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2023

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September 1, 2023

Abstract

Employing a VAR model, this work delves into Madagascar's economic dynamics, particularly its GDP growth, agricultural production, and land use, with a pronounced emphasis on the profound influence of temperature fluctuations. The results illuminate the intricate interplay between economic activities and climatic variations, emphasizing the susceptibility of the economy to temperature changes. This underscores the urgency of formulating adaptive strategies that mitigate the adverse effects of temperature fluctuations, enabling not only economic growth but also environmental sustainability—a synergy crucial for Madagascar's prosperous future.

Keywords: VAR model, Madagascar, GDP growth, agricultural production, land use, temperature fluctuations, economic dynamics, climate change, environmental sustainability

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1 Introduction

Climate change is an international issue. This phenomenon is described as a significant variation in average weather conditions. One of them is global warming. Annual average temperature is extremely increasing year by year and NASA reports 2022 Tied for the 5th Warmest Year on Record (NASA). In developed countries like United-States, the climate change has impact to economic Gross Domestic Product, in agriculture, in water management [4, 29]. In the following sections, we want to determine the impact of temperature on variation GDP of Madagascar identified as developing country. In addition of Temperature, we use as supplementary variable the Agricultural land percentage and Agriculture value added.

2 Literature Review

The intricate interplay between temperature fluctuations and Gross Domestic Product (GDP) in developing countries has garnered substantial attention within the realm of climate economics. Extensive scholarly exploration has delved into the nuanced repercussions of temperature changes on economic growth, particularly focusing on the vulnerabilities and challenges faced by nations aiming to advance amidst a changing climate.

Empirical investigations have underscored that temperature variations wield discernible consequences on the agricultural sector, often serving as a linchpin in the economies of developing nations. Elevated temperatures, particularly in regions reliant on rain-fed agriculture, have been associated with diminished crop yields, reduced agricultural productivity, and compromised food security [5, 12]. These repercussions can reverberate throughout the economy, impacting livelihoods, rural incomes, and overall economic expansion.

Furthermore, temperature oscillations can exert disproportionate effects on the industrial and manufacturing sectors in developing countries. Instances of extreme heat have the potential to disrupt industrial processes, resulting in reduced output and potential supply chain disruptions [18]. Elevated temperatures can also engender augmented demand for cooling and air conditioning, potentially straining energy resources and amplifying costs for enterprises.

The tourism sector, a pivotal economic domain for numerous developing nations, remains acutely sensitive to temperature oscillations. Escalated temperatures can catalyze shifts in tourism patterns by influencing the appeal of destinations and outdoor activities [2]. These fluctuations, in turn, have the potential to affect tourism revenues, subsequently propagating effects through local economies.

The formulation and implementation of adaptation strategies play an instrumental role in alleviating the adverse impacts of temperature changes on GDP. Developing nations, often constrained by resource limitations and institutional capacities, grapple with challenges in effectively executing adaptive measures [1]. Investments in climate-resilient infrastructure, enhancements in agricultural practices, and the formulation of targeted policies constitute avenues for attenuating the detrimental ramifications of temperature oscillations.

Temperature changes relative to their historical norms are causing growth opportunity cost losses for least developed countries like Madagascar. Indeed, the growing socio-economic impacts of global warming present themselves as an obstacle to be overcome in the development of national policies. Its impact is all the more pronounced in a country like Madagascar, where the economy is unable to take off and is therefore vulnerable to external shocks. The costs associated with climate change are therefore disproportionately borne by poor countries that have contributed very little to climate change. These lost opportunity costs in terms of growth are transmitted through several channels, with distinct sectoral effects. Indeed, it is first necessary to look at a few theoretical reviews and then move on to the empirical ones.

2.1 Theory review

A number of theories have explained the relationship between climate change and GDP, including an early theory called *the Kuznets theory: the Environmental Kuznets Curve in 1955.* The Environmental Kuznets Curve, a theory derived from the Kuznets Theory of economics, proposes an analytical model for understanding how economic development and environmental damage can be linked. According to this hypothesis, there is a curved relationship between these two aspects.

At the beginning of the economic development process, when countries have relatively modest incomes, the industrial and production activities needed to stimulate economic growth can have negative repercussions on the environment. This can be attributed to the priority given to economic growth, less stringent environmental regulations and a lack of environmental awareness. These negative consequences, in the form of air and water pollution, deforestation and over-exploitation of resources, may be evident at this stage. However, as average incomes rise with the economy, attention to environmental issues also tends to increase. The harmful effects of environmental deterioration become more apparent, leading to increased demand for more sustainable practices and regulations. In this phase of development, countries can direct their efforts towards adopting environmentally-friendly technologies and methods. Growing awareness within society, as well as efforts by companies to improve their image through sustainable practices, are helping to reverse the trend that is damaging the environment. However, it is essential to note that the relevance of the Environmental Kuznets Curve varies from country to country and from circumstance to circumstance. The interactions between economic development and its impact on the environment are influenced by various factors, including politics, culture, natural resources and technological progress [20, 35].

