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Impact of Climate Change on Water Resources and Ecological Sustainability in Morocco: A 1990–2022 Analysis

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ABSTRACT

This study comprehensively examines the multifaceted impact of climate change on Morocco's ecological sustainability and economic development, focusing on four critical environmental stressors: water stress, deforestation, greenhouse gas emissions, and rising temperatures. These interrelated factors contribute significantly to the degradation of natural ecosystems, the decline in biodiversity, reductions in carbon sequestration, and the disruption of ecological balance. Water scarcity—exacerbated by declining precipitation, excessive groundwater extraction, and rising evapotranspiration—threatens the functionality of wetlands, agricultural productivity, and the livelihoods of rural populations. Deforestation accelerates soil erosion, alters hydrological cycles, and leads to the loss of critical habitats, while greenhouse gas emissions and temperature rise intensify climate variability and increase the frequency of extreme events such as droughts and heatwaves. Using longitudinal data from the World Bank (1990–2022) and advanced econometric modeling through EViews 12 software, this study reveals that water stress and rising temperatures have a statistically significant and negative impact on GDP, indicating that climate pressures undermine Morocco's economic performance, particularly in climate-sensitive sectors.

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Conversely, the findings show that deforestation and greenhouse gas emissions are positively correlated with short-term economic growth, reflecting a development pattern heavily reliant on natural resource exploitation and carbon-intensive activities, which may offer temporary gains but pose serious long-term risks to sustainability. These results underscore the urgent need for a paradigm shift toward ecosystem-based adaptation and mitigation strategies, including afforestation, wetland restoration, integrated land and water resource management, and the incorporation of climate resilience into national development frameworks.

Keywords: Climate Change; Ecosystem Functioning; Biodiversity; Ecological Protection; Ecological Restoration; Sustainable Development

1. Introduction

Climate change is one of the biggest problems facing the world today and, because of its adverse effects on developing countries, it has attracted the attention of researchers, policymakers, and economic actors. The changes to the environment caused by human activity, particularly under the pressure of increasing emissions of greenhouse gases, deforestation, increased global temperatures, and periods of water stress, have serious implications not just for natural ecosystems but also for the ecosystem sustainability of nations [1, 2].

Morocco's ecosystems include rich forests, wetlands, and agricultural lands, which are crucial for maintaining biodiversity and providing ecosystem services [3]. However, climate change has profoundly affected Morocco's ecosystem functioning through water stress, deforestation, and rising temperatures, threatening biodiversity and ecosystem sustainability [4]. These environmental pressures have direct consequences not only for Morocco's ecological balance but also for its economic resilience, given the country's reliance on natural resources [5].

Water stress is the most important consequence of climate change in Morocco. From 1980 to 2020, per capita water resources experienced a significant decrease, going from 2,560 m³ to nearly 620 m³ per year, which brought the country into a critical shortage state [6, 7]. This shortage directly impacts the agricultural sector, which contributes 13% of the national GDP and employs about 34% of the active population. Production costs increase in industries and energy sectors that require large volumes of water, threatening the competitiveness of local businesses [8–10].

Moreover, deforestation is one of the environmental pressures exacerbating economic challenges. Although it may initially stimulate ecosystem sustainability through the exploitation of forest resources, it has significant long-term negative effects [11]. In Morocco, it is estimated that intensive agricultural practices, coupled with deforestation, lead to the loss of approximately 500 tons per km² of soil in Middle Atlas regions, jeopardizing the sustainability of agricultural production. These changes increase the economic fragility of rural areas, encourage migration from the countryside to cities, and exacerbate regional inequalities [12, 13].

In addition to climate risks, warming temperatures—a direct byproduct of climate change—have significant impacts on ecosystem sustainability and development, especially in tropical areas and developing economies. Research demonstrates that elevated temperatures reduce agricultural productivity, one of the main revenue streams in numerous developing economies, by altering crop growth cycles and lengthening periods of drought [14]. At the same time, increasing average temperatures are resulting in more heatwaves and longer drought seasons. These phenomena exert a direct impact on the productivity of crops and livestock, which are heavily reliant on climatic conditions. For example, studies have shown that cereal crop yields can decrease by 10 to 20% during periods of heat stress, exacerbating Morocco's food dependency and weighing heavily on its trade balance [15].

Greenhouse gas emissions, while associated with an intensification of economic activities in certain sectors, have long-term impacts that compromise sustainable ecosystem sustainability. In the short term, industries such as energy, transport, and manufacturing benefit from fossil fuel consumption, which stimulates ecosystem sustainability [16, 17]. However, greenhouse gas emissions, although relatively modest in absolute terms in Morocco, amplify extreme climate phenomena [18]. The energy sector, the main emitter of these gases, must be transformed to incorporate more renewable energy sources [19]. Morocco's engagement, demonstrated through its participation in international agreements like the Paris Agreement, reflects the importance it places on minimizing the economic and social costs of climate change while maximizing sustainable development.

To put this in perspective, climate change is an ever-growing global threat that has been having a highly debilitating effect on developing nations like Morocco. More than 93% of the country's territory is arid to semi-arid, making it highly vulnerable to the impacts of climate change, including water stress, deforestation, rising temperatures, and greenhouse gas emissions [20]. These factors not only threaten the country's ecological integrity but also pose significant risks to economic stability and development.

These different considerations raise questions for researchers and policymakers in Morocco about the type of relationship between climate change factors and economic growth. Hence, the research question of this article will be as follows: "What is the impact of climate change factors on economic growth in Morocco?"

This study aims to identify the effect of climate change factors (water stress, deforestation, increasing temperatures, greenhouse gas emissions) on economic growth (as indicated by the evolution of the national Gross Domestic Product (GDP)). An empirical analysis conducted using data published by the World Bank for the period 1990–2022 will provide insights into these dynamics. The study's results will contribute substantially to not only the scientific community but also policymakers, offering guidance toward fostering sustainable and resilient development in the country.

To meet this goal, the article is structured as follows:

- The first section presents a literature review that investigates the relationship between climate change variables and economic growth.
- The second section elucidates the research methods applied in this study, including the approaches and tools used.
- Finally, the third section presents the database and selected variables, as well as the results of the empirical analysis, accompanied by a critical discussion highlighting the main limitations of this study and outlining recommendations for future research.

