WORKING paper

BANQUE DE FRANCE
EUROSYSTÈME

# On the Nature of Things: Designing Macroeconomic Scenarios of Nature-related risks for France

**Lauriane Benoist[1], Stéphane Dees[1,2], Elise Kremer[1], Clément Payerols[1] and Oriane Wegner[1]**

May 2026, WP #1046

## Abstract

This paper explores the macroeconomic implications of nature-related risks for France through a forward-looking scenario analysis. We first identify and prioritize key nature-related shocks with potential macroeconomic relevance. Using a multi-country semi-structural model, we then design two illustrative scenarios: one focused on water-related shocks - combining chronic scarcity, declining quality, and acute disruptions - and another on agricultural shocks, including domestic yield losses and a multiple breadbasket failure. The simulations suggest that both scenarios generate material impacts on economic activity and inflation in France. Water-related shocks lead to a stagflationary episode marked by a sharp and persistent decline in output and rising prices, while agricultural shocks result in deeper output losses due to global spillovers and food price surges. These findings highlight the macro-economic relevance of nature-related risks and call for further work on their implications for financial stability.

Keywords: Nature-related risks, Ecosystem services, Macro-economic modeling, Scenario analysis.

JEL: Q54, E32, C68.

[1] Banque de France
[2] Bordeaux School of Economics

L. Benoist conducted this work while at the Banque de France.

Corresponding author: stephane.dees@banque-france.fr. This paper benefited from input from Vladimir Hurstel and discussions with Nicola Ranger, Jimena Alvarez, Andrej Ceglar, Ian Hurst, Iana Ladze, Emmanuelle Assouan, Elsa Allman, Ludivine Berret, Jean Boissinot, Laurent Clerc, and Thibaut Tarabbia. 

# NON-TECHNICAL SUMMARY

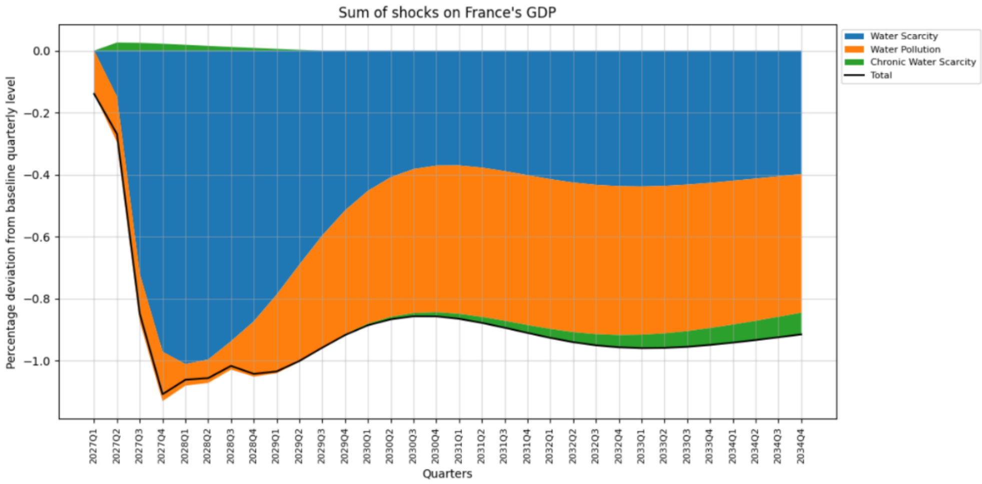
Nature provides the global economy with indispensable ecosystem services – such as water provision, soil formation, and pollination – that form the foundation of human well-being and economic activity. However, scientific evidence indicates that this natural capital is eroding at an alarming rate: nearly half of the world's natural habitats have disappeared since the 1970s, and vertebrate populations have declined by more than 70%. While climate-related risks are increasingly monitored, nature-related risks are more spatially diverse and complex, making them difficult to quantify in traditional macroeconomic terms. This study addresses this gap by examining how nature degradation can trigger tangible economic shocks, using a forward-looking analysis focused on the French economy.

First, we conduct a prioritization exercise to identify the most economically material nature-related risks. Based on a survey of environmental scientists, economists, and financial experts, we constructed probability and materiality scores to filter a wide range of ecological threats. By analysing expert assessments of how these risks interact, we identified six primary risk clusters, focusing our modelling on those with the highest impact: water cycle disruptions and agricultural productivity. Using the NiGEM multi-country macroeconomic model, we simulate, first, a water-related scenario that combines chronic scarcity with acute droughts. Our results show that such disruptions lead to a stagflationary episode in France, characterized by a persistent decline in economic activity alongside rising prices, as water constraints act as a long-term drag on industrial and energy production.

In a second exercise, we model the impact of agricultural shocks, specifically focusing on a multiple breadbasket failure. This scenario explores a situation where domestic yield losses in France occur simultaneously with harvest failures in other major global producers. Because the French economy is deeply integrated into global trade networks, these shocks propagate through international supply chains, leading to even deeper output losses than the water scenario. Our simulations indicate that such events cause sharp surges in food prices and significant inflationary pressure, illustrating that nature degradation in one region can have immediate and severe financial consequences for households and businesses across borders.

Together, these two illustrative exercises demonstrate that nature degradation is not only an environmental issue, but also a material threat to macroeconomic and price stability. If such shocks become more frequent or persistent, they could pose significant challenges for monetary policy, particularly regarding the risk of de-anchoring inflation expectations. Our study also highlights that standard macroeconomic models often struggle to capture the complex, non-linear feedback loops and sectoral interdependencies inherent in nature-economy interactions. Consequently, better data and improved modeling are required to systematically integrate nature into macro-financial risk assessments. Central banks have a critical role to play in enhancing the representation of these risks and ensuring they are integrated into future policymaking and financial stability frameworks.

**Chronic and acute water-related scenario – Impact on France's GDP**




Note: Sum of the contributions of the three shocks to GDP (% deviation from baseline). Chronic water scarcity refers to clay shrink-swell damage, temporarily boosting GDP via repair expenditure before turning negative due to higher insurance premiums.

# De la nature des choses : Élaboration de scénarios macroéconomiques des risques liés à la nature pour la France


## RÉSUMÉ

Cette étude explore les implications macroéconomiques des risques liés à la nature pour la France à travers une analyse de scénarios prospectifs. Nous identifions et hiérarchisons d'abord les principaux chocs naturels présentant une pertinence macroéconomique potentielle. À l'aide d'un modèle semi-structurel multi-pays, nous concevons ensuite deux scénarios illustratifs : l'un centré sur les chocs liés à l'eau — combinant rareté chronique, dégradation de la qualité et ruptures d'approvisionnement aiguës — et l'autre sur les chocs agricoles, incluant des pertes de rendement domestiques et une défaillance simultanée des principaux greniers à blé mondiaux. Les simulations suggèrent que ces deux scénarios génèrent des impacts significatifs sur l'activité économique et l'inflation en France. Les chocs liés à l'eau entraînent un épisode stagflationniste marqué par une baisse brutale et persistante de la production et une hausse des prix, tandis que les chocs agricoles se traduisent par des pertes de production encore plus profondes en raison des répercussions mondiales et de la flambée des prix alimentaires. Ces résultats soulignent la pertinence macroéconomique des risques liés à la nature et appellent à approfondir les travaux sur leurs conséquences pour la stabilité financière.



Mots-clés : risques liés à la nature ; services écosystémiques ; modélisation macroéconomique ; scénarios

# 1 Introduction

Ecosystems provide indispensable services, such as food and water provision, soil formation, pollination, and climate regulation that form the foundation of human well-being and economic activity. Yet, scientific evidence points to an alarming rate of biodiversity loss and ecosystem decline: since 1970, the average size of monitored vertebrate populations has declined by approximately 70% (WWF, 2024), while habitat degradation and land conversion substantially reduced natural ecosystems in many regions (IPBES, 2019). The pressures driving this erosion, including land-use change, overexploitation of resources, pollution, climate change, and invasive species, are intensifying, threatening to disrupt the very systems on which economic production depends (Cardinale et al., 2012; Dasgupta, 2021; Cimatti et al., 2023; Le Provost et al., 2023).

The global economy is deeply embedded in nature: the World Economic Forum estimates that more than half of global GDP is moderately or highly dependent on ecosystem services (WEF, 2020). Disruptions to these services can therefore propagate across sectors and countries through complex production networks and trade linkages. Compared to climate-related risks, nature-related risks are more spatially heterogeneous, and lack a common unit of measurement comparable to carbon dioxide. These features make them difficult to quantify, aggregate, and integrate into forward-looking macroeconomic assessments with the models that were adapted for climate-risks.

For central banks and financial supervisors, this gap is an increasing priority. The degradation of natural capital can generate both chronic and acute shocks with direct implications for price stability and financial stability. Ecosystem collapse, water scarcity, soil depletion, or declines in agricultural productivity can lead to supply constraints, food and commodity price spikes, and long-lasting macroeconomic disruptions. In recognition of these links, several institutions, including the European Central Bank and members of the Network for Greening the Financial System (NGFS), have highlighted the need to integrate nature-related risks into macroeconomic and financial stability frameworks (ECB, 2025; NGFS, 2023b). Yet, empirical and modeling exercises that explore the transmission channels from nature degradation to the macroeconomy remain scarce.

Recent research by central banks has begun to document the economic and financial implications of nature-related risks, focusing on two complementary approaches. First, several institutions have sought to map exposures of the economy and financial system to ecosystem degradation, providing an empirical basis for assessing the materiality of these risks based on the ENCORE database (Natural Capital Finance Alliance, 2019). Among these first studies, De Nederlandsche Bank (DNB, 2020) assessed sectoral exposures across the Dutch economy, while Banque de France (Svartzman, 2021) analyzed the French financial system's dependencies on ecosystem services. These methodologies aim to identify points of vulnerability and inform risk assessment frameworks, and have been used by other jurisdictions since then (Boffo (2024) for Hungary, Calice et al. (2021) for Brazil, World Bank and Bank Negara Malaysia (2022) for Malaysia).