A second theory, called *the tragedy of the commons' theory in Hardin's 1968 model*, also explains this relationship. The theory formulated by economist Garrett Hardin in 1968, known as the tragedy of the commons, explores the challenges of preserving and managing shared resources. Hardin illustrates this idea by focusing on the problem of overpopulation and the excessive use of shared natural resources, such as common grazing areas and oceans. According to his vision, when several individuals act autonomously and rationally in pursuit of their personal interests, they tend to exploit these common resources to the maximum, leading to their impoverishment or degradation. The "tragedy" aspect of this theory stems from the fact that individual actions, while sensible on a small scale, can have considerable negative effects on a large scale. Each individual is encouraged to exploit resources to the maximum, because this directly benefits him or her, but this collective logic ultimately leads to harmful consequences for everyone. As a result, resources are depleted or deteriorate, causing lasting damage to the environment and society as a whole. To resolve this dilemma, Hardin suggests two main solutions: privatization of common resources, which would assign responsibility to specific individuals or entities, or government regulation to establish rules and limits on the use of shared resources. The theory of the tragedy of the commons emphasizes the importance of cooperation, collective management and informed decision-making in avoiding the harmful consequences of excessive exploitation of common resources. It seeks to balance individual interests with long-term collective one [21].

2.2 Empirical Review

Empirical studies investigating the nexus between temperature variations and GDP in developing countries have provided invaluable insights into the complex interplay between climate dynamics and economic growth. Notably, the study conducted by Burke, M., Hsiang, S. M., & Miguel, E. [5] employed a global dataset to underscore the nonlinear impact of temperature on economic production. Their findings revealed that deviations from the optimal temperature range are associated with substantial economic losses, particularly in agricultural-dependent economies.

Dell, M., Jones, B. F., & Olken, B. A. [12] contributed to this discourse by elucidating the non-linear relationship between temperature and income across various nations. By utilizing panel data, their analysis highlighted the implications of temperature shifts on economic well-being, thereby revealing the potential for decreasing incomes under rising temperatures.

The work of Foster, J., Bell, W., Misra, K., & Kumar, A. [18] delved into the industrial implications of temperature fluctuations. By examining the relationship between emissions and industrial output, they illuminated the intricate ways in which temperature variations can disrupt industrial processes, thereby influencing economic production.

Amelung, B., & Viner, D. [2] conducted a comprehensive analysis of Mediterranean tourism, uncovering the sensitivities of the tourism sector to changing climate patterns. Through the utilization of the Tourism Climate Index, their research demonstrated how temperature changes can impact the attractiveness of destinations and subsequently influence tourism revenues.

Cashin, P., Sosa, S. [7] through VAR models have analyzed that the economic cycles of island developing countries are vulnerable to climate shocks and natural disasters.

Furthermore, Colacito, R., Hoffmann, B., Phan, M. H. [8], using data from the US economy, concluded that rising temperatures lead to lower GDP growth.

Hsiang S., Kopp R., Jina A., Rising J., Delgado M., Mohan S., Rasmussen D., Muir-Wood R, Wilson P. et Oppenheimer M. [23], increasing terrestrial heat will exacerbate already existing inequalities and decrease GDP in territories by examining the likely effects of climate change on a range of economic outcomes concerning several countries.

For predominantly agricultural countries, based on the use of a precipitation-evapotranspiration index, Couharde, C., Généroso, R. [10] explain that climate variability negatively impacts economic growth in these countries. Similarly, using the same index, Couharde C., Damette 0., Generoso R., et Mohaddes K. [9] show that people in low-income countries are highly dependent on local climatic conditions for their production.

Furthermore, according to Burke, M., Hsiang, S. M., & Miguel, E. [5], the negative effects of climate change on economic activities are the same for high-income and developing countries in terms of productivity. However, these adverse effects diminish as countries become wealthier. As a result, poorer countries find it increasingly difficult to adapt over time, while richer countries are able to adapt or at least mitigate the effects of global warming.

Yet, according to Diffenbaugh, N. S., Burke, M. [13], the hottest temperatures will be localized in the poorest countries, so income inequalities between countries will only worsen. Economic growth in these countries will be hampered by reduced production, lower output from workers exposed to high temperatures, a slowdown in investment and a deterioration in producers' health. As a result, the adaptation policies undertaken by these countries will have only limited effects on growth and production.

Other authors, such as Kahn M. E., Mohaddes K., Pesaran M. H., Raissi M., et Yang J. -C. [26] have observed the decline in real per capita output of developing and developed countries following increases in temperature and precipitation relative to their historical norms using the ARDL model with a linear specification. In these analyses, labor productivity is the main transmission channel.

In conclusion, the empirical landscape provides substantive evidence to support the intricate associations between temperature variations and GDP in developing countries. These studies underscore the multifaceted nature of the phenomenon, calling for nuanced policy responses to bolster economic resilience in the face of a changing climate.

