate change, directly impacting investments in sustainable technologies and resilience measures. Economic security depends on adaptability to climate shocks. Economies that fail to adapt face increased risks of systemic disruptions, with long-term effects on economic growth and stability. Understanding these interdependencies is crucial for developing effective strategies that address climate risks and promote economic growth.

The term “Climate Change Risk” refers to the complex challenges generated by changes in the Earth's climate, affecting both natural and human ecosystems. Risks stem from the interaction between specific climatic hazards such as sea-level rise and global temperatures and the vulnerability of communities and natural habitats [4, 5]. The “Macroeconomic Situation” describes the broad and general context in which significant events, prevailing trends, or critical decisions occur, profoundly impacting outcomes in various fields, including economics, politics, and social structures. In economics, it reflects the state and direction of a nation or the global economy, encompassing essential indicators such as GDP growth, inflation rates, trade balances, and fiscal policies. The term “Economic System Security” refers to the capacity of an economic system to remain stable, resilient, and robust in the face of vulnerabilities [6]. This involves the system's adaptability to sudden shocks such as financial crises, natural disasters, or geopolitical events, as well as the ability to sustain a sustainable growth trajectory [7].

Häyhä et al. [8] explores how to translate the planetary boundaries framework globally into national and regional contexts for effective environmental governance. Government policies during the COVID-19 pandemic proved a significant reduction in global CO_2 emissions [9, 10]. For example, various fiscal recovery strategies had the potential to either reinforce a fossil fuel-intensive economy or transition to a cleaner energy system [11]. Schwalm et al. [12] discuss the relevance of the Representative Concentration Pathway (RCP) 8.5 scenario in climate modelling, due to continuous growth in energy demand and reliance on fossil fuels, emphasising the importance of major advancements in technology and reliance on significant changes in public policies. Due to the impact of renewable and non-renewable energy consumption on the ecological footprint [13] clear focus on evaluating various sustainable hybrid renewable energy systems for electricity production is clearly needed after uncovering the undebatable relationship between energy consumption, industrialisation, and CO_2 emissions [14, 15].

The impact of different long-term climate policies on global energy security has already been studied over the past decade and there are clear effects of these policies based on various assumptions regarding GDP growth and fossil fuel availability [16]. For example, the automotive industry's response to climate change concerning regulatory pressures, internal governance, and corporate strategies [17], while the efficiency of environmental policies, particularly market-based and non-market instruments, in reducing environmental damage associated with economic growth [18].

The European Central Bank [19] examines the impact of climate change on monetary policy in the Eurosystem, but there is also clear interaction between economic growth and environmental sustainability. The current challenges faced by cities, including congestion, pollution, and waste management, identify key interventions that can address these issues while mitigating climate change [20]. Therefore, we can refer to an intersection of climate change mitigation and fiscal policy [21], proving the effectiveness of environmental taxes in European countries leading in the environmental performance index [22], but also to how financial globalisation and the complexity of economic relationships have made economies more susceptible to crises, highlighting the importance of auditing in this context [23].

A comprehensive examination of the literature reveals that climate change risk is deeply entrenched in vast scientific research. The predominant focus is on essential factors such as CO_2 emissions, energy consumption patterns, and the varied outcomes resulting from different mitigation and adaptation strategies implemented globally, as well as their linkage with numerous phenomena describing economic situation and security.

3 Methodology

Considering climate change risk as reflective of the potential negative effects on the environment and society due to changing climatic conditions, the macroeconomic situation as the general state and performance of a country's economy, and the stability of the economic system as reflecting the resilience and consistent functioning of an economy ensuring sustainable growth and capacity to withstand shocks, we utilised Principal Component Analysis in Q Research Software and econometric analysis with EViews software. Given the objectives of this paper and data availability, the first step was to select the indicators whose data availability fully met the requirements of the 2002-2020 interval. Therefore, we set 24 indicators for Climate Change Risk (CCR), eight for Macroeconomic Situation (MS), and eight for Economic System Security (ESS), as presented in Table 1. Our database includes the 27 EU member states.