Second, a few scholars have started to investigate the potential macroeconomic consequences of ecosystem degradation through forward-looking scenario analysis. In the United Kingdom, Ranger et al. (2024) developed scenarios exploring the economic and financial impacts of declining ecosystem services for the UK. In addition, Stevanović et al. (2024) also propose global climate-nature scenarios designed to quantify how biodiversity loss and environmental degradation may affect economic output and financial exposures. At the country level, World Bank (2025) assessed the cases of India, Uganda, and Sri Lanka, integrating nature-related shocks into macroeconomic models to illustrate potential growth and fiscal implications. In Europe, Prodani et al. (2023) developed scenarios for the Netherlands that emphasise transition risks linked to nature degradation, together with pollination shocks, highlighting channels through which ecological pressures may affect both the real economy and financial stability. Building on this work, the Banque de France initiated analyses on France, including a study by Wegner et al. (2025) that models the transmission of international agricultural productivity shocks to food prices and inflation in France. These pioneering exercises provide a methodological foundation for short-term macroeconomic scenario development in the context of nature-related risks, complementing ongoing efforts by the NGFS to integrate environmental shocks into central bank modeling frameworks (NGFS, 2025).

This paper contributes to this emerging field by developing a forward-looking analytical framework to assess the macroeconomic implications of nature-related shocks through scenario analysis. We first conduct an exercise to prioritize the most probable and economically material nature-related physical risks, based on the results of a survey of environmental scientists, economists, and financial experts. Building on this survey-based assessment, we construct probability and materiality scores for each nature-related risk by averaging expert evaluations. Overall, a relatively strong convergence was observed among the experts. Risks are mapped in a probability-materiality matrix, allowing for the identification of several categories of risks. To capture interdependencies, experts assess pairwise correlations, which informs a hierarchical clustering analysis. This exercise identifies six non-exclusive clusters of risks: water cycle disruption, threatened crops, animal health and biosecurity, coastal vulnerability, extreme events, and global systemic risks. The present study focuses on three of them: water-related shocks and agriculture, which combines the risks to both crops and animal health.

We then design two stylized scenarios that represent the types of impacts that can arise from these risk clusters. The water-related scenario encompasses both chronic risks – such as declining water availability and deteriorating quality – and acute risks linked to severe droughts or supply disruptions. The second scenario, related to agriculture-related shocks, combines domestic and international effects, including cross-border propagation through trade and the potential for a multiple breadbasket failure.

These scenarios are implemented using NiGEM, a multi-country semi-structural macroeconomic model widely used by central banks and international organizations for scenario analysis. Using the existing literature, we calibrate the magnitude and persistence of the shocks to ensure consistency with the observed historical impacts and recent empirical estimates. The simulations explore how these shocks transmit through production, trade, prices, and financial market channels, highlighting the macroeconomic implications of nature degradation.

The simulation results illustrate that nature-related shocks can generate substantial macroeconomic effects. The water-related scenario leads to a material decline in economic activity and a simultaneous rise in inflation, resulting in a stagflationary episode with lasting persistence. The agricultural scenario produces even stronger output losses due to international spillovers and trade disruptions, while food prices surge sharply, adding inflationary pressure. These findings demonstrate the relevance of nature-related risks for macroeconomic stability and highlight the need to integrate them into stress-testing and policy frameworks. The implications for financial stability are discussed and left for future research.

By integrating nature-related shocks into a well-established macroeconomic modeling framework, this paper seeks to bridge the gap between environmental science and macroeconomic analysis. Beyond providing a first quantitative assessment of the potential short- and medium-term impacts of ecosystem degradation on the French economy, it aims to lay the grounds for the development of nature-related stress testing frameworks, complementing ongoing efforts on climate-related risks.

The remainder of the paper is structured as follows. Section 2 presents the prioritization of nature-related risks, identifying key environmental challenges that can affect macroeconomic dynamics. Section 3 presents the methodological foundations of our nature-related macroeconomic scenarios, explaining how we calibrate and simulate water- and agriculture-related shocks. Section 4 focuses on applications for France, providing a detailed quantification of the two separate scenarios and analyzing their macroeconomic and financial implications, including effects on economic activity, inflation, and financial variables. Finally, Section 5 concludes with a discussion of the main findings, methodological challenges, and avenues for future research.

## 2 Prioritizing Nature-Related Risks

While the degradation of nature is documented through biophysical indicators such as water stress, deforestation, and biodiversity loss (IPBES, 2019), and the main channels through which ecosystem disruptions can affect economic activity and the financial system are well understood (NGFS, 2023a), assessments of the associated economic and financial costs remain limited.

Translating ecological hazards into macroeconomic and financial outcomes is challenging because nature-related physical risks arise from a wide range of disrupted ecological processes and degraded ecosystems, often materialising locally and unevenly across regions. Yet their effects can propagate beyond their point of origin through supply chains, trade and financial linkages. The diversity of hazards and their heterogeneous impacts mean that global scenarios cannot be directly applied to all jurisdictions and must instead be adapted to the specific exposures and vulnerabilities of each economy (NGFS, 2023a; Dasgupta, 2021).

For central banks and financial supervisors, this raises a sequencing challenge. Before quantifying economic and financial impacts, they must first identify which risks are sufficiently likely and material to affect their mandates. The NGFS conceptual framework for nature-related risks reflects this approach by placing risk identification and prioritization as the first step in integrating nature-related considerations into macroeconomic and financial analysis (NGFS, 2023a).

In this section, we therefore conduct a prioritisation exercise for the French economy over a 5-10 year horizon, considering both domestic and imported shocks (both from the EU and beyond). The goal is not to forecast future events, but to narrow the scope of risks considered and provide the foundation for the scenarios used in the remainder of the paper.

## 2.1 Survey of Nature-Related Risks

We construct a Nature-Related Risk Inventory (NRRI) for France, starting from a set of nature-related physical hazards identified by Ranger et al. (2024) for the UK and adapting them to the French context. The resulting inventory comprises 28 risks that may affect France either directly on its territory or indirectly through international spillovers (see Appendix A)

For each risk, we prepared ID cards summarising potential macro-financial materiality and likelihood at three scales: France, the EU, and globally, whenever literature allowed (see the online Supplementary Material). The purpose of these evidence statement is not to provide a definitive assessment, but to ensure that expert judgments rely on a common information base

We then surveyed a panel of 23 experts drawn from 10 institutions, including academia, international organizations, public institutions, and NGOs, with expertise in environmental science, economics, and financial risk analysis[1]. Each expert reviewed the full set of risks and provided two scores for each: a materiality score, capturing the potential of the risk to affect economic activity and the financial system (from 0, no impact, to 5, very large impact), and a likelihood score, reflecting the probability that the risk could affect France over the 5-10 year horizon (from 0, highly unlikely, to 5, highly likely). Experts were also asked to report their confidence in each score on a scale from 0 to 5. This confidence measure is intended to downweight assessments for which experts express greater uncertainty, whether because the underlying risk remains poorly characterised in the scientific literature or because it falls outside their primary area of expertise. While this double interpretation combines different sources of uncertainty, it is suited to our purpose of relative risk-ranking rather than producing precise estimates of materiality and likelihood.

Experts also assessed pairwise correlations among the 28 risks to capture interdependencies. These correlations, based solely on co-occurrence, informed the clustering analysis described below.

## 2.2 Materiality and Likelihood Scores and Matrix

For each risk, we then computed uncertainty-weighted average materiality and likelihood across experts, and the associated standard deviations (see the online Supplementary Material). Overall, a relatively strong convergence was observed among the experts. We used these weighted scores in two ways. First, we combined materiality and likelihood into an aggregate indicator, defined as their product and ranging theoretically from 0 (no materiality and no likelihood) to 25 (maximum materiality and likelihood). Figure 1 shows a top-10 ranking of those risks, with and without weighting by confidence. Once weighted by confidence, the list is dominated by water-related hazards (scarcity, flooding, pollution) and agriculture-related risks (loss of pollination, outbreaks of pests or pathogens, soil degradation). This pattern is consistent with the risks prioritised for scenario development in the United Kingdom by Ranger et al. (2024), even though the specific risks in each group differ, reflecting differences between France the United Kingdom (e.g. France is more exposed to water shortages). One possible reason for those differences could be that, as shown in 1, weighting materiality and likelihood ratings by confidence also

[1]See Appendix B for more information on the expert profiles and affiliations

affects the ranking, pushing some risks down (different approaches in assessing this confidence could therefore explain part of the difference, in particular risks whose probability is complex to estimate, like zoonoses, or for which the literature is less developed).

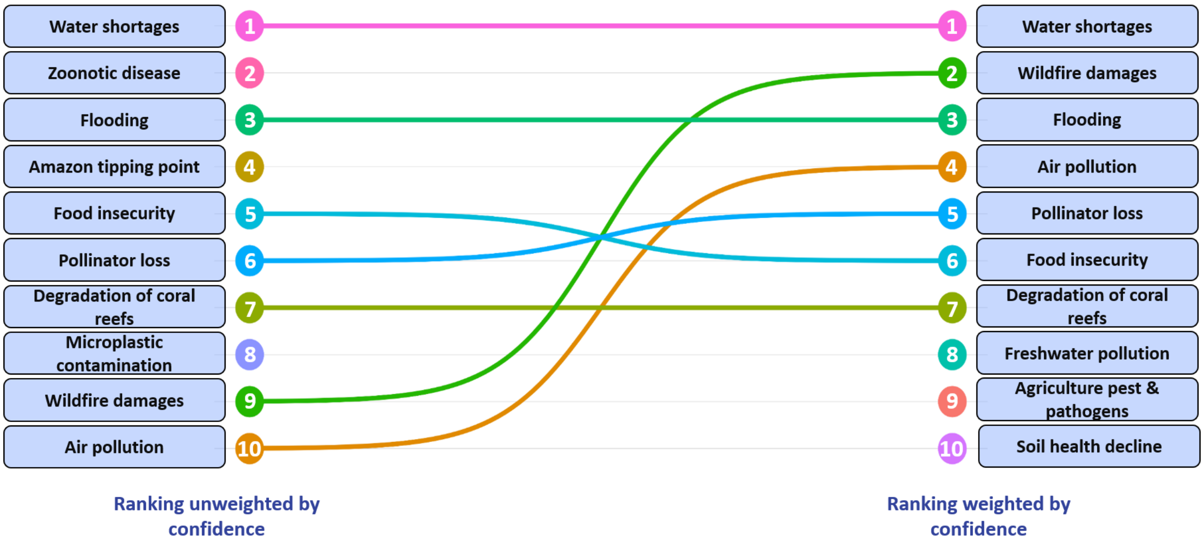



Figure 1: Top ten nature-related physical risks for France, unweighted (left) and weighted (right) by confidence

Second, to retain distinctions between materiality and likelihood, we mapped the uncertainty-weighted scores into a likelihood–materiality matrix (see Figure 2). Median values along each axis divide the matrix into four quadrants, each corresponding to a distinct risk category:

- **High likelihood, high materiality risks**: The upper-right quadrant includes risks that should be prioritised when designing scenarios.
- **Low likelihood, low materiality risks**: The lower-left quadrant contains risks which are not central to the scenario design developed in this paper.
- **High likelihood, low materiality**: While individually less material, the accumulation of such risks may nonetheless contribute to higher aggregate economic and financial costs and should not be overlooked.
- **Low likelihood, high materiality**: Although these risks are less likely to occur within the 5-10 year horizon, their potential economic and financial consequences are sufficiently large that they need to be incorporated in scenarios to capture tail-risk outcomes.