3 Analysis of Climate Change in Madagascar Using RCP 2.6 and RCP 6.0 Scenarios

Climate change presents itself as one of the most pressing challenges of our time, with implications spanning global regions. Madagascar, renowned for its unparalleled biodiversity and diverse geography, remains susceptible to the impacts of this phenomenon. In this section, we embark on an exhaustive descriptive analysis of projected climate trends in Madagascar, utilizing data from two distinct scenarios: RCP 2.6 and RCP 6.0. The RCP scenarios, part of the Representative Concentration Pathways (RCPs), depict potential outcomes based on varying greenhouse gas concentration trajectories. RCP 2.6 envisions a future where immediate and stringent mitigation efforts lead to lower greenhouse gas concentrations, while RCP 6.0 portrays a trajectory with continued, though moderated, emissions growth. By employing these datasets, we delve into projections regarding temperature, precipitation patterns, and other vital climatic parameters for Madagascar throughout the 21st century.

This descriptive analysis seeks to enhance our understanding of plausible climate-related challenges that Madagascar may encounter, providing a foundation for a comprehensive evaluation of necessary adaptation measures. Through this exploration, we aim to underscore Madagascar's unique vulnerabilities to climate shifts, acknowledging the intricate interplay of environmental, geographical, and socio-economic factors that will shape these impacts. This analysis serves as a preliminary step towards a comprehensive assessment of strategies aimed at mitigating risks and safeguarding Madagascar's intrinsic natural and cultural wealth in an era marked by climate fluctuations.

3.1 Projected Climate Changes

3.1.1 Anticipated Evolution of Climate Changes - Temperature

In response to the rise in greenhouse gas (GHG) concentrations, the climate of Madagascar is expected to undergo an increase in air temperature. By 2080, compared to the reference year 1876, this elevation is projected to range from 1.5°C to 3.2°C (highly likely range), depending on various GHG emission scenarios (Figure 1).

Compared to pre-industrial levels, climate models suggest a median increase of about 1.6°C by 2030 and 1.8°C by 2050 and 2080, under the emissions reduction scenario RCP2.6. In the context of moderate to high emissions (RCP6.0 [1]), models predict a median temperature increase of 1.5°C by 2030, 2.0°C by 2050, and 2.8°C by 2080.

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[1] The representative Concentration Pathway 6.0 scenario projects a moderate level of greenhouse gas emissions and associated radioactive forcing by the year 2100(IPCC,Year)

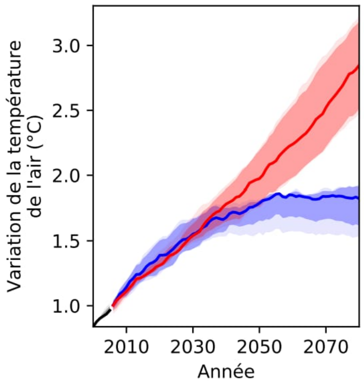

Figure 1: Temperature projections for different greenhouse gas emission scenarios in Madagascar

3.1.2 Increasing Frequency of Very Hot Days

Alongside the rise in annual average temperatures, the number of days characterized by intense heat (where the maximum temperature exceeds 35°C) is expected to significantly increase, particularly in the western part of Madagascar (Figure 2).

According to the moderate to high emissions' scenario RCP6.0, the median of multiple model projections (the countrywide average) indicates an increase of 5 very hot days per year by 2030 compared to the year 2000, followed by an increase of 8 days by 2050 and 24 days by 2080. In certain regions of the country, especially on the west coast of Madagascar, this could result in around 90 very hot days per year by 2080.

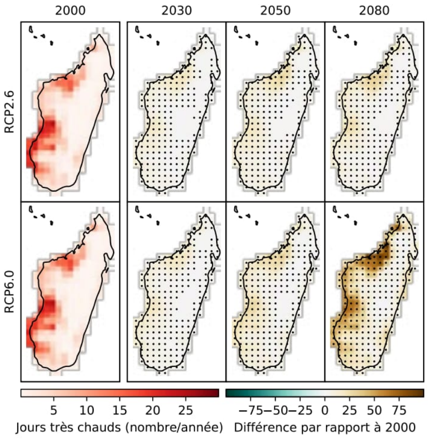

Figure 2: Projections of the annual number of very hot days (daily maximum temperatures exceeding 35°C) in Madagascar for different greenhouse gas emission scenarios

3.1.3 Sea Level Rise

In response to global temperature rise, the sea level surrounding the island of Madagascar is expected to experience an elevation (Figure 3). The two emission scenarios present similar projections up to 2050. Under the RCP6.0 scenario, compared to 2000 levels, the median climate model predicts a sea level rise of 11 cm by 2030, 22 cm by 2050, and 43 cm by 2080. This evolution poses a threat to coastal communities in Madagascar and could lead to saltwater intrusion into coastal rivers and aquifers.