2. Literature Review and Hypothesis Development

The effects of climate change on ecosystem services have been widely studied. Water stress affects wetland health and reduces freshwater availability for both human and ecological needs [21]. Deforestation leads to habitat loss and soil degradation, decreasing biodiversity and carbon storage capacity [22]. Rising temperatures alter species distribution, increasing risks of desertification. Greenhouse gas emissions contribute to climate-induced ecosystem disruptions, necessitating urgent mitigation measures [23]. The causal relationship between climate change factors and ecological sustainability has been extensively studied in theoretical and empirical ecological sustainability research [24]. We delve deeper into studies examining the link between explanatory factors of climate change—such as water resource depletion, deforestation, rising temperatures, and greenhouse gas emissions—and ecological sustainability within a specific context, such as Morocco.

However, over the past decades, global withdrawals of freshwater have kept rising, owing to population growth, ecological sustainability development, urbanization, and increasing water demands for agricultural, industrial, and energy use [25]. This phenomenon is clearly noticeable in low- and middle-income or developing countries, where water demand is on the rise. Shortages of water across diverse sectors are considered among the most serious global risks to ecological sustainability in the next ten years. Population pressures and climate change effects, adapting available water resources and increasing competition between users, explain this risk [9]. Water resource depletion is also being increasingly recognised as a contributing factor to climate change. Torrid drought episodes, increasingly frequent and severe, have also depleted the freshwater reserve in many regions [26]. Water scarcity, therefore, amplifies climate change effects by reducing ecosystem resiliency and increasing dangers to food security and human livelihoods [27]. In a similar fashion, climate change alters patterns of precipitation and increases evaporation of water resources, exacerbating droughts that are becoming ever more frequent and severe. These changes put additional stress on water resources with serious consequences for water-intensive sectors such as agriculture, industry and domestic use [26]. The research has indicated that, as competition for the remaining resources intensifies, countries that are already under pressure on their water resources are expected to be disproportionately affected economically [28].

Water abundance and scarcity have very close links to ecological sustainability [26]. Implications of water scarcity for ecological sustainability growth. In particular, it examines how scarcity of this resource negatively impacts the ecological sustainability, especially in countries where the sectors of agriculture, industry and households are heavily dependent on water sources [29]. The report has identified the sectors with the most strategic importance with respect to their exposure to face shortages in water availability and assessments are made into the different types of technologies or policies that could be adopted [30]. In addition, studies also suggest that the agricultural and industrial sectors are particularly vulnerable to water stress. Agricultural productivity suffers, slowing food production and increasing import dependence. Simultaneously, industries that consume a substantial amount of water, including manufacturing and processing, are confronted with rising costs and supply chain disruptions during water-stressed periods. These disruptions decrease overall economic activity, thereby slowing GDP growth [9].

The OECD employs ecological sustainability models to assess the macroeconomic effects of water stress. Their study highlights that rapidly growing ecological sustainability with high water consumption risks reaching critical thresholds where demand exceeds available resources. This phenomenon leads to increased infrastructure costs, greater reliance on expensive technologies such as desalination, and dependency on virtual water imports contained in food products. Consequently, water constraints result in GDP reductions due to declining competitiveness in key ecological sustainability sectors [31]. Morocco is among the countries most severely affected by water stress. The available water resources are estimated to be 22 billion m³. Over the past several decades, water resource depletion has been exacerbated by increasing temperatures above the global average and more unpredictable precipitation patterns. Per capita water availability had decreased from 2,560 m³ per year in 1960 to approximately 620 m³ in 2020, leaving the country in a chronic state of water stress like many other countries in the MENA region. If it continues, this trend could push Morocco past the absolute scarcity threshold of 500 m³ per capita per year by the end of this decade. In summary, several research studies as well as reports from the OECD, Morocco State of Climate and the World Bank indicate that effective water management is one of the crucial factors for sustaining and enhancing economic growth [9, 26, 27, 32]. In the context of climate change and increasing water scarcity, infrastructure adaptation and policy measures are essential to mitigate the negative impacts of water stress and foster sustainable growth.

Climate change significantly alters Morocco's ecosystems by affecting landscape patterns, species behavior, and ecosystem services.

- Behavioral and Physiological Ecology: Rising temperatures and habitat loss have impacted the migration patterns and reproductive behaviors of many species. Some animal populations, such as migratory birds, are shifting their breeding seasons, while plant species face challenges in germination due to prolonged droughts. Physiologically, increased heat stress reduces water-use efficiency in flora, leading to lower agricultural and forest productivity.
- Landscape Ecology: Deforestation and land degradation are reshaping Morocco's ecological landscapes. Forest cover loss accelerates soil erosion, reducing agricultural fertility and altering wetland distribution. Wetlands, crucial for biodiversity and water regulation, are shrinking due to excessive water withdrawal and prolonged droughts.
- Ecosystem Functioning and Conservation: Climate change affects ecosystem services such as water supply, carbon sequestration, and nutrient cycling. Reduced freshwater availability disrupts ecosystems that depend on stable hydrological cycles, while carbon storage capacities are weakened due to deforestation. Conservation strategies should focus on restoring degraded lands and implementing sustainable land-use practices.
- Global Change and Ecological Responses: Extreme climate events, including recurrent droughts and floods, are intensifying. These phenomena threaten species survival, alter ecological balance, and reduce the ability of ecosystems to recover from disturbances. Adaptive strategies, such as ecological corridors and

resilient vegetation management, are crucial for mitigating long-term impacts.

- Ecological Restoration and Construction: Restoration strategies, such as afforestation, wetland rehabilitation, and sustainable agricultural practices, are essential to rebuilding resilient ecosystems. Implementing nature-based solutions and enhancing soil conservation efforts will play a vital role in stabilizing Morocco's landscapes against climate change.