Table 1. Indicators available for Climate Change Risk, Macroeconomic Situation, and Economic System Security, over the period 2002-2020

Index	Indicator	Description	Measure Unit	Source
CCR	CO2 Emissions	Includes carbon dioxide produced during the consumption of solid, liquid, gaseous fuels, and gas flaring.	Metric tons per capita	World Bank
CCR	Renewable Energy Consumption	The share of renewable energy in total final energy consumption.	% of total final energy consumption	World Bank
CCR	Precipitation	Average annual precipitation in the country.	mm per year	UN - FAO
CCR	Total Water Productivity	GDP at constant prices divided by the annual total water withdrawal.	USD 2015 GDP per cubic meter of fresh water	World Bank
CCR	Agricultural Methane Emissions	Emissions from livestock, animal waste, rice production, agricultural waste burning, and savannah burning.	Thousands of metric tons CO2 equivalent	World Bank
CCR	Total Natural Resource Rents	The sum of rents for oil, natural gas, coal (hard and soft), minerals, and forestry rents.	% of GDP	World Bank
CCR	Annual Water Withdrawal Total	Total water withdrawals.	% of internal resources	World Bank
CCR	Fossil Fuel Electricity Capacity	Installed capacity for electricity production from fossil fuels, including oil, coal, and natural gas.	Million kilowatts	World Bank
CCR	Fossil Fuel Electricity Generation	Electricity generated from fossil fuels, including oil, coal, and natural gas.	Billion kilowatt-hours	World Bank
CCR	Wind Electricity Capacity	Installed capacity for electricity production from wind.	Million kilowatts	World Bank
CCR	Wind Electricity Generation	Electricity generated from wind.	Billion kilowatt-hours	World Bank
CCR	Solar Electricity Capacity	Installed capacity for electricity production from sunlight.	Million kilowatts	World Bank
CCR	Solar Electricity Generation	Electricity generated from sunlight.	Billion kilowatt-hours	World Bank

Index	Indicator	Description	Measure Unit	Source
CCR	Hydroelectricity Capacity	Installed capacity for hydroelectricity production.	Million kilowatts	World Bank
CCR	Hydroelectricity Generation	Hydroelectricity generation, excluding pumped storage hydroelectricity generation.	Billion kilowatt-hours	World Bank
CCR	Nuclear Electricity Capacity	Installed capacity for electricity production from nuclear power plants.	Million kilowatts	World Bank
CCR	Nuclear Electricity Generation	Net nuclear electricity generation.	Billion kilowatt-hours	World Bank
CCR	Geothermal Electricity Capacity	Installed capacity for geothermal electricity production.	Million kilowatts	World Bank
CCR	Geothermal Electricity Generation	Geothermal electricity generated.	Billion kilowatt-hours	World Bank
CCR	Forest Area	Land under natural or planted tree stands of at least 5 meters in situ.	% of land area	UN - FAO
CCR	Arable Land	Includes land defined by the FAO as arable.	% of total land area	World Bank
CCR	Greenhouse Gas Emissions	Total greenhouse gas emissions in kt CO2 equivalent, comprising total CO2 emissions.	Kt CO2 equivalent	World Bank
CCR	Renewable Energy Generation	Total net electricity generation from renewable sources.	Billion kilowatt-hours	IEA
CCR	Renewable Energy Capacity	Total capacity to produce electricity from renewable resources.	Million kilowatts	IEA
MS	GDP Growth	Annual percentage growth rate of GDP	% per year	World Bank
MS	Inflation, Consumer Prices	Annual percentage change in the average cost to the consumer	% per year	OECD
MS	Economic Globalization Index	Measures the economic dimension of globalization	Scale 0-100	KOF Swiss E.I.
MS	Political Globalization Index	Measures the political dimension of globalization	Scale 0-100	KOF Swiss E.I.
MS	Social Globalization Index	Measures the social dimension of globalization	Scale 0-100	KOF Swiss E.I.
MS	Human Development Index	Measures three basic dimensions of human development: long and healthy life, knowledge, and decent standard of living.	Scale 0-1	UN-DP
MS	Capital Investments	Comprises outlays for additions to the fixed assets of the economy plus net changes in the level of inventories.	% of GDP	World Bank
MS	Household Consumption	Final consumption expenditure of households	% of GDP	World Bank

