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**The Macroeconomic Impact of Climate Change and the Role of the
Central Bank of Congo**

By

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Abstract

This study investigated the impact of climate change on the economy of the DRC by applying descriptive and a non-linear autoregressive distributed lag model to monthly data from 1990 to 2021. Specifically, the study analyzed the trends between indicators of climate change and financial stability and estimated the impact of carbon dioxide emissions on agricultural production. The descriptive analysis showed that climate shocks, particularly extreme weather events, adversely affect the agricultural and mining sectors and increases non-performing loans (NPLs) which is a threat to financial systemic stability. However, the econometric results show a positive relationship between CO2 and agriculture production both in the short run and in the long run implying that elevated CO2 levels enhance agricultural production, especially in C3 plants. There is therefore need for proactive monetary and prudential measures by the Central Bank of Congo to mitigate climate-related financial risks and ensure balanced monetary policy actions, given the non-uniform effects of climate change on the agriculture sector. Additionally, the DRC authorities should integrate climate stress tests, adjust macroprudential measures, and regularly update their models to enhance the financial sector's resilience to these climate risks. Increased regulation of climate risk disclosures is also necessary and regulators should mandate financial institutions to publish reports detailing their exposure to climate risks.

Keywords: Greenhouse gases, agricultural sector, NARDL model.

JEL Classification: C32, G21, O44, Q53, Q54, Q56, R11.

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I. Introduction

Climate change theories posit that greenhouse gas emissions have led to a rise in global temperatures and extreme weather events over the past fifty years (Hansen, 1981; Hulme, 1996; Adams et al., 1998). These emissions have also impacted on the economy by reducing crop yields, productivity, consumption, investment, and output (Dell et al., 2012; Ericksen, 2009). Global temperatures have increased by over 1.1°C relative to pre-industrial averages and could rise up to 4°C in the coming century (IPCC, 2021). This increase is expected to heighten the frequency and severity of weather-related disasters.

In this context, global landscapes are increasingly vulnerable to climate change risks and the associated long-term impact on the global economy, with a disproportionate effect on developing countries. In these countries, mitigation and adaptation strategies remain limited, and they are affected by the variability of their climate risk profiles, geographical heterogeneity and sector-specific characteristics (BIS, 2021; Koetter et al., 2020; Odongo et al., 2022). The banking sector in these economies is thus exposed to climate risks, regardless of the bank's size, complexity, or economic model. This exposure can be direct, through household balances and climate-sensitive sectors, or indirect, through the effects of climate change on the economy and the financial system at large.

It is crucial to emphasize that the scale of impacts from climate events varies significantly based on the level of economic development of states. Low-income and middle-income countries including the Democratic Republic of Congo (DRC), despite being less polluting, are generally more susceptible to climate risks. Despite its vast forest potential, representing two-thirds of the Congo Basin's forests, the DRC is ranked as the 5th most vulnerable country to climate change globally, according to the ND-GAIN vulnerability index (2021)¹. Due to its low level of economic development, the DRC is also among the 10 most exposed countries to major climate risks such as flooding, localized droughts, coastal erosion, and extreme temperatures. Climate change affects the Congolese economy from both supply and demand sides.

On the supply side, climate events severely disrupt economic activity, particularly in the agricultural sector. Reduced agricultural production leads to higher food prices, which affects the cost of living and deteriorates the trade balance in case of food imports. Additionally, damage to infrastructure necessitates redirecting expenditures towards reconstruction and replacement, impacting productivity, accelerating capital depreciation, and increasing repair costs.

On the demand side, repair and replacement expenditures for damaged goods and infrastructure increase, while investment and consumption for other goods decrease. This situation weakens households and businesses, with ripple effects throughout the economy. These supply and demand shocks result in opposing trends in production and inflation, creating a trade-off for the Central Bank of Congo (BCC) between stabilizing inflation and stabilizing output fluctuations. According to various development scenarios as per the World Bank Report for DRC, (World Bank, 2023), if the DRC continues its current growth trajectory, climate change could lead to GDP losses of between 4.7% and 12.9% by 2050, in the absence of adaptation and mitigation policies. In monetary terms, public investments needed to partially offset climate-related risks

¹ <https://gain.nd.eu/>.

are estimated at around \$2.3 billion by 2030 and \$8.5 billion for 2030–2050, totaling at least \$10.9 billion by 2050, primarily for building improved infrastructure (new and upgraded roads and bridges), creating cooling options to positively impact health and labor productivity, and reducing flood risks for urban infrastructure and livelihoods.² The most significant economic impacts of climate change are expected to stem from thermal stress on rural workers experiencing extreme heat waves, with losses amounting to 4.8% of GDP and potentially reaching 8%, according to the most pessimistic climate scenario. The results of the analysis further highlight the significant impact of adaptation measures in reducing economic damages. By the year 2050, these measures could reduce the impact of climate change on GDP in the most pessimistic climate scenario. Conversely, the absence of such measures would lead to increased budgetary costs.

In response to these challenges, it is imperative for the BCC to integrate climate aspects into its traditional approach to monetary and financial policy. Indeed, the traditional role of the BCC, which includes regulating the money supply, controlling inflation, and preserving financial stability, is now closely linked to managing environmental and climate risks. The central question to examine is: How does climate change influence macroeconomic and financial aggregates in the DRC, and what monetary and prudential policies can the BCC implement? To date, only a few empirical studies have examined the relationship between climate change, macroeconomic aggregates, and monetary policy in the DRC, which makes this study pioneering and unprecedented within the national context. To this end, the objective of this study is to assess the macroeconomic and financial impact of climate change in the DRC, with particular attention to key sectors such as agriculture and mining.

The rest of the study is organized as follows: the next section provides stylized facts on climate change indicators in the DRC while section 3 presents the literature review. The fourth section focuses on the methodology while the fifth section reports the results and provides policy recommendations.