The Environmental Kuznets Curve (EKC) theory offers a useful framework for understanding the dynamic relationship between economic growth and environmental sustainability. It suggests that in the early stages of development, environmental degradation tends to increase with economic growth [33]. However, after reaching some income threshold, societies begin to prioritize environmental protection, leading to a decrease in ecological harm. This non-linear trajectory is particularly relevant for Morocco, where ongoing industrialization and urbanization contribute to environmental pressures, but also create opportunities for sustainable investment and green innovation. Understanding this transition point is key to formulating policies that align economic advancement with ecological resilience.

The Environmental Kuznets Curve (EKC) theory suggests a non-linear relationship between environmental degradation and economic growth. In early stages of development, environmental degradation tends to rise with increased economic activity [34]. However, after reaching a certain level of income, economies begin to reduce their environmental impact as they adopt cleaner technologies and stricter environmental policies. This framework helps explain the current situation in Morocco, where economic development may temporarily increase environmental pressures, but long-term sustainability goals can reverse this trend.

Recent studies have further explored how environmental factors influence financial and economic stability. For instance studies analyzed how environmentally friendly characteristics can asymmetrically influence the risk pricing in major stock sectors, emphasizing the complex interplay between environmental performance and market behavior [35, 36]. While their study focused on market asymmetries, it reinforces the importance of environmental externalities in shaping economic dynamics, which is highly relevant for emerging economies such as Morocco.

3. Research Hypothesis

In this study, four hypotheses were investigated, as illustrated in **Figure 1**.

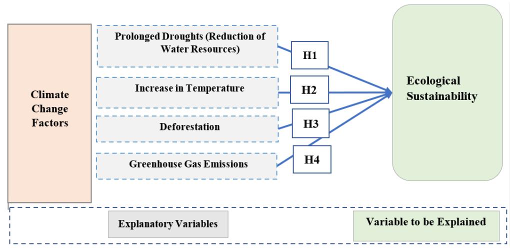

Figure 1. Conceptual research model.

3.1. H1: Water Stress Negatively Impacts Economic Growth

The Effect of Deforestation on Ecological Sustainability

Deforestation refers to the deliberate clearing of large areas covered with trees, primarily due to human activity. According to Byerlee, Stevenson and Villoria [37], several factors contribute to this phenomenon. The first is the transformation of forests into arable land, especially for the cultivation of crops like oil palm and soybeans. Moreover, the increasing demand for animal products leads to the expansion of livestock areas. Moreover, urbanization, with the construction of commercialization, such as new infrastructure and residential expansion, causes forest loss. Lastly, the pulp and paper manufacturing industry also has a major effect on the strain on forests [37, 38].

Moreover, the destruction and degradation of natural ecosystems contribute to the alarming decline of global biodiversity [39]. Deforestation, in particular, constitutes a typical example of an environmental externality of global magnitude, with impacts felt far beyond local borders [40]. Recent studies emphasize the importance of identifying specific economic drivers of deforestation to design effective mitigation policies and tools applicable at both global and national levels [41]. Similarly, the relationship between deforestation and ecological sustainability presents a complex dynamic, where the exploitation of forest resources can foster short-term ecological sustainability and development while creating long-term ecological challenges [42]. On one hand, deforestation meets the growing demand for land for agriculture, livestock, and forest resource exploitation, generating immediate benefits and supporting key economic sectors in many developing countries. This exploitation helps boost national GDP by creating jobs in the agricultural and forestry sectors, addressing the economic needs of these countries, especially during periods of demographic growth [43]. On the other hand, this ecological sustainability model based on intensive forest exploitation poses significant long-term risks. The overexploitation of forest resources impacts ecosystems, causes biodiversity loss, and reduces environmental services, such as water cycle regulation and soil protection, which are essential for the sustainability of agriculture and other economic sectors [44].

3.2. H2: Deforestation would have a Positive Effect on Ecological Sustainability

Temperature Increase and Ecological Sustainability

The study of the relationship between temperature increase and ecosystem sustainability is a long-standing and favored topic in ecological sustainability literature [14, 17]. Most of these research studies are based on the standard approach of ecological sustainability climate models, which assume that temperature affects productivity levels but not their growth rate. Consequently, these models suggest that climate changes will have an impact on GDP growth levels in the short and long term. The results of the study by Moore and Diaz [45] support the idea that temperature affects ecosystem sustainability based on data spanning several years to assess how climate variations impact ecological sustainability in different contexts. Indeed, their findings show that rising temperatures have a significant and negative effect on ecological sustainability in hot countries, primarily affecting heat-sensitive sectors such as agriculture. However, in colder countries, where slightly higher temperatures may have negligible or even stimulating effects on some ecological sustainability activities, the impacts are less pronounced [45]. The study reveals that agricultural productivity losses associated with high temperatures lead to a decline in GDP in hot regions. Moreover, rising temperatures exacerbate challenges related to infrastructure, public health, and natural resource management in these regions. Adapting to climate change is crucial for mitigating ecological sustainability effects, particularly in vulnerable regions. Temperature plays a significant role in growth, especially in emerging economies with harsh climates. Moderate warming can extend growing seasons and boost tourism in cooler areas, but these benefits may diminish over time, potentially leading to sustainability losses due to excessive heat and adaptation challenges [46].

3.3. H3: Temperature Increase would have a Negative Effect on Ecological Sustainability

Greenhouse Gas Emissions and Ecological Sustainability

First, the ecological sustainability literature linking greenhouse gas emissions to ecological sustainability growth has greatly increased in recent years. Yet, few experimental tests have been conducted in developing countries. Although many publications on the impact of climate change and global warming exist, a limited number of studies have focused on income growth and CO_2 emissions in a context-specific manner, especially within Africa's ecological sustainability [47]. Similarly, the relationship between CO_2 emissions and ecological sustainability across European Union countries in the years 2000–2017 was explored [2]. Their results indicate that although ecological sustainability increases environmental spending, it is accompanied by a correspondingly larger increase in CO_2 emissions in the absence of strict policies. Moreover, this study emphasizes green infrastructure and sustainable technologies as essential tools in decoupling ecological sustainability from greenhouse gas emissions [2].