Nature-related physical risks rarely materialise in isolation, but often co-occur or unfold sequentially, reinforcing one another. For example, freshwater scarcity can increase pollutant concentrations, while water pollution reduces effective water availability, jointly amplifying stress on the economy. Ignoring such interactions risks understating macroeconomic and financial impacts. To account for these interdependencies, experts participating in the survey were asked to assess pairwise correlations between the 28 nature-related physical risks included in the inventory, which we use for clustering risks in consistent risk groups.

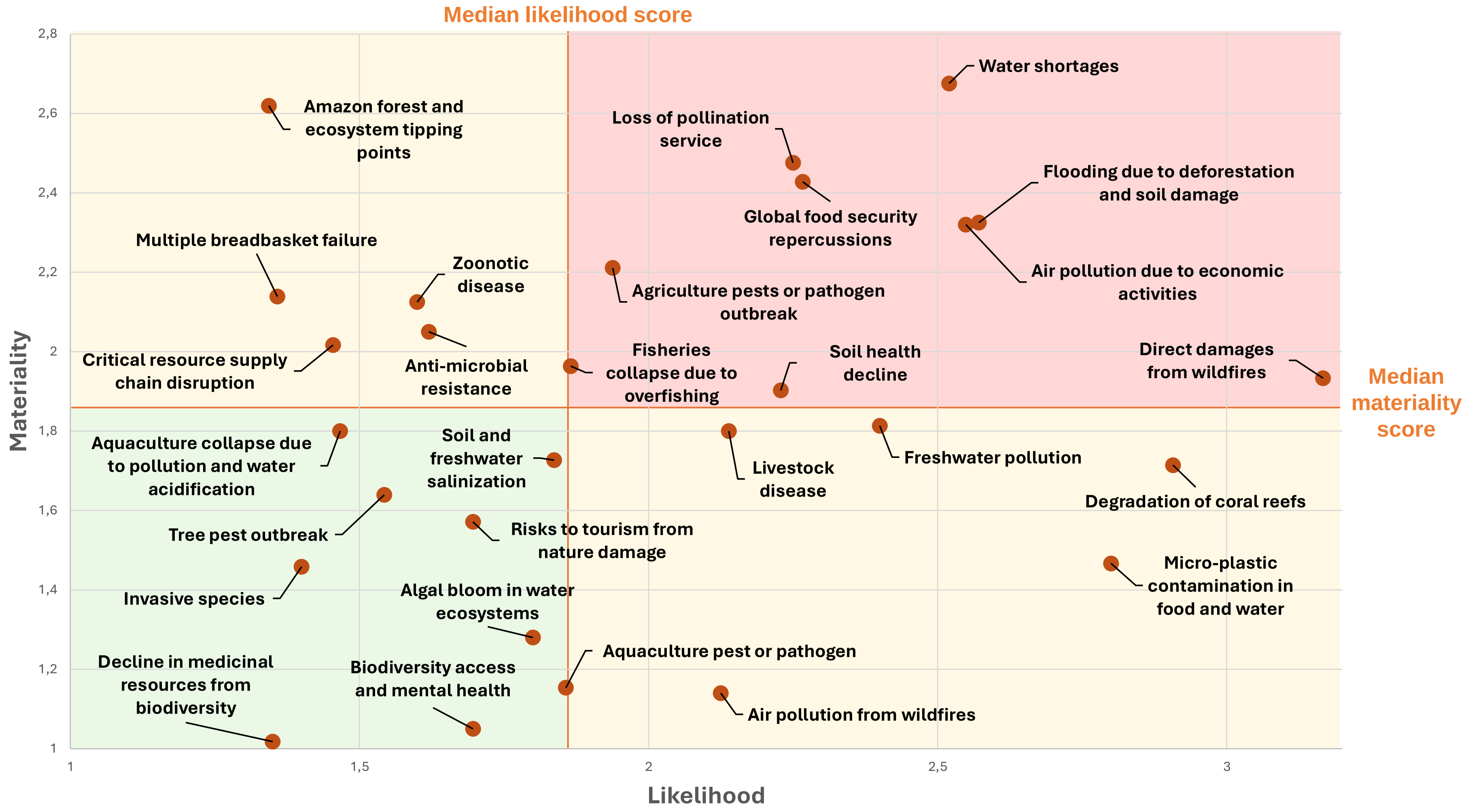



Figure 2: Uncertainty-weighted likelihood-materiality matrix of nature-related physical risks

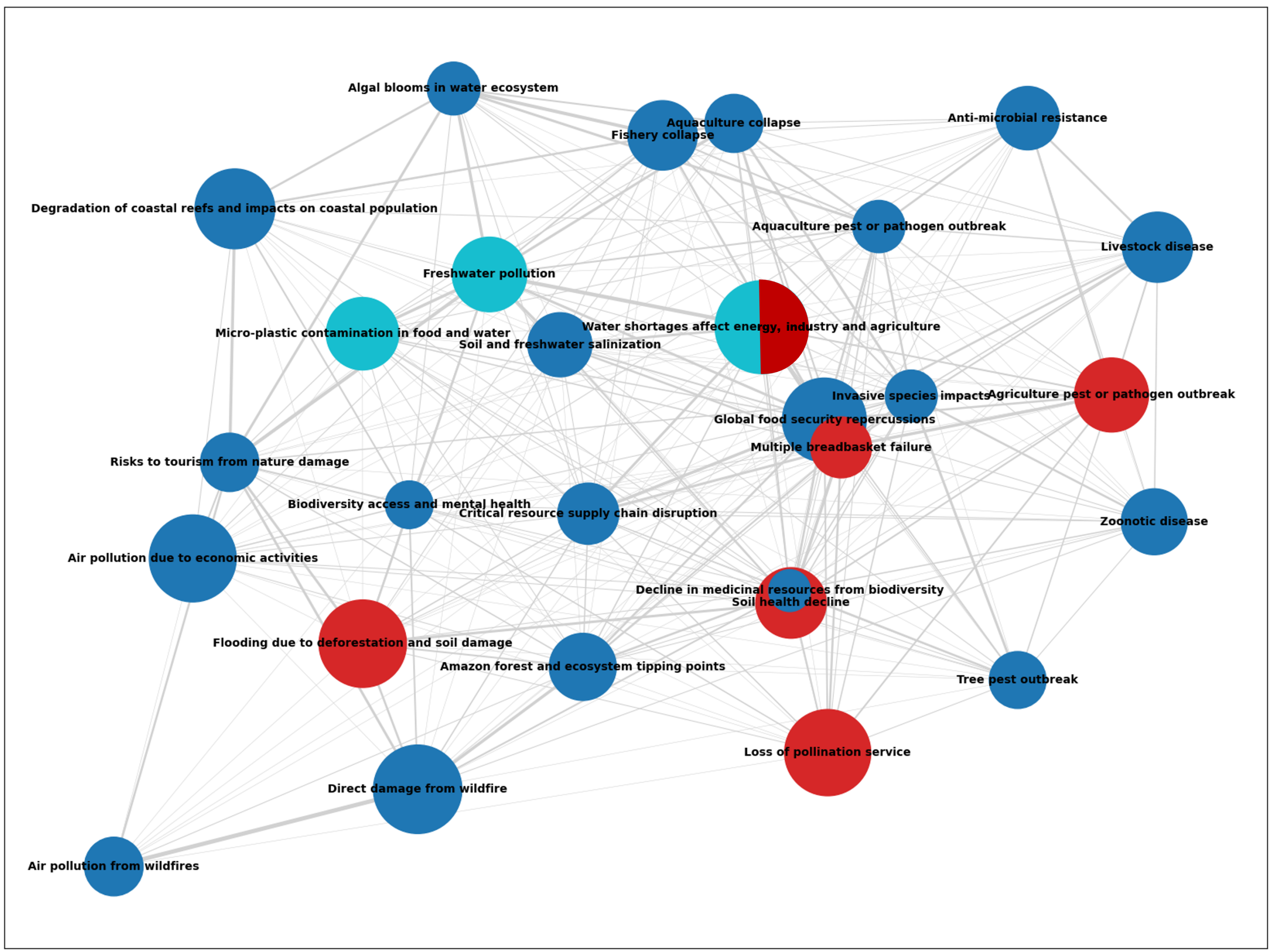



Figure 3: Risks were positioned relatively to each other, using average correlations obtained from the expert panel. In cyan, the group of risks related to disruptions of the water cycle. In red, the group of risks related to threatened crops. In blue, other risks.

For each group, we summarise the constituent risks and their main economic transmission channels. The first three groups (see Tables 1, 2 and 3) serve as the basis for the scenario design developed in the remainder of the paper (the remainder of the groups can be found in Appendix C, together with details on the clustering methodology).