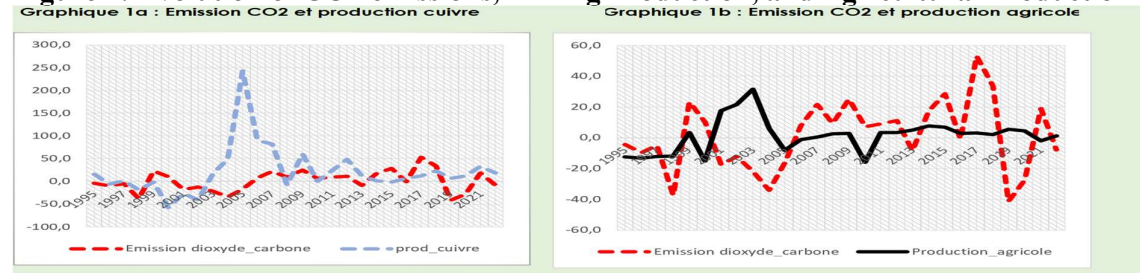
II. Stylized Facts

2.1 Macroeconomic Arguments of Climate Change in the DRC

The analysis in Figure 1a shows a mixed pattern of the evolution of the relationship between shocks (CO₂) and copper production but with a bias towards a positive relationship between copper production and CO₂ emissions. Similarly, the analysis of stylized facts highlights an inverse relationship between CO₂ emissions and agriculture production: as emissions rise, agricultural output tends to decline in the DRC (Figure 1b). This decline, by reducing local food supply, exerts upward pressure on food prices.

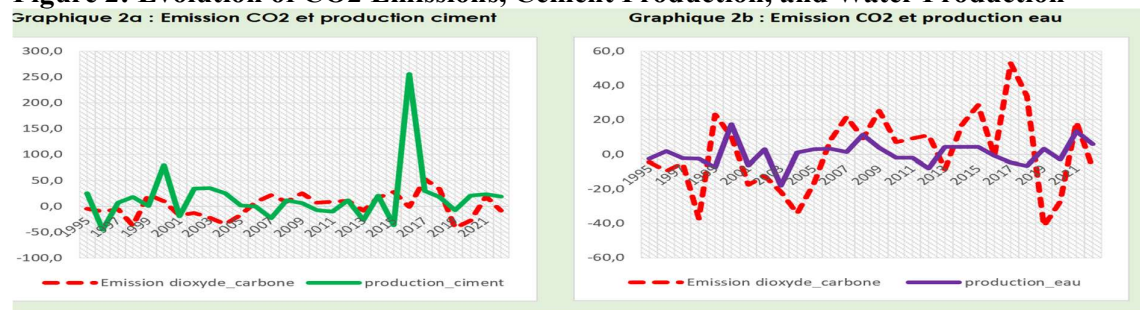
² The details are available in the Country Climate and Development Report for the DRC (World Bank, 2023). As per the Report, the macroeconomic consequences of climate change are evaluated under four distinct scenarios. These scenarios combine two growth trajectories a baseline scenario of maintaining the status quo and an ambitious scenario reflecting accelerated growth with two adaptation options, namely with and without adaptation measures. This approach allows for a comprehensive assessment of the potential impacts of climate change the role of adaptative strategies in mitigating adverse macroeconomic effects,

Figure 1: Evolution of CO2 emissions, Mining Production, and Agricultural Production



The resulting price increases spill over into overall inflation and weigh on households' purchasing power. They also lead to greater reliance on food imports to cover the production shortfall, thereby worsening trade balance deficits and slowing economic growth. Finally, this situation heightens social vulnerability and the risk of food insecurity, particularly among already fragile rural populations.

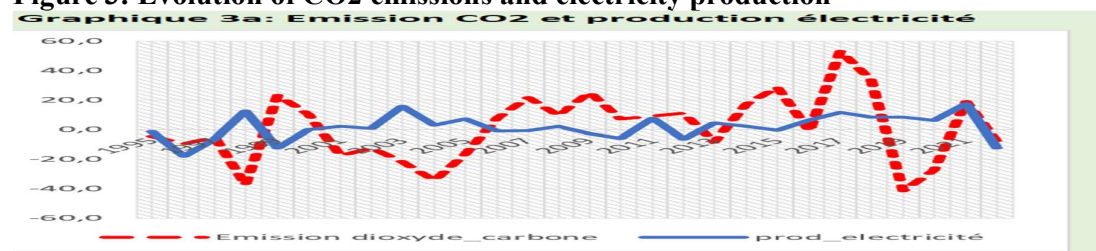
Figure 2: Evolution of CO2 Emissions, Cement Production, and Water Production



Source : Author

Cement production in the DRC follows a similar trend to CO2 emissions, indicating that the increase in these emissions is closely related to cement production. In contrast, CO2 emissions lead to variability in water production with period of positive co-movement and negative patterns, particularly in the last one decade indicating the impact of global warming on weather patterns (Figure 2b). This link suggests that CO2 emissions may contribute to the scarcity of water resources, affecting both potable water supply and agricultural activities.

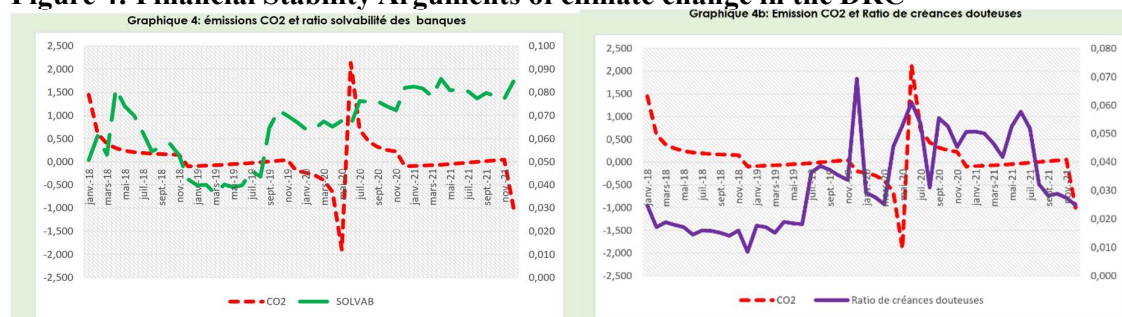
Figure 3: Evolution of CO2 emissions and electricity production



Source : Author

Figure 3 shows a nearly divergent trend between CO2 emissions and electricity production in the DRC, suggesting that climate effects related to CO2 impact electricity production. Fluctuations in water levels caused by droughts or floods reduce the efficiency of hydroelectric dams, thereby disrupting electricity supply. These disruptions affect not only the electricity sector but also the economic, agricultural, and banking sectors.