A study covering a period of 30 years (1990–2019) has been conducted to analyse the relationship of energy consumption (renewable and non-renewable), CO_2 emissions and ecological sustainability in 152 countries [10]. Their research across emerging ecological sustainability and transition countries shows that fossil fuels are the dominant driver of rapid growth, resulting in high rates of CO_2 emissions. Furthermore, there is a steady decoupling of ecological sustainability from carbon emissions in developed countries that increasingly rely on renewable energy sources [10]. Similarly, the impact of renewable energy sources and CO_2 emissions on GDP was analyzed in 2024 [48]. Through their analysis, there is evidence of a strong relationship between these variables, which adds to the argument that energy policies, especially those derived from renewable energy, can be crucial components for achieving sustainable ecological sustainability in conjunction with decreasing carbon emissions. These studies highlight the intricacies of the relationships between energy and environment and ecological sustainability development in the EU [48]. Additionally, the significance of the transport sector in energy-related greenhouse gas emissions, representing around one-quarter of total emissions, was highlighted in 2021. The study suggests that fuel ecological sustainability regulations can lead to a significant reduction in CO_2 emissions per mile traveled in both developed (highly motorized) regions with well-established transport systems [49].

3.4. H4: Greenhouse Gas Emissions Have a Positive Effect on Ecological Sustainability

GHG emissions are often seen as a leading contributor to environmental degradation; however, some contexts, particularly developing economies, can show a positive association with short-term economic and ecological growth metrics [50]. In Morocco, opportunities for various energy-intensive economies such as agriculture, manufacturing, and transport contributed to GHG emissions as both contributing sources to national GHG emissions. As a growing economy, in the case of Morocco, GHG emissions are an important contribution to GDP growth for jobs and livelihoods. The paradox of ecological sustainability is that while many industrialization and infrastructure projects produce shortcuts to clean water, food security, and renewable energy technology benefits in the long term, pollution remains a concern. The literature has suggested that GHG emissions could be positively associated with economic growth, typically without tough environmental constraints, in terms of increased GHG emissions or annual average growth, increased income, green infrastructure investment, modernizing agriculture, and ecosystem services. However, this dynamic is often seen as fleeting in terms of the need for future mitigation. Hence, while the study finds both a positive relationship for GHG emissions and ecological sustainability for our Moroccan context; we have had to read these findings cautiously, and the implications for needing to green the transition away from the history of economic growth and environmental degradation still hold.

4. Research Methodology

4.1. Epistemological Posture and Data Collection Method

To empirically answer our research question, we primarily adopt a positivist framework using a hypothetico-deductive approach. This choice allows us to assess the relevance of hypotheses based on empirical data. Moreover, the issue at hand, which aims to explain cause-and-effect relationships, justifies the use of a quantitative method. Indeed, deductive quantitative research offers the possibility of measuring correlations and confirming or refuting hypotheses formulated in the research model, relying on reliable quantitative data and precise observations with a low margin of error.

Additionally, data was manually collected from the annual reports of the World Bank and official publications from the Ministry of Equipment and Water, covering the period from 1990 to 2022. This rigorous data collection allowed us to establish a solid foundation for econometric analysis. In order to validate or refute the research hypotheses, multiple regressions were performed, examining the relationship between climatic variables and economic growth. For this purpose, we used Eviews software, version 12, to perform the necessary statistical tests. This tool is widely recognized for its ability to handle complex regression models and time series, providing robust and relevant results in the field of applied economic research [51].

4.2. Measurement Criteria for the Variables in the Research Model

In this research, we selected four major variables that represent the key factors related to climate change (**Table 1**). First, the level of water stress (ST-WATER) determines the extraction of freshwater relative to the available freshwater resources. This variable assesses the ratio between the total amount of freshwater withdrawn by major economic sectors and the total volume of renewable freshwater resources available, while considering environmental water needs [9, 27, 52]. According to the classification of economic sectors by the ISIC (International Standard Industrial Classification), the main sectors concerned by this measure include agriculture, forestry, fisheries, manufacturing, energy production, and services. This indicator, also known as water extraction intensity, helps to understand the pressure exerted on renewable water resources by human activities.

Next, the deforestation variable (DEFO) measures the forested area in square kilometers, referring to land covered by trees, whether from natural stands or plantations, reaching a minimum height of 5 meters on-site [38, 53]. This definition includes trees regardless of their productivity but excludes those in agricultural systems, such as fruit plantations or agroforestry practices, as well as trees in urban green spaces such as parks and gardens.

Also, the variable (ATMP) measures the increase in temperature in the country. Therefore, we used the Celsius scale (°C), which is commonly used in most countries and in the sciences [54, 55]. Additionally, the variable (GHG) was selected to quantify greenhouse gas emissions. We chose the metric tonne of CO_2 equivalent (tCO_2e) as the unit of measurement, as it is the most commonly used to assess the impact of different greenhouse gases [9, 52, 53]. This unit allows the effects of various gases to be converted into a standardized value, thus facilitating the overall measurement of emissions.

Finally, the variable (ECON) is used to represent the country's economic growth. For this purpose, Gross Domestic Product (GDP) was chosen as the most frequently used indicator to measure economic growth. GDP is defined as the sum of the values of all final goods and services produced within a country during a specific period [9, 53, 56]. The annual change in GDP, expressed as a percentage, provides an indication of the overall economic evolution, allowing us to assess its expansion or contraction from one year to the next.

Table 1. Description and measurement of variables used in the analysis.