Index	Indicator	Description	Measure Unit	Source
ESS	Enrollment in Primary Schools	Total number of students enrolled in primary education institutions, public and private, regardless of age.	% of all eligible students	UNESCO
ESS	Enrollment in Secondary Schools	Total number of students enrolled in secondary education institutions, public and private, regardless of age.	% of all eligible students	UNESCO
ESS	Health Expenditure per Capita	Current health expenditure estimates include the consumption of health goods and services each year.	USD per capita	World Bank
ESS	Health Expenditure as % of GDP	Level of current health expenditure expressed as a percentage of GDP	% of GDP	World Bank
ESS	Life Expectancy	Number of years a newborn would live if current mortality patterns at the time of birth remained the same throughout life.	Years	UN-PD
ESS	Unemployment Rate	The proportion of the labor force that is without work but available for and seeking employment.	% of total labor force	World Bank
ESS	Alternative and Nuclear Energy	The share of renewable energy in total final energy consumption.	% of total energy use	World Bank
ESS	Access to Electricity	The percentage of the population with access to electricity.	% of population	World Bank

Source: data processed by the author

The next step in data processing was normalising or standardising them to calculate the composite indicators of the three phenomena. Accordingly, we have employed the Min-Max normalisation method, presented below in the first equation, to adjust the scale of the variable values. This is a common technique in data preprocessing for statistics.

$$V_{norm} = \frac{V - V_{min}}{V_{max} - V_{min}} \quad (1)$$

where:

- V is the initial data value;
- V_{norm} is the normalised value;
- V_{min} is the minimum value of the dataset;
- V_{max} is the maximum value of the dataset.

A major advantage of this method is that it preserves the ordered relationship between the original values. Normalisation is useful in data processing for machine learning models, statistical analysis, and many other fields where fair comparison between different data sets is necessary.

The weight assignment was approached using Principal Component Analysis (PCA) to construct the composite indices. This statistical technique facilitates identifying the most significant patterns in data by transforming the original set of variables into a new set of uncorrelated indicators known as principal components. These components are derived so that the first component captures the largest amount of variation present in the data set, and each subsequent component accounts for the maximum remaining variance with the restriction of being orthogonal to the previous components.

We continued data processing using the weight assignment methods established in the

OECD Handbook for Constructing Composite Indicators [24], specifically the Principal Components (PC) method, based on which we processed the data obtained in PCA by applying the following steps:

$$Qi = Vi^2$$
$$EVi = Qi_{Sum}$$
$$ETi = \frac{EVi}{EVi_{Sum}}$$
$$Ri = \frac{Qi}{EVi}$$
$$Xi = \frac{Ri}{TVC} * ETi$$
$$W = \frac{Xi_{Max}}{X_{MaxSum}} \quad (2)$$

where:

- Vi is the indicator value reported to the component following PCA;
- Qi is the squared indicator value reported to the component;
- Qi_{Sum} is the sum of Qi per component;
- EVi is the variance explained by the factor of the indicator per component;
- EVi_{Sum} is the sum of the explained variances of all components;
- ETi s the explained variance of the component divided by the total component variance;
- Ri is the rescaled indicator value per component;
- TVC is the total value of the component variance explained;
- Xi is the initial weighted coefficient of the indicator per component;
- Xi_{Max} is the maximum value taken by the indicator reported to all components;
- Xi_{MaxSum} is the sum of the maximum values of all indicators;
- W is the weighting coefficient assigned to the indicator.

The final step in our econometric analysis will be to test an ordinary least squares regression, which will overview the influence of the Macroeconomic Situation (MS) and Economic System Security (ESS) proxies on Climate Change Risk (CCR).