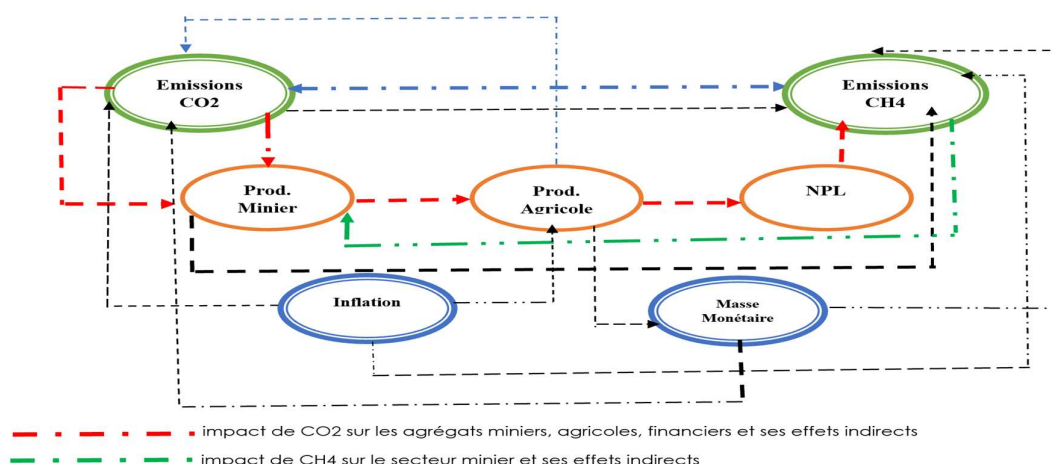
Figure 4: Financial Stability Arguments of climate change in the DRC



Source : Author

The trend analysis of indicators of financial stability shows that extreme climatic events have a significant negative impact on key indicators in the banking sector, including the non-performing loan (NPL) ratio. In this case, events such as droughts, floods, or heatwaves directly affect the agricultural and mining sectors. As a result, household and corporate income decline leading to a reduction in purchasing power. In turn, lower incomes reduce the ability of businesses and households to service their loans, leading to rising defaults and an increase in the NPL ratio. Consequently, the deterioration of bank balance sheets weakens lending capacity, creating liquidity stress and lowering profitability. Credit contraction slows investment and economic growth, while systemic risks threaten the stability of the financial system.

Figure 5: Transmission of Climate Shocks to the Agricultural and Banking Sectors



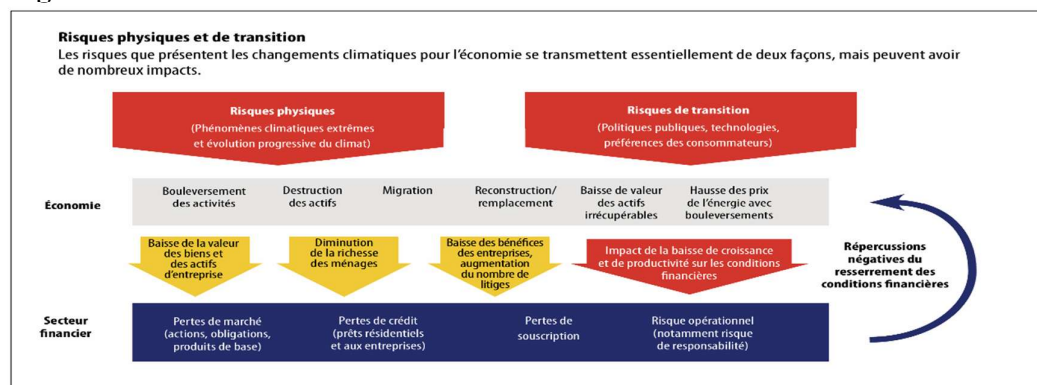
Source: Author

The mechanism of transmission of climate shocks to economic and financial aggregates in the DRC is complex, with interconnected direct and indirect effects across different sectors. CO2 and CH4 emissions interact, mutually amplifying their impact on critical sectors such as agriculture, mining, and banking.

Figure 5 illustrates how climate shocks affect the real economy and the financial sector, highlighting the transmission mechanisms through physical and transition risks. In DRC, climate shocks like extreme rainfall and floods can damage agricultural production and mining infrastructure. For example, floods in 2022 caused crop losses (maize and cassava) and disrupted mining operations (copper and cobalt exports), leading to higher food prices and

reduced export revenues. These disruptions increase inflation, strain household incomes, and raise non-performing loans (NPLs) in local banks, affecting overall economic stability. The interplay of CO₂ and CH₄ emissions from deforestation and mining exacerbates these challenges, further amplifying the economic and financial risks.

Figure 6: Climate shocks



Source: IMF, 2019.

1. **Physical Risks in the DRC:** Direct damage to property, infrastructure, and land leads to significant economic disruptions.
 - In 2019, floods in South Kivu caused agricultural losses estimated at USD 1.2 million, affecting food production and household incomes.³
 - In 2020, crop production declined with a reduction of maize yields by 15%. This leads to increased food costs and decreased farmers' incomes in Tanganyika.
2. **Transition Risks in the DRC:** Changes in climate policies and technologies pose risks to financial assets and the economy:
 - Asset Valuation: The transition to greener technologies has negatively impacted the value of investments in the mining sector in the DRC, which represents about 2% of the national GDP.
 - In summary, climate shocks in the DRC trigger cascading effects on the real economy and the banking sector, from asset depreciation and reduced household wealth to increased non-performing loans and losses on public securities. Proactive management and adaptation of financial policies are crucial to mitigate these impacts.