Table 1: Group of risks related to disruptions of the water cycle

| **Risks** | **Primary transmission channels** |
|---|---|
| Water shortages | Agriculture, industry, energy, real estate |
| Freshwater pollution | Agriculture, industry, fishing/aquaculture, water treatment |
| Microplastic contamination | Human health |

Table 2: Group of risks related to threatened crops

| **Risks** | **Primary transmission channels** |
|---|---|
| Agriculture pest or pathogen outbreak | Agriculture, food industry |
| Flooding due to soil degradation and deforestation | Agriculture, real estate, industry |
| Water shortages | Agriculture, industry, energy |
| Loss of pollination service | Agriculture, food industry |
| Soil health decline | Agriculture, water treatment |
| Multiple breadbasket failure | Agriculture, food industry |

Table 3: Group of risks related to animal health and biosecurity

| **Risks** | **Primary transmission channels** |
|---|---|
| Livestock disease | Agriculture, food industry, human health |
| Zoonotic disease | Human health, public expenditure, business interruption, tourism |
| Fishery collapse due to overfishing | Fishing industry |
| Anti-microbial resistance | Human health |

## 3 Building Nature-Related Macroeconomic Scenarios

The primary objective of our quantitative analysis is to generate macroeconomic trajectories under scenarios of nature-related risks and to assess their effects on key macroeconomic variables, notably output and inflation. As in Ranger et al. (2024), we rely on NiGEM (the National Institute Global Econometric Model), a global macroeconometric model developed by the National Institute of Economic and Social Research (NIESR). The model is used to simulate the transmission of nature-related shocks, which are identified and calibrated *ex ante* on the basis of scenario narratives and a dedicated calibration exercise.

### 3.1 The Global Macroeconomic Model

NiGEM is widely used by central banks, governmental institutions, and private organizations for economic forecasting, scenario analysis, and stress testing. In the typology proposed by Blanchard (2018), NiGEM can be classified primarily as a policy model, designed to assess the quantitative impact of macroeconomic shocks or policy interventions while maintaining close adherence to the empirical characteristics of historical data.

From a theoretical perspective, NiGEM belongs to the family of global general equilibrium models inspired by Walrasian theory. In the long run, economies converge to market equilibrium through adjustments in relative prices. Simultaneously, the model incorporates short-term rigidities, such as slow price adjustments, which make economic policies effective over shorter horizons.

NiGEM is structured as a system of interconnected national models, linked through trade in goods and services as well as capital markets. Each national module is neo-Keynesian in structure, embedded within a closed-world framework: the output of one country corresponds to the demand of other countries. The model has a quarterly frequency and is estimated using historical data, enabling it to reproduce key country-specific dynamics and elasticities. Each country model explicitly accounts for the determinants of domestic demand, external trade, prices, current account, and financial positions.

Production within each country is represented by a three-factor Cobb-Douglas function - labor, capital, and energy - assuming constant returns to scale. The energy input is further specified through a nested CES function, which allows for substitution between different energy sources such as coal, oil, gas, and electricity. Among the key features of NiGEM are price rigidities, adaptive or rational expectations (selectable by the user), a flexible monetary policy framework, and long-term fiscal solvency constraints.

### 3.2 Identification and Calibration of Nature-Related Shocks

In our scenario design, the shocks that constitute each scenario are first identified through carefully constructed narratives that describe plausible future pathways of socio-economic, environmental and policy developments. These narratives serve as storylines outlining the key drivers and triggers of nature-related risks and help to characterise specific hazards that could materialise and propagate through the economy. This narrative-based approach to defining shocks is widely used in macroeconomic stress testing and scenario analysis, where expert judgment and internally consistent descriptions of possible futures are translated into model inputs and shock specifications rather than being derived solely from historical data patterns. This is consistent with the NGFS recommendations on nature-related scenarios, which has emphasised narrative scenario design as a way for central banks to identify relevant hazards and pathways for subsequent modelling exercises (NGFS, 2023a).

The narratives are composed of a set of specific shocks, each representing a distinct phenomenon under study. For each shock, the narrative phase identifies the affected sector or market, its domestic or international scope, and the main economic transmission channel, whether operating through prices, supply, demand, or labour markets. Next, the transmission channels of each shock are analyzed within the model. This step determines how the shock propagates through the broader economy, distinguishing country-specific shocks from those with global reach. Particular attention is given to the multiple dimensions of each shock, including simultaneous effects on supply, demand, and prices, as well as potential indirect or unintended consequences.

In a subsequent step, these qualitatively defined shocks are translated into quantitative inputs through a calibration exercise that determines their magnitude, timing and persistence. This calibration is informed by the existing literature, drawing either on empirical studies of historical episodes or on forward-looking scientific and modelling exercises assessing the potential economic impacts of future nature-related risks. In practice, calibration may involve a direct adjustment of the relevant model channels or the replication of impacts estimated in the literature or derived from sectoral expertise. The implementation of shocks is consistent with NiGEM's modelling framework and policy rules, including endogenous two-pillar monetary rule and standard fiscal responses as well as adaptive or rational behaviour by economic agents.

This stepwise approach, illustrated in Figure 4, offers an initial estimation of the systemic risks stemming from ecosystem degradation. Although the underlying macroeconomic model was not specifically designed to incorporate ecosystem services, this method provides a viable way to approximate those linkages. Building on this approach, which is similar to Ranger et al. (2024), individual shocks can be combined into integrated scenarios to evaluate the broader macroeconomic impacts of nature-related risks.

# 4 Building Nature-Related Scenarios Applied to France

In this section, we design narratives and illustrative scenarios for two major categories of nature-related physical risks identified in the NRRI: water-related shocks and agriculture-related shocks. These two scenarios vary in their underlying risk drivers and geographical scopes. The water-related shock predominantly reflects domestic vulnerabilities, whereas the agriculture-related shock captures international spillovers transmitted through global food markets and trade linkages.

## 4.1 Water-Related Shocks: Chronic and Acute Risks to Economic Activity and Inflation

We first detail the water-related scenario, focusing on how scarcity and quality degradation affect the macroeconomic variables.

### 4.1.1 Narrative of the Water-Related Scenario: Scarcity and Quality Degradation

The contemporary challenge of water management is defined by a dual risk: the rarefaction of the resource (scarcity) and the degradation of its quality (pollution). These two threats, intrinsically linked to climate change, demographic growth, and the intensification of uses, constitute a major strategic constraint for France.

These pressures are exacerbated under scarcity conditions, which reduce dilution capacity and lead to higher concentrations of pollutant loads in rivers and aquifers.

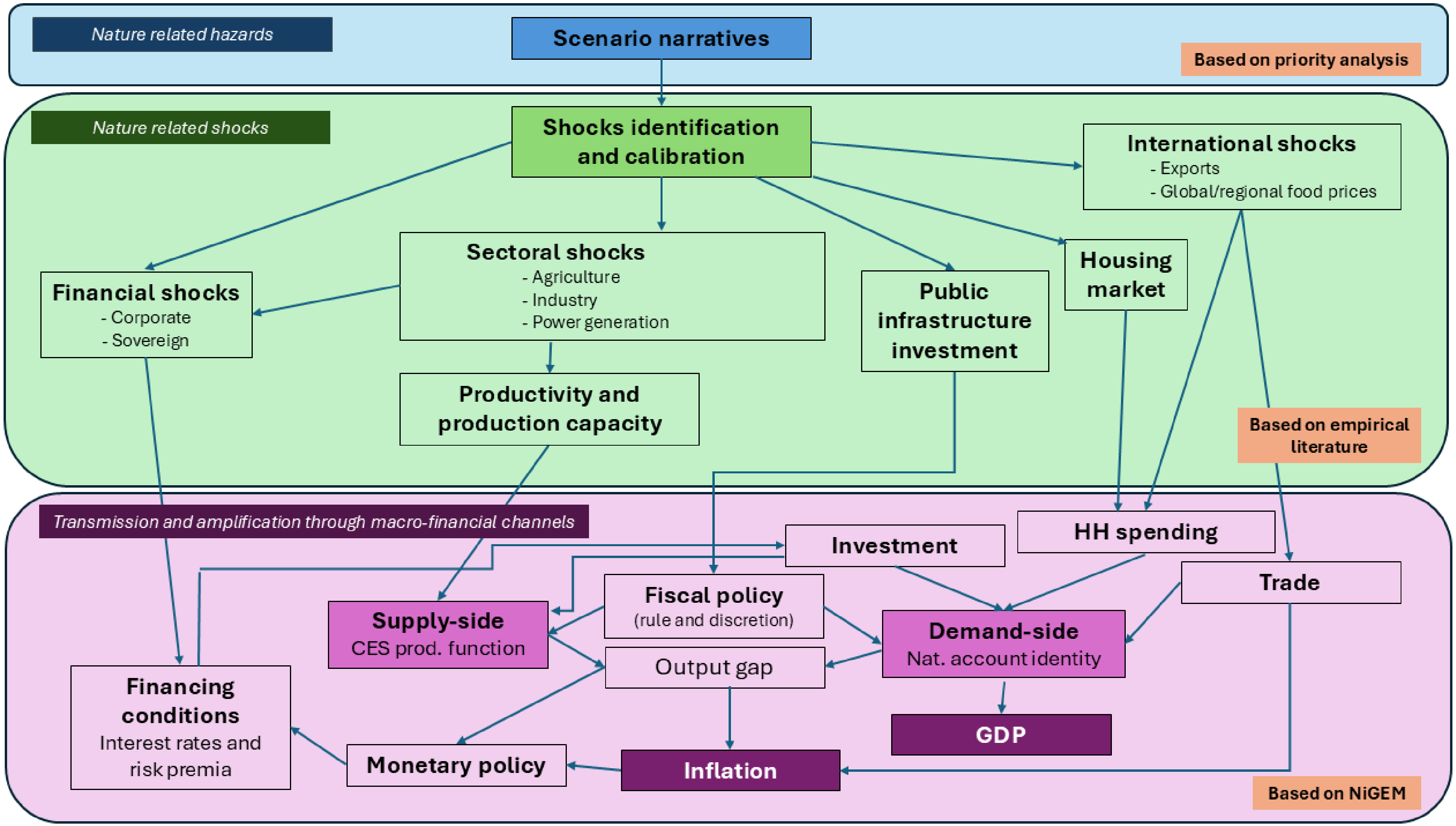



Figure 4: A flowchart of the approach to build nature-related scenarios

Freshwater scarcity is defined as the sustained insufficiency of resources to cover the needs of human uses and ecosystems. It encompasses the physical rarefaction phenomena linked to droughts (meteorological, hydrological, or edaphic). The materiality of this risk for France is significant, particularly for key sectors. Agriculture is highly vulnerable: the CGAAER (2022) anticipates water-related additional costs and losses due to extreme climatic events (including droughts) that could each reach one billion euros, against a total value added of plant production of approximately 40 billion euros. The energy sector, especially nuclear power, also faces environmental constraints. The Cour des Comptes (2023) reported losses in nuclear electricity production (1.4% of total production in 2003) related to high river temperatures and low flows, losses that are expected to intensify in the coming years. Furthermore, precipitation anomalies induce significant reductions in hydroelectric production (Colesanti Senni et al., 2024).