4 Results & Discussions

The component loadings from PCA, which measure each original variable's contribution to the principal components, were extracted to determine the weights. Therefore, tables 2, 3 and 4 illustrate the PCA conducted in Q Research Software. When evaluating the quality of a PCA model, we generally look for a balance between data simplification and retaining enough variance to make meaningful interpretations. The goal is to reduce dimensionality while capturing the essence of the original data.

Table 2. PCA of CCR Indicators

Component variance	**85.1%**	**Components**					
Indicators		C1 30.5%	C2 16.7%	C3 12.4%	C4 11.2%	C5 7.84%	C6 6.39%
Wind electricity capacity		0.976	0.139	-0.011	-0.070	-0.017	0.001
Wind electricity generation		0.955	0.130	0.011	-0.111	-0.047	-0.019
Solar electricity capacity		0.934	-0.006	-0.032	0.098	-0.013	-0.095
Solar electricity generation		0.927	0.002	-0.013	0.130	-0.053	-0.123
Renewable power capacity		0.927	0.291	0.113	0.125	-0.094	-0.071
Renewable power generation		0.835	0.404	0.225	0.170	-0.129	-0.081
Fossil fuels electricity capacity		0.796	0.266	-0.144	0.434	0.039	0.194

Fossil fuels electricity generation	0.717	0.212	-0.212	0.389	0.127	0.290
Greenhouse gas emissions	0.682	0.498	-0.199	0.300	0.101	0.247
Nuclear power generation	0.151	0.947	-0.053	-0.135	-0.021	-0.056
Nuclear electricity capacity	0.129	0.947	-0.052	-0.133	-0.024	-0.066
Agricultural methane emissions	0.536	0.748	-0.192	0.189	0.043	0.057
Hydroelectricity capacity	0.252	0.702	0.363	0.346	0.255	-0.121
Hydroelectricity generation	0.236	0.680	0.436	0.306	-0.223	-0.140
Forest area	-0.012	0.037	0.883	-0.023	-0.017	0.132
Renewable energy consumption	0.054	-0.029	0.800	-0.118	-0.391	0.021
Annual freshwater withdrawals total	0.035	-0.070	-0.783	-0.023	-0.268	0.017
Arable land	0.118	0.120	-0.580	-0.062	-0.029	0.443
Geothermal electricity generation	0.154	0.003	-0.005	0.963	-0.049	-0.084
Geothermal electricity capacity	0.170	0.005	-0.004	0.959	-0.051	-0.089
CO2 emissions	0.001	-0.096	-0.049	-0.002	0.904	0.026
Water productivity total	-0.046	-0.076	0.021	-0.110	0.732	-0.228
Total natural resources rents	-0.165	-0.132	0.179	-0.054	-0.027	0.821
Precipitation	-0.082	0.094	0.175	0.112	0.348	-0.560

Source: data processed by the authors in Q Research Software

Table 3. PCA of MS Indicators

Component variance	**64.8%**	**Components**	
Indicators		C1 40.2%	C2 24.6%
Social globalization index		0.893	-0.264
Economic globalization index		0.877	0.153
Household consumption as percent of GDP		-0.859	-0.183
Human Development Index		0.849	-0.339
Capital investment as percent of GDP		0.019	0.790
GDP growth annual %		0.009	0.725
Inflation consumer prices		-0.434	0.540
Political globalization index		0.023	-0.536

Source: data processed by the authors in Q Research Software

Table 4. PCA of ESS Indicators

Component variance	**66.2%**	**Components**		
Indicators		C1 38.4%	C2 14.1%	C3 13.7%
Health spending per capita		0.864	-0.220	-0.005
Life expectancy		0.849	-0.071	0.206
Health spending as percent of GDP		0.834	-0.005	-0.107
Secondary school enrollment		0.671	0.238	-0.081
Unemployment rate		-0.198	0.722	0.139
Alternative and nuclear energy percent of total energy use		0.140	0.669	-0.162
Access to electricity		0.454	0.121	0.718
Primary school enrollment		0.442	0.180	-0.686

Source: data processed by the authors in Q Research Software

In the first PCA analysis, where six components explain 85.1% of the variance, the percentage is considered high as it means the components have retained almost all the information from the original variables with minimal information loss. In the second PCA analysis, where two components explain 64.8% of the variance, the value is moderate. This could be considered sufficient, though over a third of the variance is not captured, meaning the model does not summarise some potentially valuable information. In the third PCA analysis with three components explaining 66.2% of the variance, the situation is similar to the second analysis. If our objective is to identify the most significant patterns or factors, 65% may be considered sufficient. However, if our goal was to understand the detailed structure of the data, higher explained variance would be needed.