2.2 Climate Change Challenges in DRC

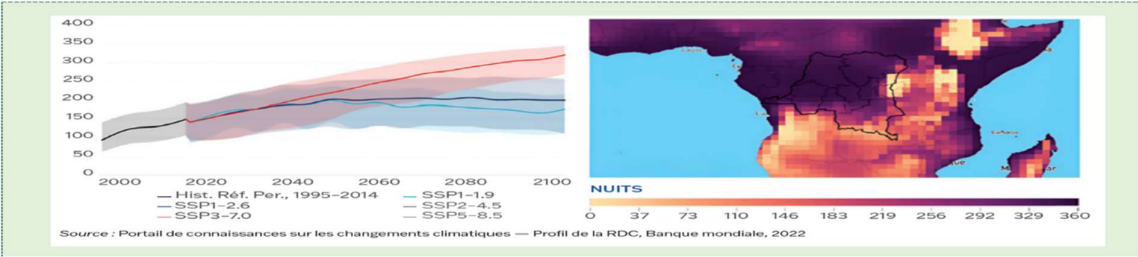
The DRC is highly vulnerable to climate change and its effects but is poorly prepared to cope with them. Ranked 182nd out of 185, the DRC is the 5th most vulnerable country in the ND-GAIN Index 2021 (ND-GAIN Index, 2021) and one of the least prepared to face the effects of climate change (185th out of 192 countries, ND-GAIN Index, 2021). Located in the Congo River Basin, the country is highly exposed to riverine flooding, particularly during episodes of heavy equatorial rainfall. Yet, despite its many water sources, the risk of forest fires has

³ OCHA, Office for the Coordination of Humanitarian Affairs: Analysis of Food Crises in the DRC, 2020.

increased with temperature variations, particularly in regions already prone to drought (IMF, 2023), exacerbating the economic vulnerabilities of the DRC. According to the World Bank (2022), climate disruptions could reduce GDP per capita by 2% to 3% per year by 2050. Extreme phenomena like droughts and floods damage infrastructure, disrupt supply chains, and increase production costs. This economic instability contributes to weaker economic growth and increased vulnerability to global financial crises.

Figure 7a: Forecast of Tropical Nights

Figure 7b: Spatial Distribution of Tropical Nights



Climate changes affecting agriculture, as well as from flooding and the subsequent damage to settlements, roads, communications, and infrastructure. The agricultural sector is likely to face the negative consequences of climate change throughout its entire value chain and workforce, including production, processing, storage, and transportation of crops. Specific details of GHG emissions by sector and economic and financial impact of climate change are detailed in Table 1 and Table 2.

Table 1: Contribution to GHG Emissions by Sector in the DRC

Sector	Contribution to GHG Emissions	Details
Land Use Change and Forestry	Over 90%	This sector is the main contributor to greenhouse gas (GHG) emissions.
Agriculture	2.9% to 4.5%	GHG emissions mainly come from bushfires and the burning of agricultural residues.
Energy	2.6% to 4.4%	CO2 and CH4 emissions have been increasing since 2004, especially after data from the eastern provinces became available. Other greenhouse gases remain stable.
Waste	Less than 1%	Minor contribution to GHG emissions.
Industrial Processes	Negligible (0.1%)	Industrial emissions were 125 Gg CO2-eq in 2000 and reached 264 Gg CO2-eq in 2008. Cement production is the main source of CO2 emissions. Other processes contribute minimally.
Source: Ministry of Environment and Sustainable Development		

This table, based on IPCC data, shows that:

1. **Land Use change and forestry:** Contributes to over 90% of greenhouse gas (GHG) emissions, highlighting the significant impact of deforestation and land-use changes.
2. **Agricultural sector:** Accounts for between 2.9% and 4.5% of emissions, mainly due to bushfires and the burning of agricultural residues. Although less significant than the forestry sector, it remains an important source of GHGs.
3. **Energy sector:** Contributes between 2.6% and 4.4% of emissions, with an upward trend due to new data from the eastern provinces. An energy transition is crucial to reducing this share.
4. **Waste and industrial processes:** Have a marginal contribution, representing less than 1% and 0.1% of total GHG emissions, respectively.

In summary, the agricultural sector is the main source of CO₂ and CH₄ emissions, with significant contributions from bushfires and the burning of residues.

Table 2: Economic and Financial Impacts of Climate Change by Province in the DRC

Region	Impact	Data (Year)	Economic Losses	Sources
Bas-Congo	Floods	2020	Approximately 100 million USD	Report from the National Observatory of Natural Disasters (ONC), 2021
Coastal Erosion	Projections for 2030	Potential loss of 15 km ² of agricultural land per year	National Institute for Environmental Studies and Research (INERE), 2020	
Ituri and Haut-Uele	Drought	2019	Approximately 50 million USD	Ministry of Agriculture of the DRC, 2020
Water Shortages	2021	Increased costs for agricultural activities	Report from the Food and Agriculture Organization (FAO), 2021	
Haut-Lomami and Tanganyika	Rainfall Variability	2021	Approximately 70 million USD	Report from the National Institute of Statistics (INS), 2022
Impact on Agriculture	Reduction in cassava and maize production	Reduced dependence on food imports	FAO, 2021	
Maniema and South Kivu	Deforestation	2015-2020	Approximately 200 million USD in ecosystem services	United Nations Environment Programme (UNEP), 2021
Soil Erosion	2021	Loss of 100,000	Institute for Nature Conservation (ICCN), 2021	