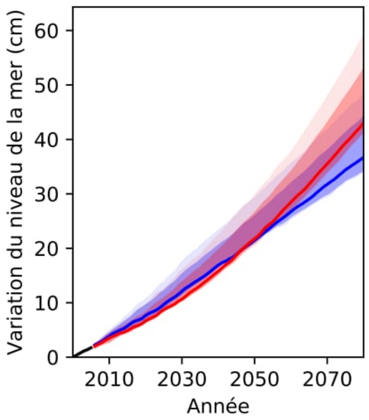

Figure 3: Sea level rise projections for Madagascar under different greenhouse gas emission scenarios compared to the year 2000

3.2 Impact of Climate Change

3.2.1 Agricultural Implications

Agriculture in Madagascar is increasingly confronted with challenges stemming from escalating uncertainty and the variability of meteorological conditions, attributable to climate change [22]. Owing to its reliance on precipitation for irrigation, the efficacy of agricultural yields is closely tied to the availability of rainfall, rendering crops vulnerable to droughts. The growing unpredictability of the rainy season, coupled with limitations in accessing irrigation systems, leads to additional difficulties. In fact, as of 2013, only 60% of irrigation potential, covering 1.5 million hectares (equivalent to 42% of the total cultivated area of the country), was equipped with irrigation systems [16]. Barriers to the implementation of adaptation strategies often encompass constraints related to access to technical equipment, financing, and extension services [22].

Rice constitutes the primary irrigated crop in Madagascar. While elevated temperatures may potentially benefit this crop by eliminating constraints posed by low temperatures, the adverse impact of prolonged high temperatures, combined with strong winds, can also affect yields [3, 19]. Furthermore, more intense drought periods facilitate the proliferation of invasive species, including the fall armyworm. In 2018, the latter contributed to a 47% reduction in maize yields in Madagascar [17].

Current projections reflect a high degree of uncertainty regarding water availability (Figure 4), resulting in similar uncertainty in drought forecasts (Figure 5). According to the median of the models employed for this analysis, the area of cultivable land exposed to at least one annual drought is projected to increase from 0.4% in 2000 to 1.4% under the RCP2.6 scenario and 2.6% under the RCP6.0 scenario by 2080. Under RCP6.0, the range of annual drought exposure probability for cultivable land expands from 0.04-

0.8% in 2000 to 0.9-6.5% in 2080. Similarly, the range of high probability broadens from 0-1.4% in 2000 to 0.4-9% in 2080, underscoring an amplified risk of drought exposure during this period.

Concerning yield forecasts, models indicate a downward trend for cassava and maize under both RCP scenarios (Figure 6). By 2080, compared to the year 2000, cassava and maize yields are projected to decline by 3.8% and 2.7%, respectively, under RCP2.6, and by 2.6% and 2.8% under the RCP6.0 scenario. In contrast, rice and sugarcane yields are anticipated to increase by 2.7% and 9.7%, respectively, under RCP6.0, while remaining stable under the RCP2.6 scenario. This favorable trend under RCP6.0 can be attributed, in part, to the fact that rice, sugarcane, and cassava belong to the C3 category, with differing metabolisms from maize (C4), enabling them to better capitalize on CO2 elevation in terms of fertilization. The anticipated subsequent decline in cassava yields can be attributed to decreased precipitation post-2050 under the RCP6.0 scenario. Although yield variations appear modest on a national scale, they may manifest more intensely in certain regions and, conversely, attenuate further in others due to the differentiated effects of climate change.

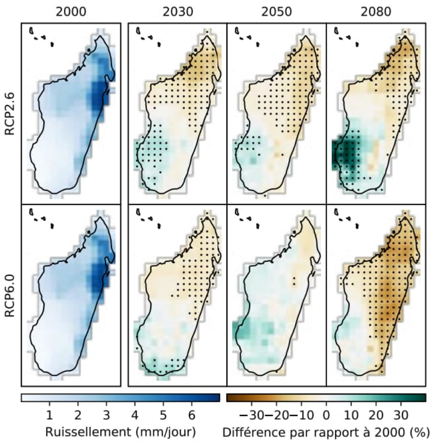

Figure 4: Projected freshwater availability in Madaagscar for different greenhouse gas emission scenarios

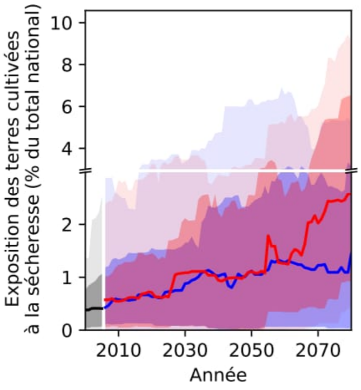

Figure 5: Projected area of arable land exposed to drought at least once a year in Madagascar for different greenhouse gas emission scenarios

3.2.2 Infrastructure Impact

The mounting occurrence of extreme climatic events, stemming from climate change, has profound implications for infrastructure in Madagascar. Escalating precipitation triggers road inundations, while rising temperatures lead to cracks and accelerated degradation of roads, bridges, and coastal structures. These phenomena necessitate proactive repairs, incurring elevated maintenance and restoration costs.

The underdeveloped railway network and limited waterway transportation intensify reliance on roads [28]. Nevertheless, the majority of roads, especially unpaved ones, exist in precarious and scarcely passable conditions, particularly during the rainy season. Madagascar boasts one of the world's lowest road densities, with a road network spanning approximately 31,640 kilometers [28]. Thus, an imperative arises for investment in climate-resilient road networks.