As a result of the calculations, we obtained the weighted values listed in table 5, which also includes the study indicators' polarity, without which we could not establish the formula for calculating the composite indicators. In the case of positive polarity, the indicator coefficient is directly multiplied by the weight, while in the case of negative polarity, the weight is multiplied by the inverse of the indicator coefficient (1 - coefficient). Thus, we managed to calculate the three composite indicators of the studied phenomena, each with values ranging between 0 and 1, where 1 represents a positive value and 0 represents negative value. The obtained indicators will be named: CCRI – Climate Change Risk Index; MSI – Macroeconomic Situation Index, and ESSI – Economic System Security Index.

Table 5. Polarities and weights of the indicators of the three analysed phenomena

Index	Indicator	Weight	Polarity
CCR	CO2 Emissions	0.04913840	-
CCR	Renewable Energy Consumption	0.03848257	+
CCR	Precipitation	0.01885646	-
CCR	Total Water Productivity	0.03221857	+
CCR	Agricultural Methane Emissions	0.03364243	-
CCR	Total Natural Resource Rents	0.04052943	-
CCR	Annual Water Withdrawal Total	0.03686444	-
CCR	Fossil Fuel Electricity Capacity	0.03809871	-
CCR	Fossil Fuel Electricity Generation	0.03091167	-
CCR	Wind Electricity Capacity	0.05727746	+
CCR	Wind Electricity Generation	0.05483917	+
CCR	Solar Electricity Capacity	0.05245391	+
CCR	Solar Electricity Generation	0.05167061	+
CCR	Hydroelectricity Capacity	0.02963182	+
CCR	Hydroelectricity Generation	0.02780366	+
CCR	Nuclear Electricity Capacity	0.05392425	+
CCR	Nuclear Electricity Generation	0.05392425	+
CCR	Geothermal Electricity Capacity	0.05529952	+
CCR	Geothermal Electricity Generation	0.05576179	+
CCR	Forest Area	0.04688194	+
CCR	Arable Land	0.02022740	-
CCR	Greenhouse Gas Emissions	0.02796745	-
CCR	Renewable Energy Generation	0.04192346	+
CCR	Renewable Energy Capacity	0.05167061	+
MS	GDP Growth	0.11056756	+
MS	Inflation Consumer Prices	0.06133936	-
MS	Economic Globalization Index	0.16178970	+
MS	Political Globalization Index	0.06043399	+
MS	Social Globalization Index	0.16774694	+
MS	Human Development Index	0.15162369	+
MS	Capital Investment	0.13128221	+
MS	Household Consumption	0.15521655	-
ESS	Primary School Enrollment	0.10301881	+
ESS	Secondary School Enrollment	0.09856287	+
ESS	Health Spending per Capita	0.16341645	+
ESS	Health Spending as Percent of GDP	0.15226511	+
ESS	Life Expectancy	0.15779153	+

Index	Indicator	Weight	Polarity
ESS	Unemployment Rate	0.11411499	-
ESS	Alternative and Nuclear Energy	0.09797619	+
ESS	Access to Electricity	0.11285406	+

Source: data processed by the authors

The next stage of the case study focuses on developing a panel-type OLS (Ordinary Least Squares) regression model. This approach initially involves performing a covariance analysis (Table 6) between the three composite indicators: CCRI, MSI, and ESSI. This analysis is essential for understanding the relationships and interdependencies between different variables, providing a solid foundation for constructing the regression model. By evaluating how variables influence each other, we can develop a more robust and accurate model that reflects conditions and trends within the European Union. The panel-type OLS model allows us to consider both the cross-sectional dimension (differences between countries) and the temporal dimension (evolution over time), thus facilitating a deeper understanding and a more comprehensive analysis of the data.