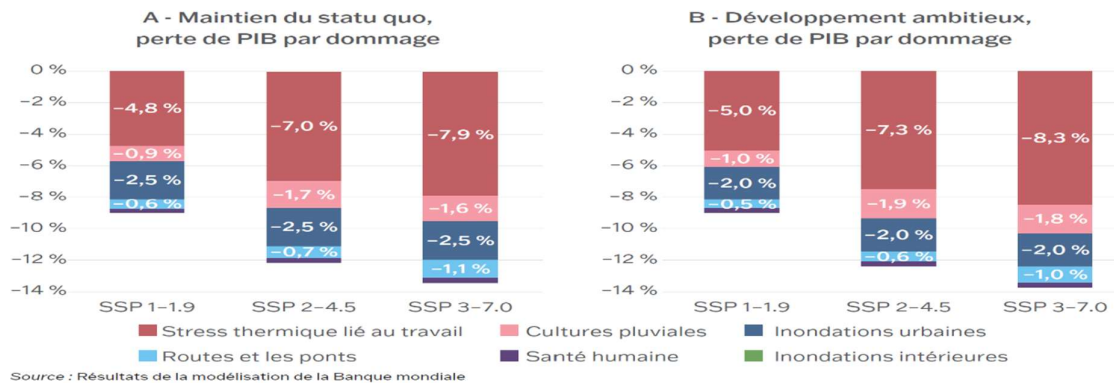
		hectares of forest per year		
Katanga	Changes in Water Resources	2020	Approximately 250 million USD	Katanga Chamber of Mines, 2021
Impact on Economic Activities	2021	Increased operational costs for extractive companies	Report from the Central Bank of Congo (BCC), 2022	
Savanna (Kasai, Tshopo)	Soil Degradation	2010-2020	Approximately 60 million USD per year	INS, 2021

2.3 Cumulative Effect of Climate Risks and Development

The primary consequence of climate change will likely come from hydrological changes that reduce agricultural productivity, access to freshwater resources, and ecosystem degradation. According to various development scenarios, climate change, without adaptation, could result in up to a 13% loss in GDP. The macroeconomic consequences of climate change have been estimated with and without adaptation, under a baseline scenario of maintaining the status quo and an ambitious, faster growth development scenario. The results highlight the significant impact of adaptation measures on reducing economic damage.

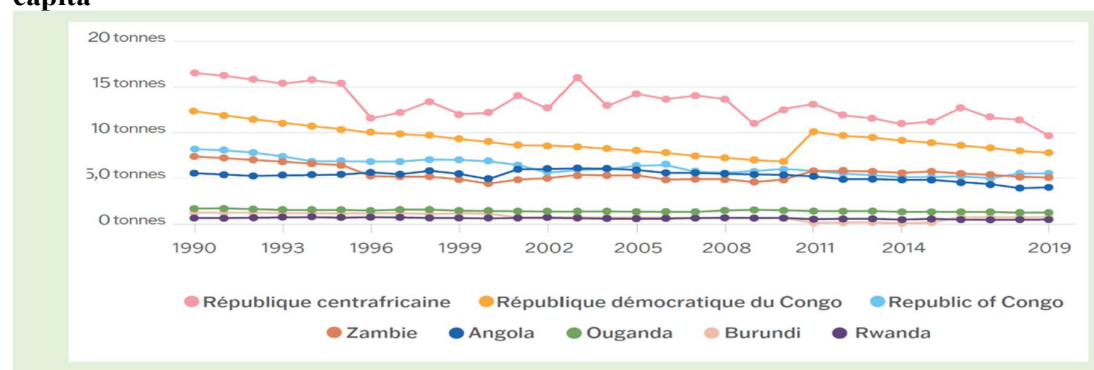
Specifically, some adaptation measures could reduce climate change-related economic damage by more than 40%, not only under the status quo scenario but also within a "resilient development" scenario combining adaptation with ambitious development reforms. If not addressed, climate change will impose significant costs on the economy and exacerbate household vulnerability. The DRC's economic development and growth will contribute to strengthening overall resilience but will not be sufficient on their own. If the DRC continues on its current growth trajectory, climate change could result in GDP losses ranging from 4.7% to 12.9% by 2050, depending on various climate scenarios.

Figure 8: Losses to GDP under Different Climate Scenarios



The most significant economic consequences of climate change are expected to come from thermal stress on rural workers experiencing extreme heatwaves, with losses amounting to 4.8% of GDP and potentially reaching 8% under the most pessimistic climate scenario (SSP3–7.0). Another important factor is the extent of urban damage caused by flooding, with losses amounting to 2.5% of GDP.

Figure 9: GHG Emissions per capita in the DRC and neighboring countries, CO2 per capita



Source: World Bank

Figure 9 shows that the main challenge in the DRC, is to alter the current emissions curve and avoid locking into a high-carbon development model, which is inefficient and costly to reverse. The DRC has reiterated its intention to position itself as a "solution country" to reduce global GHG emissions, with high carbon sequestration potential due to its vast forest resources, significant hydropower production essential to meet the expected increase in energy demand, and to become a low-carbon supplier of transition minerals for clean energy (primarily copper and cobalt).

To achieve these aspirations, it will be necessary to leverage sectors with high growth potential (mining, energy) and allocate the resulting revenues to investments that strengthen the resilience of sectors with high employment and medium-term growth potential (namely agroforestry, commercial agriculture, agro-industry, clean cooking, and services). Clean cooking is a key climate change mitigation measure in the DRC's 2021 Nationally Determined Contributions (NDC), aligned with the United Nations Sustainable Development Goals (SDGs), as well as SDGs 1, 3, and 13.

III. Literature Review

Economic literature has extensively examined the macroeconomic implications of climate change and the role of central banks. Analyses show that climate shocks can have major repercussions on production, inflation, employment, and financial stability through various transmission channels (Stern, 2008; IPCC, 2021).