The risk of freshwater pollution corresponds to the degradation of the quality of water bodies (groundwater and surface water) resulting from the discharge of chemical, biological, or physical substances. In France, chemical pollution originating from agriculture, industry, or wastewater treatment plants remains the primary source of contamination. Although the Ministry of Ecological Transition (Ministère de la Transition Écologique, 2026) observed until 2022 a general improvement in the ecological and chemical status of water bodies, a significant portion of water masses remains polluted, particularly in the northern half of the country. This progress is slowed by a notable stagnation in pollution from nitrogen and pesticides/herbicides. A major emerging challenge is posed by per- and polyfluoroalkyl substances (PFAS), dubbed "forever chemicals" due to their non-degradable nature (CNRS, 2025), whose concentration in ecosystems and the human body is increasing.

The impact of pollution translates into substantial economic costs. At the macroeconomic level, academic literature confirms the materiality of the risk: moderate water pollution can lead to a reduction in the GDP growth rate of 2.5 percentage points in middle-income countries, while a high level of pollution can reduce GDP growth by approximately 0.3% in developed countries (Russ et al., 2022). These estimates can be considered conservative as they do not include PFAS in the scope of pollutants.

Beyond their respective impacts, water scarcity and water pollution interact through a set of reinforcing mechanisms that determine the availability of usable water for economic activities. Reduced river flows and declining groundwater levels increase the concentration of pollutants, contributing to poorer water quality during periods of scarcity (see, e.g., van Vliet et al., 2017 or Mosley, 2015). Conversely, degraded water quality limits the range of uses, particularly for drinking water, agriculture, energy production, and industrial processes, effectively reducing the volume of water that can be used even when physical quantities remain available (Li et al., 2022). The two risks therefore compound, amplifying their macroeconomic consequences.

Our "Integrated Water Stress Scenario" models the macroeconomic implications of an exacerbated water stress trajectory, encompassing a chronic degradation of water resources (quantity and quality) culminating in a major acute event in 2027. The chronic component, characterized by intensifying supply-demand imbalances and persistent pollution, imposes a growing structural burden on the economy.

The scenario spans over the period 2027-2032 (Figure 5). In 2027, an episode of excep-

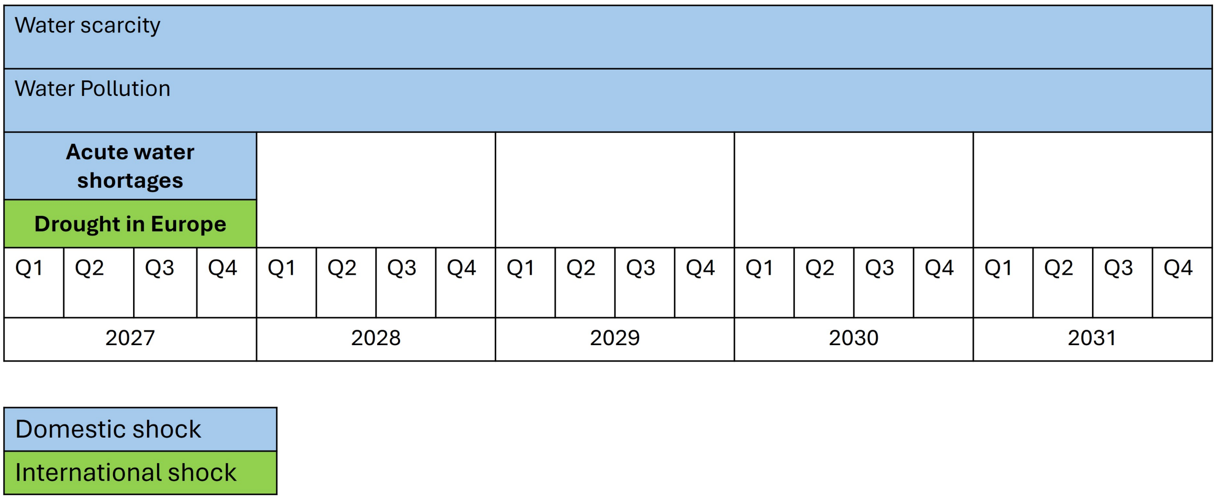



Figure 5: Description of the Water-Related Scenario and its Timing

tional intensity and duration strikes France and a large part of Southern and Northern Europe simultaneously. This acute shock severely exacerbates the impacts of chronic water imbalance:

- **Energy and Industry:** Low flows and high river temperatures lead to widespread shutdowns of nuclear power plants and necessitating a reduction in electricity exports. Water restrictions are extended to non-essential industrial sites, causing widespread production slowdowns.

- **Agriculture and Food Prices**: Water use restrictions become generalized, leading to a drastic fall in agricultural yields. The pan-European nature of drought amplifies crop shortages across the continent, immediately resulting in severe food price inflation and disruption of national supply chains.

- **Geo-Hazards**: Long-term soil desiccation exacerbates geotechnical risks related to clay shrinkage and swelling. This phenomenon causes extensive structural damage to infrastructure and buildings, leading to increased insurance costs and substantial public expenditure on emergency repairs.

In addition to this quantity-related issues, the scenario includes the costs of managing water quality[2]. The cumulative cost of emergency water supply measures, and essential programs to renew obsolete water networks results in a significant increase in public expenditure. This surge puts pressure on sovereign finances, leading to a widening of sovereign spreads as the market prices in the long-term financial liability associated with water infrastructure deficits.

Finally, the financial sector reacts to the heightened risks by increasing selectivity financing costs. Institutions exerting high pressure on water quality (e.g., through chemical or pesticide discharge) face higher risk premiums or credit restrictions, reflecting the growing materiality of pollution risk. This tightening particularly affects water-intensive or polluting agricultural SMEs and industrial firms, putting downward pressures on their investment expenditures and exacerbating failures among vulnerable businesses.

[2]While freshwater pollution also affects human health – acting as a primary transmission channel for nature-related risks – this dimension is not explicitly quantified as a shock in our current frameworkdue to a lack of literature on emerging pollutants.

### 4.1.2 Calibration of the Water-Related Shocks

The calibration of the shocks included in the scenario is detailed in Table 4. Acute water scarcity events, primarily driven by severe drought, are modeled as immediate, high-impact shocks across critical sectors. The primary transmission channel is a direct disruption of productive capacity, quantified as a significant reduction in trend capacity output. This is evident in the energy sector, where both nuclear power (via temperature constraints on discharge) and hydroelectric production (via reduced river flows) incur immediate losses. Furthermore, the shock cascades into the real economy through widespread industrial restrictions and severe agricultural losses, which also translate into a direct inflationary pressure on food prices. The acute shocks emphasize the immediate macroeconomic materiality of insufficient water supply on GDP growth potential. In addition, we incorporate a reduction in export volumes linked to the decline in nuclear energy production. The magnitude of these water-scarcity-related shocks is calibrated using historical production losses observed in France. For the agricultural sector and its price effects, the calibration draws on empirical evidence of how droughts affect consumer price inflation, using estimates expanded to the European country sample. For chronic shocks (both water scarcity and pollution), when the calibration relies on projected values, we assume a linear increase from zero at the starting point to the projected value in 2050 (the sources of shock calibration are detailed in Table 4).

Table 4: Summary of Water Risks (Scarcity and Pollution)

| **Risk** | **Transmission Channel** | **Impact (NiGEM variable names in parentheses)** | **Shock Value** | **Sources** |
|---|---|---|---|---|
| **Acute Water Scarcity** | Energy production losses: Nuclear production due to water discharge temperature regulations | Reduction in exports (FRXVOL) | 2027Q3 : -0.37% | Historical losses - Year 2022 (Cour des Comptes, 2023) |
| | Energy production losses: Losses in hydroelectric production due to reduced river flow | Reduction in trend capacity output (FRYCAP) | 2027Q2 : -2% | Historical losses - Year 2022 (Rannou, 2025) |
| | Agricultural losses: Production losses in the agricultural sector due to soil drought and water restrictions | Reduction in trend capacity output (FRYCAP) | 2027Q1 to Q3 : -0.90%, -1.81%, -0.90% | Projected losses (OECD, 2025) |

Continued below

**Table 4 continued from previous page**

| **Risk** | **Transmission Channel** | **Impact** (NiGEM variable names in parentheses) | **Shock Value** | **Sources** |
|---|---|---|---|---|
| | Agricultural losses: Food inflation | Increase in consumer prices (CED in European countries) | 2027Q3 : +0.45 | Historical values - Year 2022 (Kotz et al. (2024)) |
| | Industrial production losses due to water restrictions | Reduction in trend capacity output (FRYCAP) | 2027Q1 to Q3 : -1.56%, -3.12%, -1.56% | Projected values (Banque de France, forthcoming) |
| **Chronic Water Scarcity** | Clay shrinkage-swelling damage: Physical deterioration of housing | Increase in depreciation rate of capital stock (housing) (FRKHDEP) | +2.14% from 2027Q2 onwards | Historical values - Year 2022 (CGDD, 2025) |
| | Clay shrinkage-swelling damage: Increase in housing-related insurance premiums | Increase in consumer prices (FRCED) | Linear interpolation from 2027Q2 to reach +0.55% in 2050Q4 | Projected values (hypothesis) |
| **Chronic Water Pollution** | Government investment in water systems | Increase in government consumption (FRGC) | Linear interpolation from 2028Q1 to reach +0.73% in 2050Q4 | Projected values (Service des données et études statistiques, 2025) |
| | Risk premiums for water polluting firms | Increase in investment risk premia (FRIPREM) | Linear interpolation from 2027Q1 to reach +0.55% in 2050Q4 | Historical values for US firms in 2022 (Coqueret et al., 2025) |

Chronic water quantity risks encompass both the persistent supply-demand imbalance and the ongoing issue of pollution, resulting in significant long-term financial liabilities. Chronic scarcity is notably linked to clay shrinkage-swelling damages, which lead to a persistent increase in the depreciation rate of the housing capital stock and rising housing-related insurance premiums that may weigh on the purchasing power of households (calibrated as an increase in the consumption deflator).