Extreme meteorological events exact devastating repercussions on densely populated areas and economic sites, particularly within densely populated urban regions such as Antananarivo, Toamasina, and Antsirabe. Informal residential zones are particularly susceptible to extreme climatic occurrences. Makeshift dwellings are frequently erected in geographically unstable areas, including steep slopes or riverbanks, exposed to fierce winds and floods, resulting in destruction, water contamination, injuries, and even fatalities. Given their impoverished circumstances and lack of risk-mitigating infrastructure, residents in these zones possess a limited capacity to adapt to such events.

For instance, the tropical cyclone Belna in December 2019 struck Madagascar's northwest coast, affecting 128,000 individuals and causing damage to roads, utility poles, and wells [17, 32]. Floods and droughts will also impact hydroelectric production, constituting 29% of the nation's energy supply [38]. Nonetheless, the variability in precipitation and climate conditions has the potential to disrupt this production.

Despite the heightened likelihood of infrastructure deterioration attributable to climate change, it remains intricate to precisely predict the location and magnitude of exposure to such phenomenon. For instance, river flood projections are marked by considerable uncertainty, stemming from precipitation forecasts and their spatial distribution, consequently influencing flood episodes. Projections indicate minimal changes in the exposure of national roads to river floods [15]. In 2000, 1.6% of major roads were affected by annual floods. By 2080, this proportion is projected to remain stable under the RCP6.0 scenario but to increase to 2% under the RCP2.6 scenario. This aligns with precipitation projections for Madagascar. The exposure of urban areas to floods is expected to remain nearly unaltered, regardless of the trajectory of greenhouse gas concentration [14]. Faced with heightened exposure of the Gross Domestic Product (GDP) to heatwaves, projected to rise from approximately 0.3% in 2000 to 2.4% (RCP2.6) and 4.8% (RCP6.0) by 2080, policymakers are advised to pinpoint heat-sensitive economic activities and sites. Furthermore,

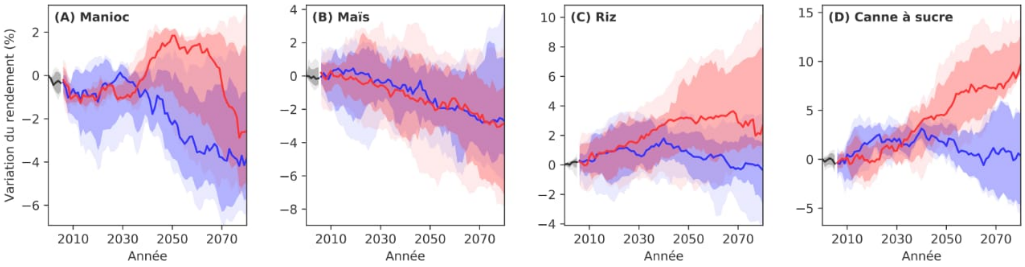

Figure 6: Projections of agricultural yield trends for key staples crops in Madagascar under different greenhouse gas emission scenarios, based on the assumption of no changes in land use and agricultural management

integrating climate change adaptation strategies, such as enhanced solar cooling systems, thermal insulation materials, or even the implementation of nocturnal work schedules, is recommended [11].

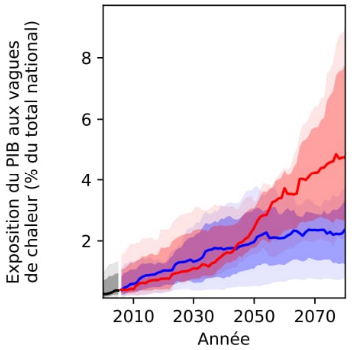

Figure 7: Exposure of Madagscar's GDP to heatwaves for different greenhouse gas emission scenarios

4 Synthesis

This analysis explores how changing temperatures due to climate change affect Madagascar's economy, particularly focusing on agriculture and infrastructure. Let's connect these findings with the broader topic of how temperature influences Madagascar's GDP.

We start by looking at the expected changes in climate. Rising temperatures, caused by more greenhouse gases, are a big deal for Madagascar's economy. By 2080, temperatures could increase by 1.5°C to 3.2°C, affecting the economy and people's lives.

A key point is the increase in very hot days, especially in western Madagascar. More hot days impact things like work, energy use, and health costs, all tied to the economy. This highlights how temperature changes can directly influence economic activities.

Also, rising sea levels due to warmer global temperatures can hurt coastal areas. This affects places that contribute to the economy, like tourism spots. Dealing with this issue becomes important to protect the economy and natural environments.

Switching to agriculture, the analysis shows that changing temperatures and rainfall patterns can affect crop yields. This matters because agriculture is a big part of Madagascar's economy. If crops like cassava and maize produce less, it can impact food supply and economic stability.

Looking at infrastructure, the study talks about how extreme weather events, linked to temperature changes, can damage roads and important structures. These disruptions can hurt trade and everyday life, impacting the economy.

Considering all this in the context of how temperature affects Madagascar's GDP, it's clear that changing temperatures are a big deal. They influence things like farming, roads, work, and coastal areas, which are all part of the economy.

5 Methodology

5.1 Data Collection

We obtained our datasets from the World Bank, which comprises annual observations of several key economic and environmental variables. The focus of our analysis is to understand the relationship between GDP growth (%) and three independent variables: temperature annual mean (TEMP), agricultural land as a% of land area (AGRIAL), and agriculture value added as a % of GDP (AGRIVA).