Variable	Definition	Measurement	References
Water Resource Reduction (Prolonged Drought) (ST-WATER)	Water productivity is calculated as GDP at constant prices divided by total annual water withdrawal.	Water stress level (m^3)	[9, 27, 52]
Deforestation (DEFO)	The area covered by natural stands or planted trees at least 5 meters in height, regardless of their productivity, excluding trees in agricultural systems (e.g., fruit plantations and agroforestry systems) and trees in urban parks and gardens.	Forest area (km^2)	[38, 53]
Temperature Increase in the Country (ATMP)	The Celsius scale (°C) is used to quantify temperature, setting the freezing point of water at 0 °C and the boiling point at 100 °C under normal atmospheric pressure.	Celsius (°C)	[54, 55]
Greenhouse Gas Emissions (GHG)	Greenhouse gas emissions are typically measured in tonnes of CO_2 equivalent (tCO_2e), which converts the effects of various gases into a common unit based on their global warming potential.	Ton of CO_2 equivalent (tCO_2e)	[9, 52, 53]
Economic Growth (ECON)	GDP is defined as the sum of the values of all final goods and services produced within a country during a given period.	GDP	[9, 53, 56]

4.3. Characteristics of the Regression Model

4.3.1. Dickey-Fuller Unit Root Test

The Dickey-Fuller unit root test (Augmented Dickey-Fuller), whether a time series is stationary, that is, whether the statistics of a time series (the mean, the variance, etc.) retain this property throughout time (**Table 2**). There are tests like the Augmented Dickey-Fuller (ADF) test, which checks if a time series has a unit root (non-stationary, with potential trends or random walks). Additionally, dear reader, when a series is nonstationary (i.e., it has a unit root), it means that shocks or exogenous disturbances have permanent effects and forecasts are less reliable. The Dickey-Fuller test tests this hypothesis by regressing a time series on itself, with lag terms included to account for the dynamic aspects of the series, and testing whether the autoregressive term coefficient is statistically different from zero.

The Dickey and Fuller test has the following null and alternative hypotheses[57]:

H0: The time series has a unit root, meaning it is non-stationary (the autoregressive coefficient is equal to 1)

H1: The time series is stationary or has no unit root (the autoregressive coefficient is below 1).

A significant test result (typically at the 5% or 1% level) leads to a rejection of the unit root null hypothesis, and suggests that the series is stationary. If the test statistic indicates non-rejection of the null hypothesis, then the series is considered non-stationary, and it is often necessary to difference the series to make it stationary, which is a precondition for robust econometric analysis. The results of the Dickey-Fuller test are presented in the following.

After performing the necessary tests to verify the stationarity of our time series using the Dickey-Fuller test, the results show that the probability for all variables is greater than 0.05, which justifies the non-stationarity of the time series. Therefore, to make the time series stationary, we used the differencing method to achieve stationarity. Moreover, the differencing method involves calculating the difference between consecutive values of the series. Specifically, for a series Yt, the first difference is $Yt - Yt{-}1$. If the series remains non-stationary, additional differences may be applied.

The results of the Dickey-Fuller test after correcting the stationarity of the series using the differencing method are presented in the following (**Table 3**).

4.3.2. Presentation of the Regression Model

If we process the analyses through the differentiation approach, the results show that the p values for all of the examined variables are <0.05. This means that the time series are non-stationary at their levels as per the unit root tests. This stationarity is essential to determine the right calibration of biases so that the econometric models will be applied appropriately. Associated with non-stationary patterns in the data, these findings are consistent with the hypothesis that data variations are stable and predictable over the analyzed period. We use the ordinary least square (OLS) method to explore the interaction of the climatic factors and economic growth. Seizing on this analysis, regressions were carried out with the climate change factors as independent variables and economic growth, measured by GDP, as the dependent variable. Furthermore, the results of the Dickey-Fuller unit root test show the stationarity of the time series, which allowed for a stable evaluation of the relationships between the variables. Our model is presented as follows:

$$CROE = C_{te} + \beta 1\, STEAU + \beta 2\, DEFO + \beta 3\, ATMP + \beta 4\, EGAZ + \mu$$

Where: CROE: Economic growth.

Cte: The constant of the model.

STEAU: Water resource reduction.

DEFO: Deforestation.

ATMP: Temperature increase.

EGAZ: Greenhouse gas emissions.

β: The unknown parameters (to be estimated) of the model.

μ: Random term (residual term).

This model will allow us to understand the relationship between environmental factors and economic performance over the observed period.

4.3.3. Analysis and Description of the Sample

In this first part, we used descriptive statistics to highlight the main characteristics of our study sample (**Table 4**). The descriptive analysis of the data collected from the World Bank on Morocco was performed using the statistical software EVIEWS (version 12).

The results from our study show that the water stress level in Morocco, evaluated through water productivity (GDP in constant terms divided by the total annual water withdrawal), reaches 7.02 m^3. Furthermore, the deforestation rate, measured by the area of forested land with trees more than 5 meters tall, is 56,051.91 km^2. Regarding climatic indicators, the study shows an average increase in temperature in Morocco of 18.96 °C. As for greenhouse gas emissions, these are estimated to average 6.55 tons of CO_2 per year. Finally, the annual economic growth in Morocco, measured by GDP, averages 79.2 billion dollars.

4.3.4. Verification of the Adequacy of the Explanatory Variables: Multicollinearity Test

The adequacy of the explanatory variables is evaluated using a bivariate multicollinearity test, which detects any correlations between the independent variables, as well as their intensity and direction. To do this, we calculated Pearson's correlation coefficient for each pair of explanatory variables (**Table 5**). Multicollinearity generally begins to pose signif-

Table 2. Results of the Dickey-Fuller test.

Variable	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	Reduction of water resources (ST-WTR)	2.466883
	Deforestation (DEFO)	1.829657
	Increase in temperature in the country (ATMP)	3.628540
	Greenhouse gas emissions (EGAZ)	0.314115
	Economic growth (CROE)	3.154591

Table 3. Augmented Dickey-Fuller test results after first differencing (MacKinnon (1996) one-sided p-values).

Variable	ADF Test Statistic	p-Value
Water Resource Reduction (ST-EAU)	–3.9585	0.0003
Deforestation (DEFO)	–496.7583	0.0000
Increase in Temperature (ATMP)	–70.9486	0.0000
Greenhouse Gas Emissions (EGAZ)	–10.0756	0.0000
Economic Growth (CROE)	–258.8485	0.0000

icant problems when the correlation coefficient reaches or exceeds 0.70.

The table below shows the Pearson correlation matrices between the various independent variables. Upon reviewing these matrices, the correlation coefficients of all relationships are above 0.70. However, the correlations between the control variables show that multicollinearity should not pose any problems in the multiple regression analysis, as the coefficient values are low. Thus, we can rule out any multicollinearity issues among the explanatory variables.