Chronic pollution is modelled as a long-term transition risk, compelling massive public investment in water systems to meet regulatory goals (e.g., the Water Framework Directive requirements and its associated directives). This commitment is captured by a structural increase in government consumption to renew water treatment infrastructure, starting in 2028, putting pressure on public finances. To reflect the consequences of that pressure on public spending, we use NiGEM's solvency rule for government finances which ensures that in the medium term, the government's budget converges to a specific annual deficit target. Short-term deviations from the target are compensated through corresponding adjustments in households' income tax rate. In this simulation, in order to dampen the positive Keynesian effects on GDP, the public-deficit target remains unchanged, and the increase in public expenditure is offset through increased taxation.

This modelling choice is a proxy of the financing structure of water-policy interventions, which rely on earmarked user charges and to ensure budgetary neutrality in water-management operations. Indeed, the financing of water investments is largely borne by local authorities, which pass these costs on through local taxes and water agency levies. Because water agency levies are borne by all water users, households are not the sole contributors to the financing of water infrastructure. In NiGEM, the incidence of a household income tax increase does not necessarily mirror the distribution of costs across users in practice. However, within the modelling framework, the income-tax adjustment provides the closest available proxy to capture the diversified burden-sharing mechanisms that characterise water-system financing.

Simultaneously, the risk of pollution is transferred to the private business sector through liability and reputational channels, modeled as increasing investment risk premia for firms that exert significant pressure on water quality. This dual pressure on public spending and corporate financing highlights water management as a structural constraint with direct implications on sovereign and corporate debt markets.

#### 4.1.3 Results of the Water-Related Scenario

During the first two years of the calibration horizon, water scarcity shocks are the main drivers of impacts on French GDP and inflation, mainly due to the acute drought striking Europe from 2027 (Figure 6). The transmission of shocks to several sectors, in particular agriculture and manufacturing, accumulated with severe food inflation due to lower agricultural yields, induces a -1% deviation on GDP over the first year of the horizon, with a relative persistence over the second year of the projection (-0.8% after 8 quarters). Water pollution risks increase gradually over the first part of the simulation and drive about half of the effects after three years of simulation (-0.4% on GDP), with a stable persistence until the end of the horizon, mainly due to the effects over time of increased risk premia for water polluting firms and of public finance deterioration. While the shocks originate on the supply side, they propagate through the economy by dampening demand (see Figures 18 and 19 in the Appendix). Unemployment rises during the first year before gradually receding (see Figure 20).

Inflation dynamics are primarily driven by risks related to water scarcity, peaking at approximately 1.2 percentage points after four quarters. This coincides with the peak of the severe European drought and includes a slight additional contribution from chronic risks (Figure 7). The observed trend is largely attributable to the inflationary shock in the euro area, calibrated following Kotz et al. (2024), which reflects the direct transmission of the supply shock to price dynamics. Consequently, there is a slight but temporary tightening of monetary policy that dissipates by the sixth quarter (Figure 21 in the Appendix) as demand-side effects begin to dominate. Water pollution has a limited impact on inflation, moderately disinflationary in the second half of the simulation horizon, mainly due to reduced consumption as a result of increased risk premia.

The next subsections further detail the results of the shocks included within each part of the narrative.

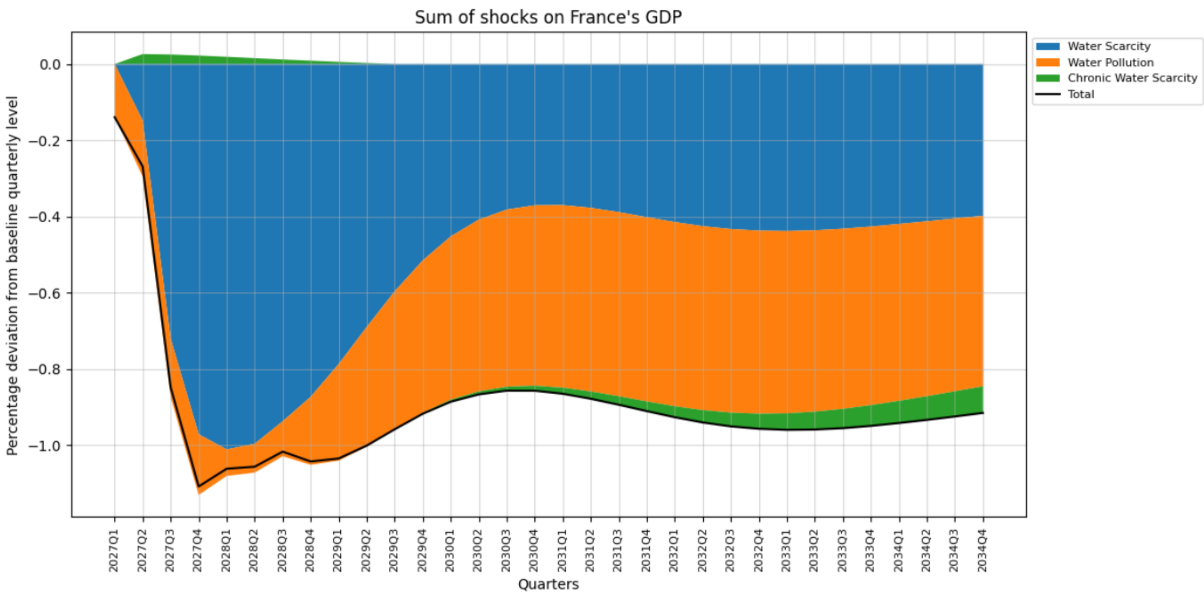



Figure 6: Aggregate Water-Related Scenario – Impact on GDP in France (percentage deviation)
*Note: This figure shows the GDP profile of the aggregate water-related scenario and the contributions of the scarcity- and quality-related shocks that are part of the scenario.*

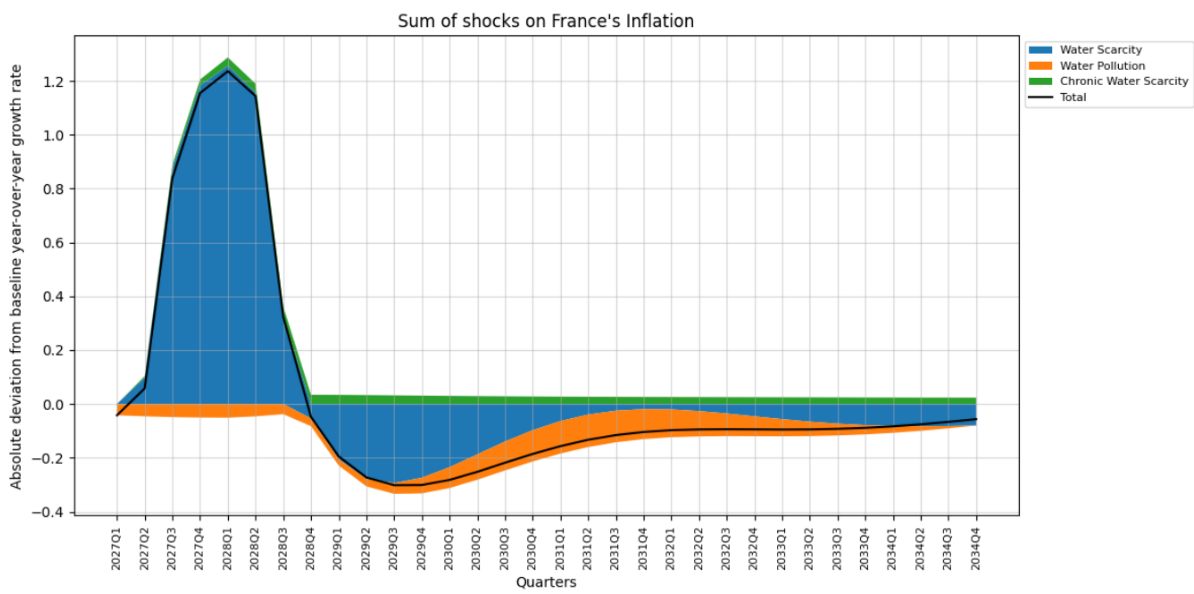



Figure 7: Aggregate Water-Related Scenario – Impact on inflation in France (absolute deviation from baseline)
*Note: This figure shows the inflation profile of the aggregate water-related scenario and the contributions of the scarcity- and quality-related shocks that are part of the scenario.*

**Water scarcity shocks**

The results illustrate a persistent negative impact of water scarcity shocks on France's GDP, driven by both supply-side constraints and price effects (Figure 8). In the short run, the GDP contraction is sharp, reaching -1% below baseline, largely explained by exogenous capacity constraints captured through the shock on trend capacity ouput. Industrial, agricultural, hydroelectric, and nuclear production losses jointly account for the initial magnitude of the shock (-0.7% after two quarters), with industrial production losses dominating in the first quarters. Water scarcity initially materialises as a capacity shock, but supply-side effects gradually fade and demand-side channels gain relative importance as macroeconomic costs are amplified and prolonged by inflationary and financial transmission mechanisms. In particular, the direct shock to euro area food inflation generates a persistent downward pressure on real activity through reduced purchasing power, becoming the main factor contributing to the GDP deviation from baseline. In addition, clay shrinkage-swelling effects on insurance, modelled via pressures on consumer prices, introduce limited additional medium-term losses. These negative effects dominate the initial positive effect of reconstruction investment triggered by capital destruction. This net negative impact on GDP appears roughly two and a half years after the onset of the shock.