3.1 Theoretical Review

Theoretically, some authors argue that central banks have not always prioritized climate-related aspects in their action plans (Carney, 2015). This choice can be justified by the fact that, in many countries, price stability objectives remain the primary focus of central banks, relegating

climate risk integration in monetary policy (IMF, 2016). However, recent theoretical analyses highlight a direct and indirect link between climate shocks and economic and financial stability. From a theoretical perspective, several potential action channels for central banks have been identified (Dikau & Volz, 2021; Monasterolo & Raberto, 2017). Nevertheless, the concrete implementation of these levers remains complex, especially in developing countries where data and institutional capacities may be more limited. In this context, the literature emphasizes the importance for central banks to develop a progressive and context-specific approach (Dikau & Volz, 2021).

Central banks are expected to integrate these emerging climate related risks into their monetary and prudential policies to preserve macroeconomic stability (Batten et al., 2016; Villeroy de Galhau, 2015). However, the precise action mechanisms are still debated in the literature, especially concerning developing countries that are heavily dependent on climate-sensitive sectors such as agriculture and mining (Volz et al., 2020; Campiglio et al., 2018).

3.2 Empirical Review

Nabila et al., (2022) used non-linear autoregressive distributional lag approaches to estimate the asymmetric effect of climate change on the economic growth of Pakistan based on annual data covering the years 1980–2021. The results indicated that CO₂ emissions and mean temperature have asymmetrical effects on economic growth, both in the long-run and short-run. On the other hand, precipitation impacted positively on economic growth. Carney (2015) has advocated for central banks to incorporate the impact of climate change on financial stability into their annual action plans. The author identifies three main channels through which climate can affect financial markets: (i) physical risks, (ii) transition risks, and (iii) liability risks. However, this study does not address liability risks.

Yang et al., (2022), used panel data models to analyze the effect of economic growth on CO₂ and CH₄ emissions, controlling for variables such as energy consumption and other economic factors. Their research confirms the Environmental Kuznets Curve for CO₂ and CH₄ emissions using panel data. They found evidence of an inverted U-shaped relationship between economic growth and emissions, suggesting that while emissions increase with economic growth in the early stages, they tend to decrease after a certain income level. Similarly, Burke, et al., (2015), used nonlinear analysis to demonstrate that extreme temperatures significantly reduce economic production. They recommend that central banks consider climate projections when formulating their macroeconomic policies.

IV. Data and Methodology

4.1 Data

This study integrates financial indicators, data on the real economy, and climate variables. Data related to financial stability and the monetary aggregate (M2) are available on a monthly basis. To harmonize all the data, we used the Chow-Lin (1976) method to convert annual aggregates into specific monthly series.

The climate variables selected for this study are carbon dioxide (CO₂) and methane (CH₄). CO₂, a major greenhouse gas, which primarily originates from the combustion of fossil fuels such as coal, oil, and natural gas, used for energy and transportation, as well as from agricultural

activities. CH₄, also an important greenhouse gas, mainly arises from agriculture (livestock, rice cultivation), organic waste, and the extraction of fossil fuels.

The macroeconomic variables analyzed include inflation and Gross Domestic Product (GDP), distinguished by the agricultural and mining sectors. Regarding financial stability, the chosen indicator is the Non-Performing Loans (NPL) ratio, which measures the risk of loss for the financial sector due to loan defaults that have been outstanding for at least 90 days. In this study, the ratio of non-performing loans to total gross loans (NPL) is used as an indicator of credit risk.

Data on climate variables and GDP are sourced from the World Bank indicators (WDI), while data related to financial stability are sourced from the Central Bank of Congo. The study covers the period from the fourth quarter of 1990 to the fourth quarter of 2023.

The study conducted unit roots tests using the Augmented Dickey-Fuller (ADF) tests. The ADF stationarity test results indicate that the selected macroeconomic variable, that is, log(GDP) and the emissions of log(CO₂) and log(CH₄) are non-stationary, but become stationary after differencing (first difference). The ADF results are provided in Annex 1.

4.2 Empirical Model

To assess the macroeconomic impact of climate change, a Nonlinear Autoregressive Distributed Lag (NARDL) model was employed, (Shin et al., 2014). This model, which extends the ARDL approach, not only captures the asymmetric effects of climate variables on economic activity but also identifies critical thresholds where a sign change between the variables may occur. However, it is important to note that, while the model highlight past statistical tendencies, it assumes that these trends will be repetitive in the future. The study aims to model the asymmetric effects of both increases and decreases in carbon dioxide (CO₂) and methane (CH₄) on key macroeconomic variables such as agricultural GDP, mining GDP, and inflation. Additionally, the impact on financial stability is also analyzed, particularly focusing on- non-performing loans (NPL) and the money supply in the DRC.

In this study, the NARDL model is specified as follows:

$$GDP_t = \alpha + \sum_{i=1}^p \phi_i GDP_{t-i} + \sum_{j=0}^q (\beta_j^+ CO2_{t-j}^+ + \beta_j^- CO2_{t-j}^- + \beta_j^+ INFL_{t-j}^+ + \beta_j^- INFL_{t-j}^-) + \varepsilon_t \quad \dots\dots\dots(1)$$

To capture the asymmetric effects, the explanatory variables CO₂ emissions and inflation are decomposed into two series: $CO2_t^+$ et $CO2_t^-$, $\beta_j^+ INFL_t^+$ et $\beta_j^- INFL_t^-$, representing the increases and decreases respectively in CO₂ and inflation.

The use of a nonlinear NARDL model is justified by the nonlinear nature of the effects of climate change on economic activity. The underlying theory is that of tipping points in the climate system. According to this theory, beyond a certain level of greenhouse gas concentration in the atmosphere, the climate may undergo abrupt and irreversible changes that would lead to significant economic and social impacts.

These nonlinear and asymmetric effects of climate change have been highlighted in scientific literature since the mid-2000s. Studies such as Lenton et al. (2008) have identified several potential tipping points in the climate system, such as accelerated ice sheet melting, disruption of ocean currents, and the disintegration of tropical forests.