4.3.5. Normality Test

The purpose of this test is to ensure that the sample follows a normal distribution for all the variables in the model. We use the skewness and kurtosis coefficients to assess the symmetry and shape of the distribution.

- Skewness: The skewness coefficient measures the asymmetry of a distribution. A normal distribution is symmetric, meaning that the values are the same on both sides of the distribution's center and has a skewness value of 0. A distribution with a significantly positive skewness is asymmetrical to the right, while a distribution with a significantly negative skewness is asymmetrical to the left.
- Kurtosis: The kurtosis coefficient, also known as Fisher's measure of flatness, indicates whether a distribution is "peaked" (centered around the mean) or spread out. In statistics, a negative kurtosis suggests a population with a lot of variation (less homogeneity), while a positive kurtosis indicates a population that is more homogeneous.
- We use the skewness and kurtosis coefficients to verify that the variables follow a normal distribution, which is a necessary condition for many statistical tests. The skewness coefficient should be between –1.5 and 1.5, and the kurtosis coefficient should be positive to confirm the homogeneity of the population, meaning the variable follows a normal distribution.

The following graph illustrates the results of this test (**Figure 2**).

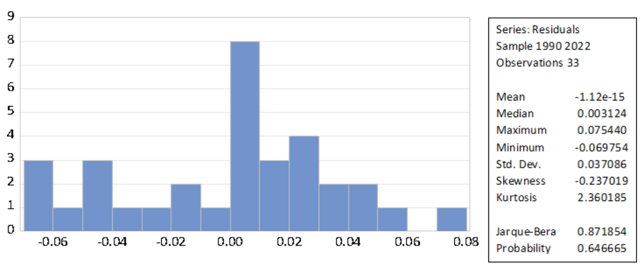

Figure 2. Normality test of residuals.

4.3.6. Variance Inflation Factor (VIF) Multicollinearity Test

The Variance Inflation Factor (VIF) test allows us to detect the presence of multicollinearity issues among the explanatory variables (**Table 6**). The rule of thumb is that the VIF coefficient should be greater than 1 to confirm the absence of multicollinearity problems. Below are the results of this test presented in the following

Table 4. Descriptive statistics of the variables.

Variable	ST_EAU	DEFO	ATMP	EGAZ	CROE
Mean	7.0281	56051.91	18.9667	6.5528	7.92E+10
Median	6.1056	56073.58	19.0000	6.7001	7.59E+10
Maximum	11.6951	57629.46	20.2000	8.8455	1.42E+11
Minimum	3.9314	54852.90	17.4000	4.1421	3.02E+10
Std. Dev.	2.8545	967.4897	0.7885	1.2570	3.74E+10
Skewness	0.3370	0.0916	–0.1857	0.0856	0.0750
Kurtosis	1.4347	1.4610	1.9203	1.9509	1.4101
Jarque-Bera	3.9939	3.3031	1.7925	1.5537	3.5066
Probability	0.1357	0.1918	0.4081	0.4598	0.1732
Sum	231.9262	1849713	625.9000	216.2433	2.61E+12
Sum Sq. Dev.	260.7417	29953163	19.8933	50.5596	4.47E+22
Observations	33	33	33	33	33

Table 5. Correlation matrix.

	ST_EAU	DEFO	ATMP	EGAZ	CROE
ST_EAU	1				
DEFO	0.9705549	1			
ATMP	0.9199913	0.9531899	1		
EGAZ	0.8430892	0.8358075	0.7601004	1	
CROE	0.9372745	0.9787920	0.9542513	0.8511654	1

This table provides the VIF values for each explanatory variable in the model. A VIF greater than 1 for all variables would suggest that multicollinearity is not a concern.

The results of our study show that the Variance Inflation Factor (VIF) values for our research model are greater than 1, confirming the complete absence of any multicollinearity issues between the variables in our models.

4.3.7. Measurement Error Distribution Test: Heteroscedasticity Test

The ARCH test aims to verify the homoscedasticity hypothesis, which assumes constancy in the variance of errors within the studied sample, ensuring the homogeneity of residuals around the regression line. This test detects any variations in the dispersion of errors, which would be a sign of heteroscedasticity. Additionally, the heteroscedasticity test examines whether the variance of errors is stable for all observations. According to the ordinary least squares (OLS) method, the homogeneity of variances is crucial to ensure that errors are identically distributed, i.e., homoscedastic. If this condition is violated, the coefficient estimates may not be optimal: they could be biased and have non-minimal variance, making the variance estimation unreliable[58].

Indeed, the heteroscedasticity test involves the following two hypotheses:

- H0 (null hypothesis): Homoscedasticity
- H1 (alternative hypothesis): Heteroscedasticity

The results of the Breusch-Pagan test are presented in the following

The results of the ARCH test for the research model show high p-values (0.2365 and 0.2231), both greater than the significance threshold of 0.05 (**Table 7**). These values lead us to accept the null hypothesis of homoscedasticity of the residuals, indicating that the variance of errors is constant in the model. Consequently, the dispersion of errors around the regression line is homogeneous, confirming that our model respects the homoscedasticity assumption.

5. Empirical Results and Discussion

This study set out to answer the central research question: What is the impact of climate change factors on economic growth in Morocco? The results clearly demonstrate that water stress and rising temperatures exert a significant and negative effect on GDP, while deforestation and greenhouse gas emissions are positively correlated with short-term economic expansion. These findings confirm that climate-related variables are not only ecological concerns but also

Table 6. Variance Inflation Factor (VIF) for the research model.

Variable	Coefficient Variance	Uncentered VIF	Centered VIF
C	3.440936	72239.69	NA
ST_EAU	0.000110	132.7348	18.30478
DEFO	1.62E–09	106799.1	30.84537
EGAZ	0.000115	106.9637	3.685049
ATMP	0.000909	6873.793	11.49955

Table 7. Results of the ARCH.