The inflation results show a pronounced but transitory increase in year-on-year inflation following water scarcity shocks, followed by a period of disinflation (Figure 9). In the short run, inflation peaks at around 1.2 percentage points above baseline, driven primarily by a direct shock to euro area food prices, which constitutes the dominant contribution in the first year. Exogenous capacity constraints in production sectors, modelled through a decrease in trend capacity output for industry, agriculture, hydroelectricity, and nuclear power, reinforce upward price pressures by tightening supply conditions. From 2029 onwards, inflation turns temporarily negative relative to baseline, reflecting the demand-side effects of lower real income and weaker activity induced by the initial shock. Over the medium term, clay shrinkage-swelling effects generate a small but persistent contribution to inflation through housing and insurance-related channels. The breakdown of shock contribution shows that water scarcity shocks initially propagate as cost-push inflation shocks, while their medium-term impact is characterised by disinflationary pressures associated with reduced demand.

**Water pollution**

Water pollution shocks generate a moderate but persistent negative impact on France's GDP. In the short term, higher government consumption related to the renewal of water treatment infrastructure provides a temporary and limited support to activity. However, this effect is quickly outweighed by rising risk premia for water-polluting firms, which significantly increase financing costs and depress private investment. In addition, the deterioration in public finances leads to an increase in French long-term interest rates, further tightening financial conditions and weighing on domestic demand. As these effects accumulate, GDP declines steadily and stabilises at a lower level than baseline over the medium term (-0.5%). These results show that water pollution shocks primarily operate as a downward pressure on economic activity through corporate debt risk premia (responsible of -0.3% after 5 years), public financing conditions, and crowding-out effects, with only limited offset from public investment.

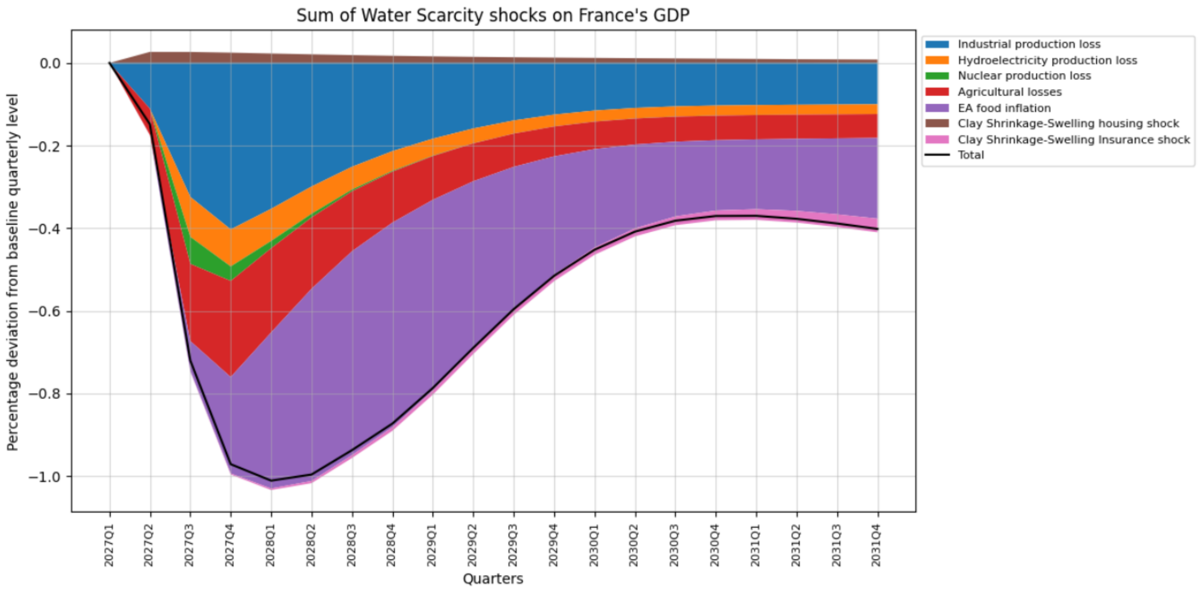



Figure 8: Scenario "Water scarcity" – Impact on GDP in France (percentage deviation from baseline)
*Note: This figure shows the GDP profile of the water scarcity scenario and the contributions of the various shocks that are part of the scenario.*

The inflation response to water pollution shocks is moderate in magnitude but persistent, and predominantly disinflationary over the medium term. In the short run, inflation remains close to baseline (-0,05pp after 1 year), as upward price pressures stemming from higher government consumption related to the renewal of water treatment systems are partly offset by other channels. Over time, the dominant drivers are financial and fiscal in nature. Higher risk premia faced by water-polluting firms weigh on investment and activity, generating downward pressure on prices (-0.1pp after 5 years). In parallel, the increase in French long-term interest rates, associated with additional pressures on public debt sustainability, introduces an additional negative effect on demand, reinforcing disinflationary pressures. Consequently, inflation gradually declines and remains consistently below the baseline in the medium term, reaching a negative deviation of 0.1 percentage points (pp) by the end of the horizon.

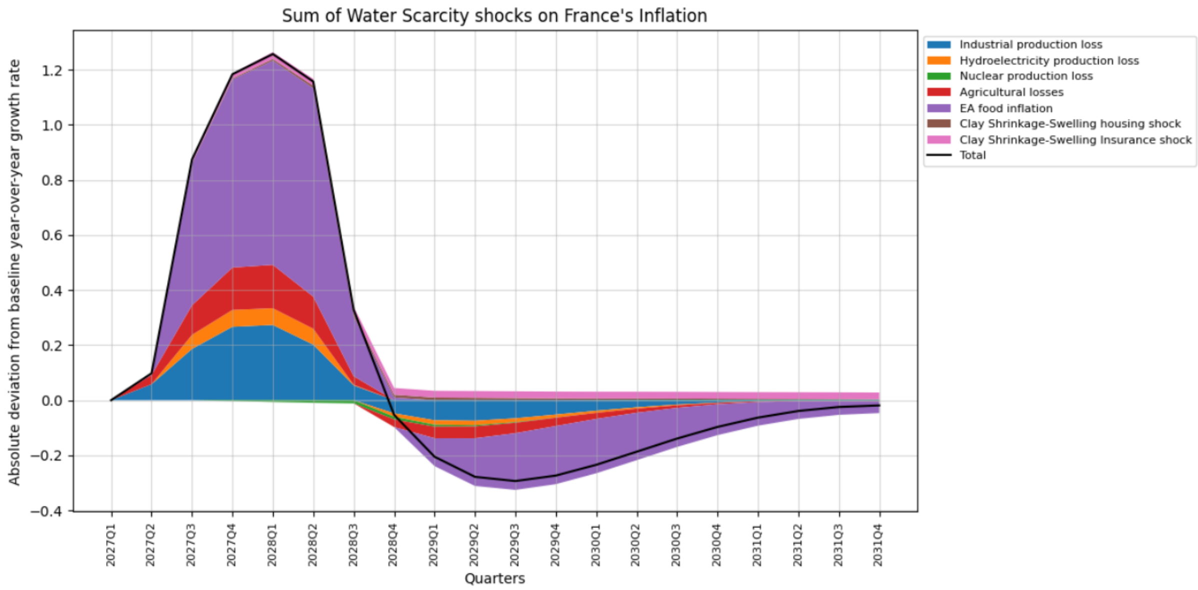



Figure 9: Scenario "Water scarcity" – Impact on inflation in France (absolute deviation from baseline)
*Note: This figure shows the inflation profile of the water scarcity scenario and the contributions of the various shocks that are part of the scenario.*

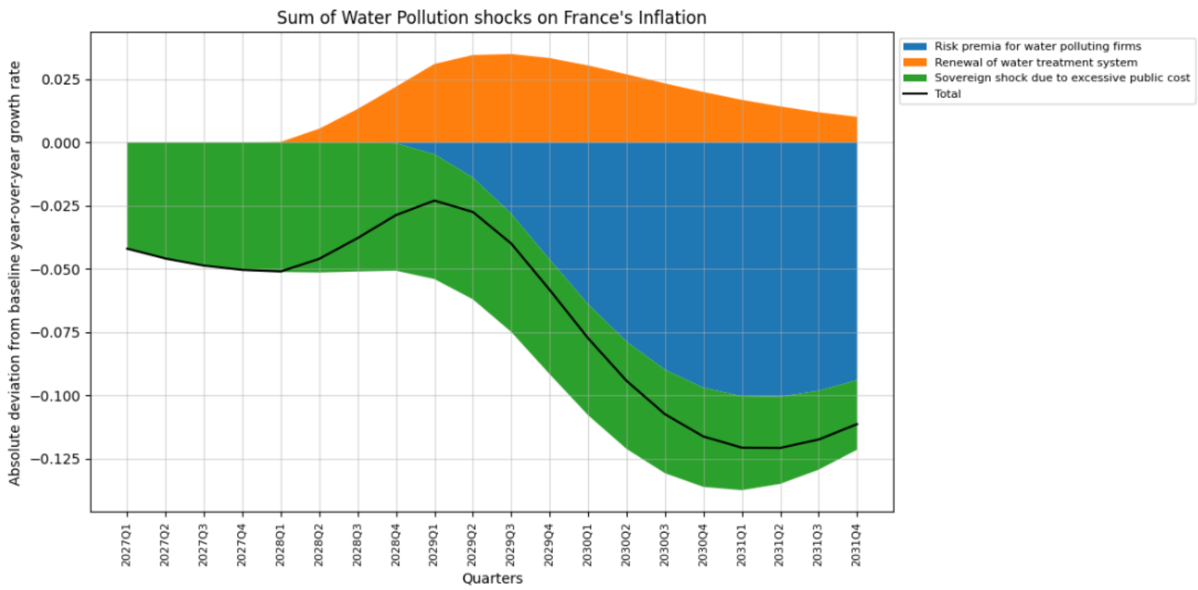



Figure 11: Scenario "Water quality" – Impact on GDP in France (percentage deviation from baseline)
*Note:* This figure shows the GDP profile of the water quality scenario and the contributions of the various shocks that are part of the scenario.