5.2 Data Transformation

Before subjecting the data to analysis, we performed essential data preprocessing steps. To stabilize variance and potentially linearize relationships, we applied a logarithmic transformation to GDP, AGRIAL, and AGRIVA, creating LGDP, LAGRIAL, and LAGRIVA. Additionally, we calculated first differences for these transformed variables, creating ΔLGDP, ΔTEMP, ΔLAGRIAL, and ΔLAGRIVA. This transformation aids in removing trends and ensures that the series are stationary, a fundamental assumption in time series analysis.

5.3 Justification for VAR Model

The choice of the Vector Autoregression (VAR) model for our analysis stems from its ability to capture the dynamic interactions and feedback mechanisms between variables. Given the multidimensional nature of our dataset, the VAR model allows us to analyze simultaneous relationships between GDP growth and the exogenous variables TEMP, AGRIVA, and AGRIAL. This is particularly valuable when exploring the potential impacts of changes in these variables on GDP growth, as well as their potential interdependencies.

The VAR model also accommodates the temporal nature of the data, which is crucial when studying economic and environmental variables. By including lagged values of the variables in the model, we can explore how past values influence the present and how variables respond to each other's changes over time.
Let $y_t = (y_{1,t}, \ldots, y_{k,t})$ a multivariate series. y_t is a realization of a VAR model if it satisfies for all t the equation:

$$y_t = \phi_0 + \phi_1 y_{t-1} + \cdots + \phi_p y_{t-p} + u_t \ , \tag{1}$$

where, ϕ_0 constant k-vector, the ϕ_i are $(k \times k)$ matrix for all $i > 0$. u_t is white noise vector in k dimensional space, which is centered and have constant covariance matrix Σ_u.

5.4 Model Estimation

After the necessary data preprocessing, we estimated a VAR model with a lag order of 2 (VAR(2)). This choice of lag order was guided by the results of Granger causality tests, which provided insights into the temporal relationships between the variables. The VAR(2) model allows us to capture short-term interactions between GDP growth and the exogenous variables, providing insights into immediate responses and potential causal effects.

In this section, we have outlined our methodology for analyzing the relationship between GDP growth and the variables TEMP, AGRIVA, AGRIAL and AGRIVA. The data has been carefully processed, and the VAR model has been selected as the appropriate framework for our analysis due to its ability to capture complex interactions and dynamic relationships within the data.
Let $y_t = (\Delta LGDP_t, \Delta TEMP_t, \Delta LAGRIAL_t, \Delta LAGRIVA_t)$ a VAR(2). The equation of $\Delta LGDP$ in this VAR model is

$$\begin{aligned}\Delta LGDP_t = c_1 & \\ & + \phi_{11,1}\Delta LGDP_{t-1} + \phi_{11,2}\Delta LGDP_{t-2} \\ & + \phi_{12,1}\Delta TEMP_{t-1} + \phi_{12,2}\Delta TEMP_{t-2} \\ & + \phi_{13,1}\Delta LAGRIAL_{t-1} + \phi_{13,2}\Delta LAGRIAL_{t-2} \\ & + \phi_{14,1}\Delta LAGRIVA_{t-1} + \phi_{14,2}\Delta LAGRIVA_{t-2} \\ & + u_{1,t} \ ,\end{aligned} \tag{2}$$

where $c_1, \phi_{ik,p}$ are constant to estimate, and $u_{1,t}$ a white noise.

6 Results

First, we do unit-root test. With stationary variables, we estimate the VAR model. After that, we test the stability and stationarity of the estimated VAR. We test the stability of the estimated coefficient. Finally, we verify the absence of autocorrelation and the normality of residuals.

6.1 Stationarity Test

We use the Augmented Dickey-Fuller test (ADF) to test the presence of unit-root which implies a non-stationarity of time series. As depicted in table 1, all variables are stationary at level.

Table 1: Result: Unit Root Test: ADF

	Intercept	with trend
$\Delta LGDP$	-5.847***	-5.711***
$\Delta TEMP$	-7.314***	-4.923***
$\Delta LAGRIAL$	-8.609***	-7.753***
$\Delta LAGRIVA$	-5.880***	-4.745***

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$

6.2 VAR Model Estimation

In the final model VAR(2),we fix to 0 the coefficient of $\Delta LAGRIVA(-2)$ witch is not significant for unconstrained model. Principally, in the estimated VAR, we are interested on the equation in witch $\Delta LGDP$ is explained. The table 2 show that the $\Delta TEMP(-2)$ and $\Delta LAGRIVA(-1)$ has a significant negative impact to $\Delta LGDP$. The $AGRIAL(-1)$ affect positively and significantly the GDP, but $AGRIAL(-2)$ impact negatively the contemporary value of $\Delta LGDP$. In addition to that, $\Delta TEMP(-1)$ affect negatively $\Delta LAGRIAL$.