Heteroskedasticity Test: ARCH			
F-statistic	1.459105	Prob. F(1,30)	0.2365
Obs*R-squared	1.484192	Prob. Chi-Square(1)	0.2231

key economic determinants in Morocco's development trajectory. The results concerned the effect of climate change factors on economic growth in Morocco. To this end, we performed a regression of economic growth, represented by the annual GDP, as a function of climate change-related variables using the Ordinary Least Squares (OLS) method. The obtained results are summarized in **Table 8**. The regression model shows a high coefficient of determination ($R^2 = 0.84$), indicating that approximately 84% of the variation in GDP is explained by the selected climate variables. The adjusted R^2 (0.80) confirms the model's robustness while correcting for the number of predictors. The Durbin-Watson statistic (1.92) is close to 2, suggesting no serious autocorrelation problem among residuals, and thus confirming the reliability of the model's estimates.

The results of the regression indicate that the Fisher statistic reaches a value of 244.202, with an associated probability ($P = 0.000$) significant at the 5% threshold. These results confirm the robustness and overall relevance of the model, demonstrating that it effectively explains the variations in the dependent variable.

The regression results indicate a statistically significant negative effect of water stress (measured by renewable water resources per capita) and average temperature on Morocco's GDP growth. Specifically, a 1% increase in temperature is associated with a 0.62% decrease in GDP, consistent with findings in similar arid-region economies. Conversely, deforestation and greenhouse gas emissions exhibit positive coefficients, reflecting the country's reliance on resource-driven economic sectors. These findings suggest that while some environmental pressures may contribute to short-term growth, they pose sustainability risks if not regulated. The high R-squared (0.84) and adjusted R-squared (0.80) indicate a strong explanatory power of the model. The Durbin-Watson statistic (1.92) suggests no significant autocorrelation among residuals.

After conducting tests on the relationship between climate change factors and economic growth in Morocco, we have derived results that support this research. The first significant finding is that the reduction of water resources per cubic meter, measured by water stress, has a negative and significant effect on economic growth. In fact, this result aligns with that of several researchers who have shown that water scarcity exacerbates the effects of climate change by reducing ecosystem resilience and increasing risks to food security and human livelihoods [26]. This justifies the validation of hypothesis H1.

In the Moroccan context, the agricultural and industrial sectors are particularly vulnerable to the impacts of water stress. In agriculture, this phenomenon leads to a significant decrease in productivity, compromising food security and increasing dependence on imports. Consequently, these effects lead to growing economic pressures due to higher import costs and food price volatility. Similarly, in the industrial sector, companies in industries dependent on large amounts of water, such as those specializing in manufacturing and processing, face significant disruptions. These industries experience increased operating costs and production interruptions during water shortages. These disruptions contribute to an overall decrease in economic activity, thereby slowing GDP growth. These findings underscore the need for effective water resource management policies to both

Table 8. Results of the regression related to the functioning of the board of directors.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	–2.930861	1.259636	–2.326753	0.0274
ST_EAU	–0.015647	0.007322	–2.137077	0.0415
DEFO	0.000245	2.37E–05	10.33317	0.0000
ATMP	–0.005192	0.002441	–2.127216	0.0423
EGAZ	0.021973	0.010454	2.101799	0.0447
R-squared	0.972134	Mean dependent var		10.84452
Adjusted R-squared	0.968153	S.D. dependent var		0.228275
S.E. of regression	0.040737	Akaike info criterion		–3.424624
Sum squared resid	0.046467	Schwarz criterion		–3.197880
Log likelihood	61.50629	Hannan-Quinn criter.		–3.348331
F-statistic	244.2027	Durbin-Watson stat		0.997420
Prob(F-statistic)	0.000000			

preserve economic growth and support the resilience of agricultural and industrial systems. In the Moroccan context, previous research highlights similar concerns. According to the Moroccan Ministry of Environment (2020), the country faces increasing water scarcity and biodiversity loss due to recurrent droughts and land degradation. A report by the High Commission for Planning [59] also emphasizes that climate variability has had measurable impacts on agricultural GDP and rural employment. These findings reinforce the relevance of this study's results within Morocco's national policy framework.

The second result shows a positive and highly significant relationship between deforestation and economic growth. This result confirms the findings of several authors [52] who argue that forest exploitation helps stimulate national GDP by strengthening employment in key sectors such as agriculture and forestry. These activities meet the economic needs of countries, particularly in contexts where population growth increases demand for food, raw materials, and jobs [38].

However, these positive effects on economic growth based on forest exploitation come with long-term intensive risks. Overexploitation of forest resources has significant effects on ecosystems, causes biodiversity loss, and reduces environmental services such as the regulation of hydrological cycles and soil protection, which play a fundamental role in the sustainability of agricultural systems and other economic sectors. Therefore, hypothesis H2 is validated [59]. Regarding temperature increase, the results show a negative and significant association with economic growth. This is consistent with studies by several [45], confirming that productivity losses in various sectors are associated with high temperatures.

Furthermore, the Moroccan economy is largely dependent on the agricultural sector, which represents a significant portion of GDP and employment. Temperature increases affect crop productivity by reducing water availability, increasing water stress, and disrupting growth cycles in various sectors. This leads to decreased agricultural yields, causing income instability for households dependent on this sector. This volatility affects their purchasing power, thus reducing their consumption capacity and, by extension, aggregate demand. Economic impacts then spread beyond rural areas, negatively influencing national economic dynamics.

Our findings indicate that water stress significantly reduces wetland sustainability and agricultural productivity, threatening biodiversity. Wetlands, which serve as crucial habitats for diverse flora and fauna, are particularly vulnerable to declining water levels. Reduced water availability leads to habitat shrinkage, loss of aquatic species, and decreased water quality, further impacting dependent organisms. The drying of wetlands also limits their role in carbon sequestration, increasing atmospheric CO_2 concentrations.

Deforestation accelerates habitat degradation, resulting in biodiversity loss and reduced carbon storage capacity. Forest ecosystems play an essential role in stabilizing the climate by sequestering carbon; however, large-scale deforestation diminishes this capacity. Additionally, the removal of forest cover leads to soil erosion, decreasing agricultural productivity and contributing to land degradation. As forests disappear, species that depend on these habitats face higher risks of extinction, further destabilizing ecological networks.