Table 6. Covariance analysis of indicators (2002-2020)

Index	CCRI	MSI	ESSI
CCRI	1.000	0.09175	0.39286
p value		0.0378	0.000
MSI	0.09175	1.000	0.75492
p value	0.0378		0.000
ESSI	0.39286	0.75492	1.000
p value	0.000	0.000	

Source: data processed by the authors through EViews

The diagonal of the table indicates the correlation of each variable with itself, which is always 1. The correlation coefficient between CCRI and MSI is 0.09175, indicating a very weak positive linear relationship at a 5% significance level. CCRI has a moderate positive correlation with ESSI, as indicated by the correlation coefficient of 0.39286 at a 1% significance level. MSI and ESSI have a strong positive correlation with a coefficient of 0.75492 at a 1% significance level, indicating a highly significant correlation between them. This correlation matrix is useful for understanding the bivariate relationships between variables.

All values are already standardised in the range 0-1, meaning no further data rescaling is needed. Since our data is annual, seasonality is not a potential issue, so there is no need to check for seasonality. Next, we test stationarity and cross-dependence between sections for each of the three statistical series. Results of the cross-sectional dependency tests (Table 7) indicate significant dependency between sections, suggesting that there are correlations between the different units within the panel data at the CCRI, MSI, and ESSI levels. The very small p-values reject the null hypothesis, which assumed no correlations between cross-sections. This suggests that estimation methods that account for this dependency should be employed. Thus, we need to use the second-generation stationarity test, which involves cross-sectional dependency.

The CIPS (Cross-sectionally Im Pesaran and Shin) test presented in Table 8 is a unit root test applied to panel data that accounts for cross-sectional dependency. The null hypothesis (H0) of the CIPS test is that there is a unit root, meaning the series is not stationary.

Table 7. Cross-Section Dependence Test for CCRI, 2002-2020.

	Null hypothesis:	No cross-section dependence		
	Test	**Statistic**	**d.f.**	**Prob.**
CCRI	Breusch-Pagan LM	5083.023	351	0.000
	Pesaran scaled LM	178.5987		0.000
	Bias-corrected scaled LM	177.8487		0.000
	Pesaran CD	70.77216		0.000
MSI	Breusch-Pagan LM	4699.497	351	0.000
	Pesaran scaled LM	164.1234		0.000
	Bias-corrected scaled LM	163.3734		0.000
	Pesaran CD	67.72129		0.000
ESSI	Breusch-Pagan LM	4735.716	351	0.000
	Pesaran scaled LM	165.4904		0.000
	Bias-corrected scaled LM	164.7404		0.000
	Pesaran CD	66.61273		0.000

Source: data processed by the authors through EViews

Table 8. Second Generation Stationarity Test, CCRI -1, illustrating panel unit root tests with cross-sectional dependence (Pesaran – CIPS)

	CIPS Unit Root Test	**Test results**		**Critical Values**		
	Statistic	**t-stat**	**p-value**	**1%**	**5%**	**10%**
D_CCRI	CIPS	-3.184	<0.01	-2.36	-2.18	-2.08
D_MSI	CIPS	-57.733	<0.01	-2.36	-2.18	-2.08
D_ESSI	CIPS	-3.973	<0.01	-2.36	-2.18	-2.08
D_CCRI	Truncated CIPS	-2.995	<0.01	-2.36	-2.18	-2.08
D_MSI	Truncated CIPS	-2.298	<0.05	-2.36	-2.18	-2.08
D_ESSI	Truncated CIPS	-3.054	<0.01	-2.36	-2.18	-2.08