6.3 Granger Causality Test

The causality of significant variables to $\Delta LGDP$ is confirmed by the Causality Test. As seen in Table 3, $\Delta LAGRIAL$ causes in the way of Granger the variable $\Delta LGDP$ at 0.01 significance. $\Delta TEMP$ Granger cause $\Delta LGDP$ at 0.01 significance. Furthermore, $\Delta TEMP$ impact in the way of Granger the variable $\Delta LAGRIAL$ at 0.01 significance. Thus, on the one hand, the variation in temperature impact $\Delta LGDP$ directly. On the other hand, it affects indirectly through $\Delta LAGRIAL$.

Table 3: Causality Test:

Dependent variable	Excluded	Chi-sq	df	Prob.	
$\Delta LGDP$	$\Delta TEMP$	4.732	2	0.0939	*
	$\Delta LAGRIAL$	8.667	2	0.0131	**
	$\Delta LAGRIVA$	–	1	–	
$\Delta LAGRIAL$	$\Delta LGDP$	0.351981	2	0.838600	
	$\Delta TEMP$	14.71253	2	0.000600	***
	$\Delta LAGRIVA$	0.074905	2	0.963200	

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$

6.4 Impulse Response Function (IRF)

We want to know the response of $\Delta LGDP$ to impulse from $\Delta TEMP$, $\Delta LAGRIAL$ and the response of this last to shock from $\Delta TEMP$. As depicted in IRF, an augmentation of $\Delta LAGRIAL$ affects the variable $\Delta LGDP$ after 2 years. The impact is decreasing and canceled after 5 years

Table 2: VAR estimation:

	$\Delta LGDP(-1)$	$\Delta LGDP(-2)$	$\Delta TEMP(-1)$	$\Delta TEMP(-2)$	$\Delta LAGRIVA(-1)$	$\Delta LAGRIVA(-2)$	$\Delta LAGRIAL(-1)$	$\Delta LAGRIAL(-2)$
$\Delta LGDP$	-0.747793	-0.128406	-0.024904	-0.104060	-0.535719	0.000000	8.715276	-6.545290
sd.err.	0.321990	0.203220	0.046270	0.048690	0.281700	–	2.967250	2.422640
t-stat.	[-2.32239]	[-0.63185]	[-0.53827]	[-2.13704]	[-1.90176]		[2.93715]	[-2.70171]
$\Delta LAGRIAL$	0.007982	0.007687	-0.615341	0.004429	-0.001367	-0.003742	0.944652	-0.293896
sd.err.	0.451000	0.428310	0.002580	0.002730	0.015460	0.014400	0.167400	0.135760
t-stat.	[0.45100]	[0.42831]	[-3.43759]	[1.62180]	[-0.08841]	[-0.25993]	[5.64310]	[-2.16474]

(Figure 8). An intensive augmentation of $\Delta TEMP$ does not affect immediately the $\Delta LGDP$. It has a first pick at period 4, then the impact decrease the next year, finally being canceled after this (Figure 9). Last, an intense variation of $\Delta TEMP$ increase the $\Delta LAGRIAL$ at period 2. The impact will gradually decrease and be canceled at 5-th year (Figure 10).

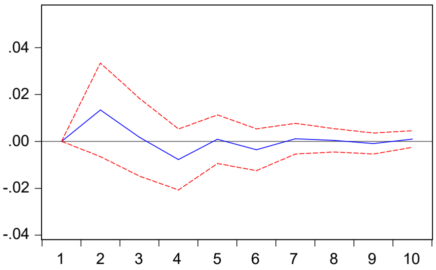

Figure 8: response of $\Delta LGDP$ to Impulse from $\Delta LAGRIAL$

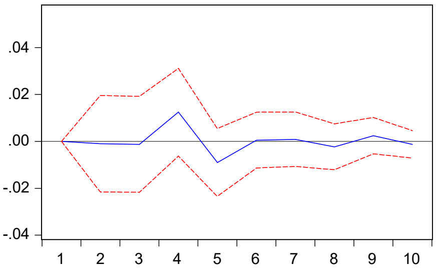

Figure 9: response of $\Delta LGDP$ to Impulse from $\Delta TEMP$

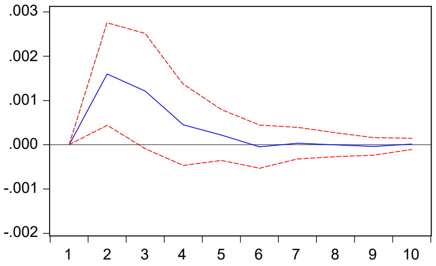

Figure 10: response of $\Delta LAGRIAL$ to Impulse from $\Delta TEMP$

6.5 Stability and Stationarity of the VAR Model

The quality of a VAR model relies on its stability, which is essential for accurate analysis. We confirm this stability by observing that all the roots of the characteristic polynomial lie within the unit disk's interior (depicted in Figure 11). This outcome substantiates the stability of our VAR model and consequently implies its stationarity.