Thus, the use of a NARDL model allows capturing these nonlinear and asymmetric dynamics, where the impacts of increases and decreases in CO2 emissions on economic activity may differ. This provides a more nuanced understanding of the transmission mechanisms between climate change and growth, which is essential for informing economic and environmental policy decisions. By integrating these components into the model, we obtain:

$$\begin{aligned}
 GDP_t = & \alpha + \sum_{i=1}^p \phi_i GDP_{t-i} + \sum_{j=0}^q \beta_j^+ \\
 & + \sum_{k=1}^{t-j} \max(\Delta CO2_k, 0) \\
 & + \sum_{j=0}^q \beta_j^- \sum_{k=1}^{t-j} \min(\Delta CO2_k, 0) \\
 & + \sum_{k=1}^{t-j} \max(\Delta INFL_k, 0) + \sum_{j=0}^q \beta_j^- \sum_{k=1}^{t-j} \min(\Delta INFL_k, 0) + \varepsilon_t
 \end{aligned}$$

$$CO2_t^+ = \sum_{k=1}^{t-j} \max(\Delta CO2_k, 0)$$

$$CO2_t^- = \sum_{k=1}^{t-j} \min(\Delta CO2_k, 0)$$

$$INFL_t^+ = \sum_{k=1}^{t-j} \max(\Delta infl_k, 0)$$

$$INFL_t^- = \sum_{k=1}^{t-j} \min(\Delta infl_k, 0)$$

- α is the constant term of the model;
- ϕ_i represents the autoregressive coefficients measuring the effects of past values of GDP on its current value;
- β_j^+ et β_j^- coefficients measuring the respective effects of increases and decreases in CO2 levels as well as inflation (INFL) on economic activity;
- ε_t is the residual error term.

The decomposed coefficients of the NARDL model and its lagged terms provide a better understanding of the asymmetric dynamics between variations in CO2, inflation, and GDP. The coefficients show how increases and decreases in CO2 differently affect economic activity, thus capturing the differential impact of positive and negative shocks on the economy.

Taking into account both short-term and long-term effects, the dynamic equation of model (1) can be written as follows:

Short-term and long-term equation

$$\Delta GDP_t = \alpha + \sum_{i=1}^p \phi_i \Delta GDP_{t-i} + \sum_{j=0}^q (\beta_j^+ \Delta CO2_{t-j}^+ + \beta_j^- \Delta CO2_{t-j}^- + (\beta_j^+ \Delta INFL_{t-j}^+ + (\beta_j^+ \Delta INFL_{t-j}^+ + \sum_{j=0}^q (\beta_j^+ CO2_{t-j}^+ + \beta_j^- CO2_{t-j}^- + \beta_j^+ INFL_{t-j}^+ + \beta_j^- INFL_{t-j}^-) + \varepsilon_t$$

.....(2)

The use of the NARDL model allows for capturing of short-term and long-term asymmetries in climatic variables, specifically carbon dioxide (CO2) and inflation.

V. Discussion of Findings

The cointegration test results are presented in Table 3 and the statistical test show an F-statistic of 4.10, which is well above the upper bound value of 3.15, indicating the presence of cointegration among the variables in the NARDL model.

Table 3: Cointegration Tests Results

Test Statistic	Value	Significance	I(0)	I(1)
	Asymptotic: n=1000			
F-statistic	4.10	10%	1.85	2.85
k	8	5%	2.11	3.15
		2.5%	2.33	3.42
		1%	2.62	3.77

The error correction term reflects the speed of adjustment of the model towards the long-term relationship after short-term shocks. This coefficient is negative and statistically significant at the 1% level, indicating the existence of a long-term relationship between the variables.

Table 4: Short-Term Results of CO2 Emissions on Agricultural GDP

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(PROD AGR(-1))	-0.200911	0.112728	-1.782255	0.0885
D(PROD AGR(-2))	0.607810	0.081684	7.441028	0.0000
D(CO22 POS)	0.922805	0.135870	6.791814	0.0000
D(CO22 NEG(-2))	-3.805911	1.022277	-3.722973	0.0012
D(INFL POS(-3))	1.185493	0.389739	3.041762	0.0060
D(INFL NEG)	-1.027838	0.266599	-3.855374	0.0009
CointEq(-1)*	-0.006844	0.000739	-9.265607	0.0000

Source: Author

In the short term, the asymmetric effects of CO2 emissions on agricultural GDP are significant. A 1% increase and a reduction in CO2 seem to increase agricultural growth by 0.92% and 3.8%,

respectively, contrary to expectations implying that in this case elevated CO2 levels enhance agricultural production, especially in C3 plants such as wheat, rice and potatoes. In addition, given the level of economic development of DRC, it is possible that emissions can contribute to increased economic expansion through increased energy use in agricultural production and other sectors such as transport that are linked to agricultural production. For inflation, a 1% increase measured three periods ago raises agricultural production by 1.18%, suggesting that past inflation may stimulate certain agricultural activities due to better price prospects on the agricultural produce.

Table 5: Long-Term results of CO2 emissions on agricultural GDP

Variable	Coefficient	Std. Error	t-Statistic	Prob.
CO2_POS	8.302126	1.582927	5.244794	0.0000
CO2_NEG	18.26418	11.81605	1.545709	0.1364
INFL_POS	-7.974302	118.3847	-0.067359	0.9469
INFL_NEG	87.43660	101.3586	0.862646	0.3976

Source: Author

Long-term results show that an increase in CO2 emissions (CO2-positive) has a significant positive impact on the agricultural sector, with a 8.30% increase in agricultural production for each percentage increase in CO2 emissions. This suggests that, in the long term, increased CO2 emissions significantly benefit the agricultural sector, leading to an 8.30% increase in agricultural production for each percentage increase in CO2 emissions. However, this benefit could be temporary, as long-term negative effects such as climate change might offset these gains. Reductions in CO2 emissions do not have a significant impact on agricultural GDP in the long term, suggesting that other factors may compensate for this effect. Similarly, variations in inflation, whether increasing or decreasing, are not significant in explaining agricultural production.