Source: data processed by the authors through EViews

According to the results obtained, the p-value is less than 0.01 for both statistics, suggesting we reject the null hypothesis with over 99% confidence, with one exception for MSI, which reaches a p-value of 0.05 (i.e. a 95% confidence level). These results imply that all-time series are stationary after accounting for cross-sectional dependency, meaning that variations or shocks in these series tend to dissipate in the long run and that the series has a constant mean and variance over time. The fact that the series are stationary gives us confidence that we can advance in econometric analysis without the need for further transformations to ensure data stationarity. With these steps completed, we can employ the ordinary least squares (OLS) regression model estimations presented in the following equation, with climate change risk as dependent variable and economic system security and macroeconomic situation as independent variables, and a dummy for the financial crisis in 2008:

$$D\_CCRI = C + D\_ESSI + D\_MSI + DUMMY \tag{3}$$

The results in Table 9 for the dependent variable D_CCRI prove that the constant has a positive coefficient (≈0.002) and is statistically significant at the 1% level, suggesting an upward trend in D_CCRI over time. The economic system security (D_ESSI) is associated with a negative but insignificant coefficient (≈-0.01, with a p-value of 0.627), indicating no meaningful relationship with the climate change risks (D_CCRI). However, the macroeconomic situation (D_MSI) suggests a significant negative relationship with D_CCRI (-0.034, and a p-value of 0.007), implying that improvements in it would correspond to an increase in climate change risks. The DUMMY variable, marking a financial crisis, is significant (≈0.002, p-value = 0.003) and associated with a decrease in risk. The model's R-squared value indicates that the independent variables explain 5.27% of the variation in D_CCRI, while the Durbin-Watson statistic (1.431) suggests some autocorrelation in the residuals.

Table 9. A Panel Least Squares model implementation with D_CCRI as dependent variable

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.0018	0.0006	2.8312	0.0048
D_ESSI	-0.0096	0.0198	-0.4856	0.6275
D_MSI	-0.0342	0.0125	-2.7225	0.0067
DUMMY	0.00198	0.0007	2.9566	0.0033
R-squared	0.0527	Mean dependent var		0.0029
Adjusted R-Squared	0.0468	S.D. dependent var		0.006
S.E. of regression	0.0061	Akaike info criterion		-7.368
Sum squared resid	0.0176	Schwarz criterion		-7.334
Log likelihood	1794.55	Hannan-Quinn criter.		-7.355
F-statistic	8.942	Durbin-Watson stat		1.431
Prob(F-statistic)	0.000			

Source: data processed by the authors through EViews

In conclusion, the model indicates a significant influence of the macroeconomic situation on climate change risk and an effect of the financial crisis during the period overviewed. However, the relatively low R-squared suggests that other variables, which were not included in the model, would have an impact on climate change risks. To improve the model, we apply various lag levels for endogenous variables. Thus, based on estimations, we concluded that the optimal model is for a lag of 3 for D_ESSI. The new regression results are presented in Table 10.

Table 10. Adjustment of the Panel Least Squares model with D_CCRI as dependent variable

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.0025	0.001	2.564	0.010
D_ESSI(-3)	-0.021	0.022	-0.948	0.3435
D_MSI	-0.037	0.014	-2.613	0.0093
DUMMY	0.0014	0.001	1.426	0.1545
R-squared	0.0335	Mean dependent var		0.0033
Adjusted R-Squared	0.0263	S.D. dependent var		0.0065
S.E. of regression	0.0064	Akaike info criterion		-7.2613
Sum squared resid	0.0163	Schwarz criterion		-7.222
Log likelihood	1474.41	Hannan-Quinn criter.		-7.2456

Variable	Coefficient	Std. Error	t-Statistic	Prob.
F-statistic	4.6335	Durbin-Watson stat		1.3609
Prob. (F-statistic)	0.0034			

Source: data processed by the authors through EViews

In the revised model, where the economic system security is replaced by its three-period lagged value D_ESSI(-3), the constant has a positive coefficient (0.0025) and it is statistically significant (p = 0.0107), suggesting a slight upward trend in D_CCRI, implying a general improvement in climate risk conditions. The coefficient for D_ESSI(-3) is negative (-0.021) but not statistically significant (p = 0.3435), indicating no meaningful impact on D_CCRI from D_ESSI values three periods ago. D_MSI remains significant with a negative coefficient (-0.0367, p = 0.0093), showing that improvements in macroeconomic conditions are associated with increased climate change risks. In this case, the DUMMY variable is not significant. The R-squared value (0.0335) indicates that the model explains 3.35% of the variation in D_CCRI, and the Durbin-Watson statistic (1.361) suggests a slight positive autocorrelation, indicating that it is not a major concern.