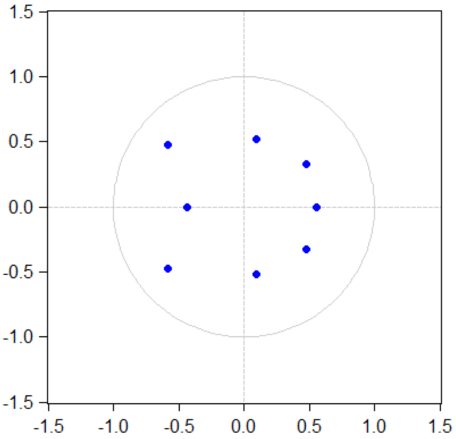

Figure 11: Inverse Root of AR Characteristic Polynomial

6.6 Residual Test

We employed the Breusch-Godfrey Serial Correlation LM Test to ascertain the absence of autocorrelation in the residuals. Our analysis indicates that the residuals of the estimated model, as defined by Equation (2), exhibit no correlation up to a lag of 4 at a significance level of 0.01. Furthermore, the Jarque-Bera test provides evidence to support the acceptance of the hypothesis that the residuals adhere to a normal distribution (as shown in Table 4).

Table 4: Residual tests

LM	F-statistic	0.040069	0.9964
Jarque-Bera	χ^2-statistic	1.5508	0.460

6.7 Coefficient Stability Test

We use the CUSUM and CUSUM-square test to identify anomalies in the fitted model. The test grants that the coefficients are long-term stable. The coefficients are stable at 95% confidence, as depicted in the figure 12.

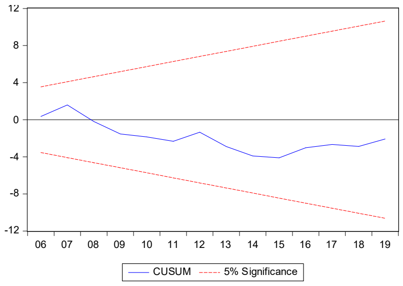

Figure 12: CUSUM test.

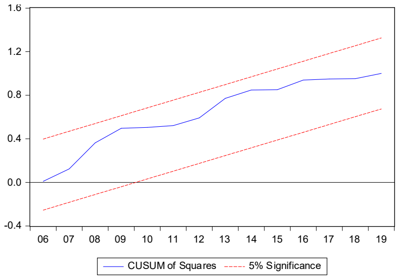

Figure 13: CUSUM-square test.

7 Discussion

The results of our VAR regression analysis have shed light on significant relationships among endogenous variables, namely GDP per capita as well as exogenous variables, namely temperature variation, agricultural production and agricultural land area. These findings resonate with the observed realities in Madagascar, where the connection between climate change and the economy is palpable.

In Madagascar, agricultural production plays a pivotal role in the national economy. More than 75% of the population relies on agriculture for sustenance, and nearly 30% of the country's GDP stems from the agricultural sector. Our observation of a significant positive correlation between GDP per capita and agricultural production aligns with this reality. Fluctuations in agricultural production due to changing climatic conditions can thus have direct ramifications on the economic well-being of the populace.

The impact of temperature variation on the Malagasy economy is also discernible. Over the years, Madagascar has experienced extreme climatic events such as cyclones and droughts. These climatic disruptions have had devastating consequences for agricultural crops, leading to harvest losses and diminished production. Our finding of a significant correlation between temperature variation and GDP per capita reflects this reality, where climatic variations directly influence the country's economic performance.

Likewise, the management of agricultural land area is a critical issue in Madagascar. Uncontrolled expansion of agricultural lands can result in deforestation, loss of biodiversity, and ecosystem degradation. However, when the growth of agricultural land area is sustainably planned, it can positively contribute to the economy. Our result of a significant correlation between agricultural land area and GDP per capita captures this duality, underscoring the importance of responsible management of agricultural resources for sustainable economic growth.

In summary, our VAR regression results find validation through concrete facts observed in Madagascar. The impact of climate change on GDP per capita, mediated by agricultural production, temperature variation, and agricultural land area, reflects the economic and environmental realities of the country. This analysis underscores the need for tailored policies and strategies to address the challenges of climate change while fostering balanced and enduring economic growth.

8 Conclusion

In conclusion, our study has employed a rigorous methodology to investigate the complex relationships between GDP growth and key economic and environmental variables in Madagascar. Through the application of the Vector Autoregression (VAR) model, we have illuminated significant insights into the interconnectedness of GDP per capita, temperature variations, agricultural production, and agricultural land area.

The findings of our analysis resonate strongly with the ground realities in Madagascar. The positive correlation between GDP per capita and agricultural production underscores the critical role of agriculture in the country's economy, where a large portion of the population relies heavily on farming for their livelihoods. Moreover, the discernible impact of temperature variations on GDP growth emphasizes the vulnerability of the economy to climatic shifts, such as cyclones and droughts, that have direct consequences on agricultural yields and, subsequently, economic performance.

Equally important is the linkage between agricultural land area and economic growth. The significant correlation between the two highlights the intricate balance that must be maintained between agricultural expansion and environmental preservation. Responsible land management is crucial to ensure sustainable economic development while safeguarding ecosystems and biodiversity.

Our study's implications are clear: addressing climate change and its ramifications is essential for fostering economic resilience and sustainability in Madagascar. Policymakers should consider these findings when designing strategies that promote economic growth while prioritizing environmental protection and adaptation measures. By acknowledging and acting upon these relationships, Madagascar can embark on a trajectory of inclusive and sustainable development that accounts for both economic and ecological factors.

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