VI. Conclusion and Recommendations

Integrating climate risks into macroeconomic analysis has become an increasing priority for central banks due to the significant impacts of climate change on economic and financial stability. This study used both descriptive and quantitative approaches to assess the macroeconomic impact of climate change and the role of the Central Bank of Congo.

The descriptive analysis show that DRC is highly vulnerable to climate change and its effects but is poorly prepared to cope with them and that it was ranked 185th out of 192 countries according to ND-Gain Index Report of 2021. Moreover, the analysis showed that the DRC would incur up to 13 percent in GDP losses by 2050 in the absence of mitigation and adaptation measures. The analysis further showed that extreme climatic events have a significant negative impact on key indicators in the banking sector with implications on financial stability. In this case, the study reveals that extreme climatic events reduce agricultural and mining revenues, which deteriorates asset quality and bank capital, leading to an increase in non-performing loans.

The econometric results show a positive relationship between CO2 and agriculture production both in the short run and in the long run implying that elevated CO2 levels enhance agricultural

production, especially in C3 plants such as wheat, rice and potatoes. In addition, given the level of economic development of DRC, it is possible that emissions contribute to increased economic expansion through increased energy use in agricultural production and other sectors such as transport that are linked to agricultural production.

The study provides three recommendations. First the DRC authorities should integrate climate stress tests, adjust macroprudential measures, and regularly update their models to enhance the financial sector's resilience to climate risks. This entails financial regulators imposing requirements on financial institutions to adjust their capital reserves based on their exposure to vulnerable sectors such as agriculture and mining. Secondly, increased regulation of climate risk disclosures is necessary. In line with the recommendations of the Task Force on Climate-related Financial Disclosures, regulators should mandate financial institutions to publish reports detailing their exposure to climate risks. This would ensure better transparency and proactive risk management within the financial system. Thirdly, the study recommends that the Central Bank of Congo consider integrating climate risks into the formulation of its monetary, exchange rate, and financial stability policies. It is crucial to strengthen the monitoring and analysis of climate-related risks, as well as to coordinate efforts with the authorities responsible for environmental and development policies.

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Annexes

Annex 1: Unit Root Test Results

Variables	ADF at Level	P-value	ADF at First Difference	P-value	Order of Integration
Log(PIBMIN)	0.97330	0.9120	-2.2273	0.0025	I(1)
Log(CO2)	0.40525	0.9031	-9.19800	0.0000	I(1)
Log(CH4)	1.41078	0.9601	-2.31647	0.0204	I(1)
Log(NPL)	0.41786	0.7996	-8.45302	0.0000	I(1)
Log(M2)	-2.168091	0.0304	-	-	I(0)
Infl	1.880043	0.0579	-	-	I(0)
Log(PIBAGRIC)	2.653673	0.9975	-2.22970	0.0264	I(1)

Source: Author's calculations.

Annex 2: Correlation Matrix of Economic and Environmental Variables

Correlation Probability	LPIBNIM	LNPL	LM2	LCH4	INFL	LCO2
LPIBNIM	1.000000 -----					
LNPL	-0.075418 0.6104	1.000000 -----				
LM2	0.973412 0.0000	-0.136544 0.3547	1.000000 -----			
LCH4	-0.059115 0.6898	-0.118018 0.4243	0.023365 0.8747	1.000000 -----		
INFL	0.015034 0.9192	0.270586 0.0629	0.028284 0.8487	-0.225328 0.1236	1.000000 -----	
LCO2	0.436213 0.0019	-0.640820 0.0000	0.585805 0.0000	0.456962 0.0011	-0.121089 0.4123	1.000000 -----

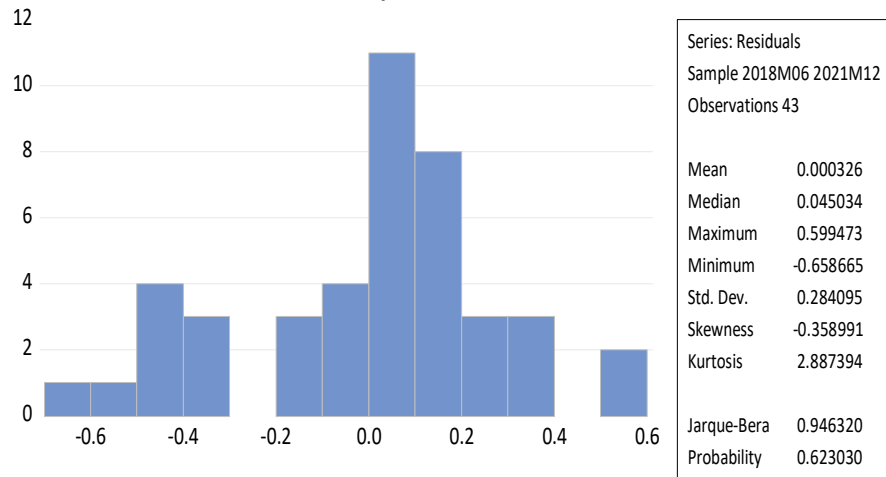
Annex 3: Autocorrelation Test

Heteroskedasticity Test: Breusch-Pagan-Godfrey

Null hypothesis: Homoskedasticity

F-statistic	1.212973	Prob. F(21,21)	0.3311
Obs*R-squared	23.56912	Prob. Chi-Square(21)	0.3144
Scaled explained SS	5.817015	Prob. Chi-Square(21)	0.9996

Annex 4 : Residual Normality Test



Annex 5 : Autocorrelation Test

Breusch-Godfrey Serial Correlation LM Test:

Null hypothesis: No serial correlation at up to 2 lags

F-statistic	0.811727	Prob. F(2,20)	0.4582
Obs*R-squared	3.228369	Prob. Chi-Square(2)	0.1991

Annex 6 : Heteroscedasticity Test

Breusch-Godfrey Serial Correlation LM Test:

Null hypothesis: No serial correlation at up to 2 lags

F-statistic	0.370495	Prob. F(2,116)	0.6912
Obs*R-squared	0.825149	Prob. Chi-Square(2)	0.6619