In conclusion, these results suggest that while D_MSI is significant and inversely correlated with D_CCRI, the lagged values of economic system security (D_ESSI(-3)) do not seem to influence D_CCRI significantly. Stern [1] also found that climate change risks could lower economic growth and negatively affect macroeconomic stability. The Stern review also evidenced that robust economic systems, such as those investing in resilience and adaptation, are crucial for mitigating climate change impacts. However, weaker economies are expected to be more vulnerable to the negative consequences of climate change. These contrasting results became the reasoning for analysing how economic security and other economic variables affect climate change risks.

5 Conclusions

This study addressed the relationship between climate change and macroeconomic parameters in the EU27 context, providing an in-depth perspective on how climate risk influences and is influenced by economic stability and security. By applying various econometric models, including fixed and random effects models, we discovered that there is a significant correlation between the macroeconomic situation (MSI) and the Climate Risk Index (CCRI). The literature review formed the basis on which our analysis was built, offering an essential perspective on previous research in the field of interaction between climate change and macroeconomic variables. We observed that literature abounds in studies exploring the impact of climate change on specific economic sectors, but there are fewer studies addressing the impact on the stability of the economic system. Additionally, the literature reveals a concern for modelling climate risks in the context of sustainable economic growth and energy transition. This review highlighted the need to adopt an interdisciplinary approach that connects climate variables with economic indicators. It became clear that understanding the impact of climate change on the economy requires collaboration between climatologists, economists, and policymakers to design effective and sustainable adaptation and mitigation strategies.

Our results indicate that an improved macroeconomic situation is associated with an increased perception of climate risk. This could reflect increased awareness or greater vulnerability to climate change impacts among developed economies at the EU-27 level. Alternatively, this result might indicate that economies with a solid macroeconomic situation may have more resources to assess and respond to climate risks. Therefore, policies should not only aim at economic growth itself but also anticipate how growth can intensify climate risk or its perception. On the other hand, we observed that the influence of the Economic

System Stability Index (ESSI) on CCRI was not significant in our models. This result suggests that there might be a time lag between changes in economic stability and effects on climate risk, or that other economic or non-economic factors may play a more determinant role. Besides these findings related to MSI and ESSI, the model included a dummy variable to capture the effects of the global financial crisis. Marginally significant coefficients suggest that major global economic events can leave a lasting imprint on how climate risks are managed and perceived.

Although advanced econometric models were applied, they might oversimplify reality by excluding relevant variables, thus limiting the ability to identify clear causal relationships. Moreover, climate change is a complex phenomenon, and the current model may not have fully captured its interactions with economic systems. This suggests the need to integrate more indicators or different indicators in calculating composite indicators to provide a more comprehensive perspective and more precise details.

The conclusions of this study are not just a reflection on the current interactions between climate change and the economy but also a bridge to future sustainable development efforts in Europe. Our results gain special significance considering the European Green Deal, the EU's ambitious initiative to transform the EU into a modern, resource-efficient, and competitive economy by 2030. The European Green Deal urges us to realise that including climate-related aspects in economic and public policy strategies is not only an obligation but also an opportunity to shape a prosperous future that lasts. In the end, this study urges us to look for a clear understanding of the current challenges and, through continuous research, innovation, and cooperation, a greener Europe with a less negative impact on the environment would take us to respect the commitments made for 2030 and beyond.

This work was supported by a grant from the Romanian Ministry of Research, Innovation and Digitalization, the project with the title „Economics and Policy Options for Climate Change Risk and Global Environmental Governance" (CF 193/28.11.2022, Funding Contract no. 760078/23.05.2023), within Romania's National Recovery and Resilience Plan (PNRR) - Pillar III, Component C9, Investment I8 (PNRR/2022/C9/MCID/I8) – Development of a program to attract highly specialised human resources from abroad in research, development and innovation activities.

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