Temperature increases negatively impact soil moisture and forest cover, leading to an expansion of desertification-prone areas. Higher temperatures alter plant growth cycles and disrupt ecological interactions, limiting the ability of species to adapt. The combined effects of rising temperatures and habitat loss create a hostile environment for both plant and animal species, pushing many to migrate or face population declines.

Greenhouse gas emissions correlate with climate variability, affecting seasonal water cycles and ecosystem stability. Increased emissions intensify the frequency of extreme weather events such as droughts and floods, leading to unpredictable environmental conditions that disrupt ecosystem services.

To mitigate these impacts, we propose a series of ecological restoration measures. Afforestation programs can help restore degraded forests and enhance carbon sequestration, while wetland restoration projects can improve biodiversity conservation and water regulation. Sustainable land management practices, such as agroforestry and soil conservation techniques, can reduce land degradation and enhance ecosystem resilience. Additionally, integrating ecosystem-based adaptation strategies into Morocco's national climate policies can strengthen conservation efforts and ensure long-term environmental sustainability.

The results of our research show that greenhouse gas emissions have a positive and significant effect on economic growth. This result is consistent with that of several authors in different countries who have confirmed a strong correlation between CO_2 emissions and economic growth [2]. Indeed, the findings of this research show that in emerging economies and transitioning countries, particularly Morocco's economy, rapid growth is primarily driven by increased industrial activity, which leads to a significant rise in CO_2 emissions. Therefore, hypotheses H3 and H4 are validated.

Moreover, sectors such as intensive agriculture, manufacturing, and fossil fuels, often associated with high emissions, make significant contributions to GDP. The use of fossil fuels for industrial production and transportation promotes economic expansion by increasing production and trade exchanges. Additionally, the modernization of infrastructure, which is often energy-intensive, stimulates short-term growth [10]. In summary, these results highlight the need for comprehensive and targeted energy policies to limit the impact of fossil fuels while responding to the growing demand for goods and services. While the model focuses on economic growth, the environmental variables used—such as water availability, forest cover, and greenhouse gas emissions—are closely linked to ecological sustainability. The results suggest that economic activities contributing to short-term GDP growth may come at the cost of long-term environmental degradation. This highlights the need to integrate environmental sustainability into economic planning, particularly in climate-sensitive sectors such as agriculture, water management, and forestry.

Our findings indicate that water stress significantly reduces wetland sustainability and agricultural productivity, threatening biodiversity. Deforestation accelerates habitat degradation, disrupting species diversity. Temperature increases negatively impact soil moisture and forest cover, leading to an expansion of desertification-prone areas. Greenhouse gas emissions correlate with climate variability, affecting seasonal water cycles and ecosystem stability. Proposed solutions include afforestation programs, wetland restoration, and sustainable land management practices. Policy recommendations emphasize the importance of integrating ecosystem-based adaptation strategies into national climate action plans.

The regression results indicate a statistically significant negative effect of water stress (measured by renewable water resources per capita) and average temperature on Morocco's GDP growth. Specifically, a 1% increase in temperature is associated with a 0.62% decrease in GDP, consistent with findings in similar arid-region economies. Conversely, deforestation and greenhouse gas emissions exhibit positive coefficients, reflecting the country's reliance on resource-driven economic sectors. These findings suggest that while some environmental pressures may contribute to short-term growth, they pose sustainability risks if not regulated. The high R-squared (0.84) and adjusted R-squared (0.80) indicate a strong explanatory power of the model. The Durbin-Watson statistic (1.92) suggests no significant autocorrelation among residuals.

The empirical findings of this study have important policy implications for Morocco's sustainable development agenda. The negative impact of water stress and rising temperatures on economic growth calls for urgent investment in water-saving technologies, resilient agricultural practices, and improved irrigation infrastructure. While deforestation and greenhouse gas emissions appear to be positively associated with economic growth in the short term, these results underline the need for a strategic transition toward renewable energy sources and sustainable land management. Implementing afforestation programs, protecting biodiversity hotspots, and integrating ecosystem services into national development plans are essential for ensuring long-term ecological sustainability. Policymakers should also consider incorporating climate resilience into macroeconomic planning and fiscal policy, promoting green jobs, and encouraging environmentally responsible private investment.

Despite the robustness of statistical analysis, this study has several limitations. First, it uses aggregated national data, which may obscure significant regional disparities in climate vulnerability and economic performance. Second, the observational nature of the study limits causal inference between variables. Third, the model does not account for other relevant macroeconomic factors such as trade flows, demographic changes, or technological innovation, which may influence economic outcomes independently of climate variables. These limitations open avenues for future research using disaggregated or sector-specific data and advanced causal modeling techniques.

6. Conclusions

The findings indicate that climate change has significantly impacted Morocco's ecosystem functioning, necessitating ecological restoration and policy interventions to enhance ecosystem resilience. Water stress, deforestation, rising temperatures, and greenhouse gas emissions have altered biodiversity patterns and ecosystem stability, requiring urgent mitigation efforts. Addressing these challenges demands an integrated approach that combines conservation strategies, sustainable land use practices, and adaptive governance frameworks. To promote ecological protection and sustainable development, national policies should prioritize reforestation efforts, habitat conservation programs, and the expansion of protected areas. Strengthening climate adaptation strategies through wetland restoration, soil conservation, and sustainable agricultural techniques will be crucial for enhancing resilience to climate variability. Additionally, fostering interdisciplinary collaboration between policymakers, researchers, and local communities can ensure the successful implementation of ecosystem-based adaptation strategies. Future research could further explore the long-term impacts of climate change on Morocco's biodiversity and how sustainable development can be achieved through ecological engineering and policy innovation. Investigating the role of renewable energy adoption, circular economy principles, and nature-based solutions in mitigating climate impacts could provide valuable insights into achieving long-term environmental sustainability. Moreover, comparative studies on ecosystem responses across different climatic regions could enhance our understanding of best practices for climate resilience and biodiversity conservation. By implementing proactive ecological management strategies and reinforcing environmental policies, Morocco can mitigate the adverse effects of climate change while ensuring the preservation of its natural ecosystems for future generations.

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Informed Consent Statement

Not applicable.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Conflicts of Interest

The author declares no conflict of interest.

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