The aggregate water-related scenario represents nature-related risks that mainly materialise in France and, more broadly, in the euro area. The transmission channels considered, via production capacity, prices, public finances and corporate financial conditions, account for the domestic physical risks associated with water scarcity and water pollution. However, this framework does not yet account for the international dimension of nature-related risks, such as global

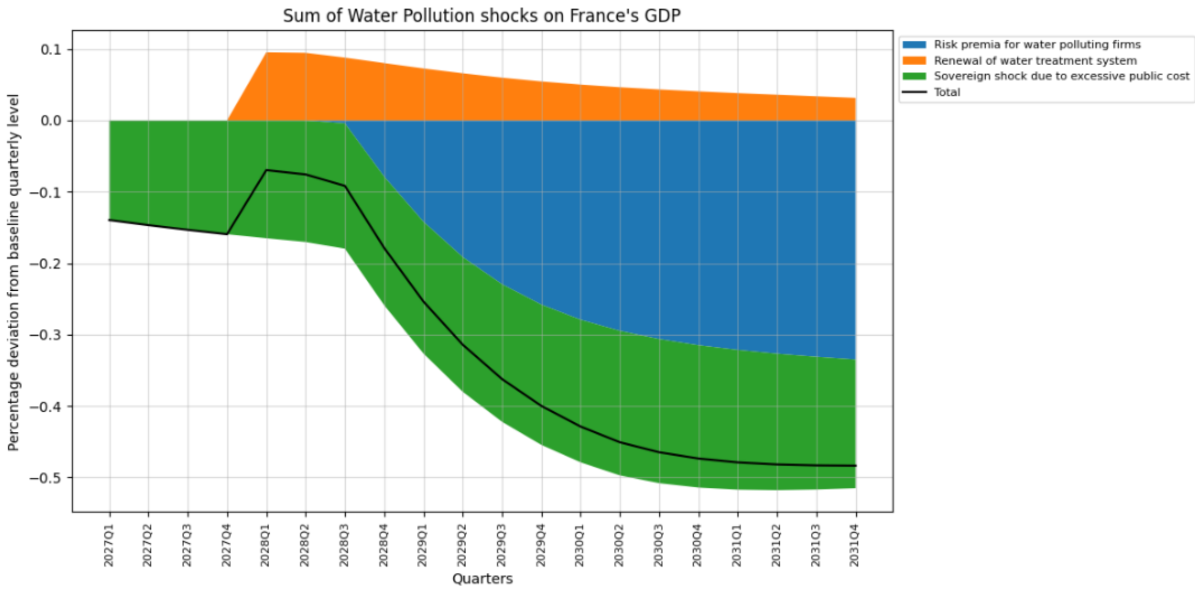



Figure 10: Scenario "Water quality" – Impact on inflation in France (absolute deviation from baseline)
*Note:* This figure shows the inflation profile of the water quality scenario and the contributions of the various shocks that are part of the scenario.

supply chain disruptions, rising import prices, or input shortages triggered by environmental shocks in major trading partner economies. Consequently, the second scenario is designed to incorporate these cross-border spillover mechanisms, which may significantly amplify the total macroeconomic impact.

## 4.2 Agriculture-Related Shocks: Domestic and Cross-Border Impacts

This second scenario examines how international environmental shocks and supply chain disruptions propagate through global trade linkages to the French economy.

### 4.2.1 Narrative of an International Cereal Crop Crisis

Consistent with the previous scenario, we build a narrative on a series of concurrent shocks: domestic biological outbreaks—specifically livestock and agricultural pathogens—followed by a synchronized multiple breadbasket failure. These acute disruptions are exacerbated by chronic environmental stressors, such as water scarcity, pollinator loss, and soil degradation, which collectively heighten the vulnerability of the global food system. As illustrated in Figure 12, the scenario timeline begins with the outbreak of pests and pathogens in France in the second half of 2027, followed by a multiple breadbasket failure in 2028. From 2029 onward, the crisis escalates through heightened geopolitical tensions, adding further instability to the global macroeconomic outlook.

In more detail, the narrative begins in the second half of 2027 with a virulent outbreak of agricultural pests and pathogens. Mutating disease strains spread across domestic farming regions, causing immediate yield losses and eroding national production capacity. This biological shock is compounded by a simultaneous avian influenza epidemic, necessitating large-scale livestock culling that further destabilizes the agricultural sector.

The crisis transcends agriculture as public anxiety regarding zoonotic contamination triggers a sharp contraction in tourism and hospitality, intensifying the domestic demand-side shock. These acute events are fundamentally underpinned by chronic environmental stressors, specifically the long-term attrition of pollinator populations and soil health[3], which compromise the baseline resilience of ecosystems.

In 2028, the crisis achieves global scale through a synchronized multiple breadbasket failure, which is defined as the simultaneous disruption of staple cereal production across several major global agricultural regions. This critical disturbance is primarily attributed to the concurrence of severe climatic events (e.g., extended drought, extreme heatwaves). As a result of this severe climatic anomalies, the world's primary grain-producing regions are hit simultaneously, resulting in a 10% contraction in global cereal production. This supply-side collapse triggers a material spike in international food prices and a reduction in trend capacity output across the main cereal producers.

The material risk reflects the vulnerability of the global food system, which is critically dependent on a limited number of crop species and high geographic concentration of output. This relies on empirical evidence, notably from Gaupp et al. (2020), which shows that the annual probability of all major producing regions simultaneously facing climate risks has significantly increased. For example, the probability for wheat production disruptions quadrupled between 1967–1990 and 1991–2012, rising from 0.3% to 1.2%.

While the European Union maintains a net export position in wheat, it remains highly vulnerable to the global transmission of food inflation due to its reliance on imported essential production inputs (fertilizers, energy) and the intrinsic interconnectedness of global commodity markets. The Russian invasion of Ukraine in 2022 served as a recent proxy, demonstrating the immediate transmission mechanism, contributing to a 15.9% food inflation spike in France between March 2022 and March 2023 (INSEE, 2025).

The global cereal crisis is thereafter significantly amplified by non-climatic factors such as geopolitical instability and conflict, which impair agricultural supply chains and input access. By 2029, persistent food insecurity catalyzes widespread geopolitical instability, manifesting as a sharp increase in investment risk premia.

#### 4.2.2 Calibration of the Agriculture-Related Shocks

The calibration of the agriculture-related scenario relies a multi-layered approach that distinguishes between acute shocks, such as biosecurity failures and harvest collapses, and chronic stressors, specifically the degradation of ecosystem services. This distinction allows the model to capture both immediate, high-frequency stresses and the long-term structural impairments to potential growth (see Table 5).

[3] We also considered incorporating a specific soil erosion shock based on Panagos et al. (2021). However, since the estimated macroeconomic impact for France was immaterial within the NiGEM framework, we have focused on pollinator losses as the primary quantified chronic shock.

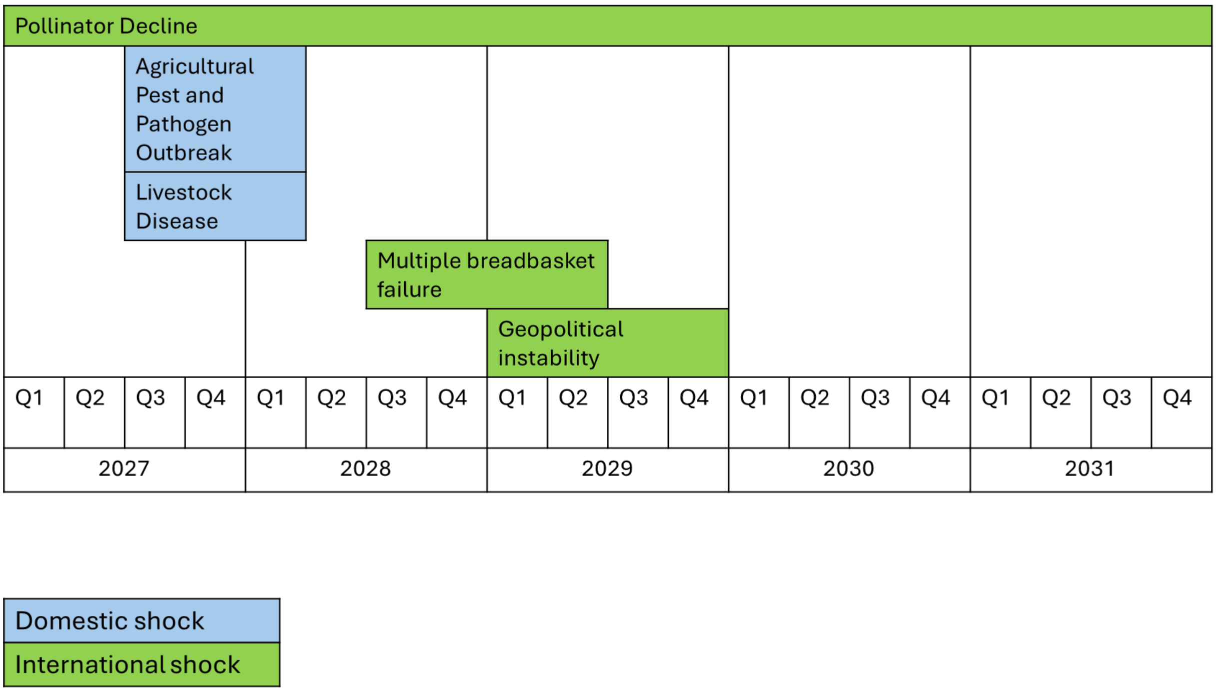



Figure 12: Description of the Agriculture-Related Scenario and its Timing

Table 5: Summary of Pollinator, Disease, and Other Nature-Related Risks

| Risk | Transmission Channel | Impact (NiGEM variable names in parentheses) | Shock Value | Sources |
|---|---|---|---|---|
| **Livestock disease** | Avian influenza outbreak : Livestock slaughterings leading to production losses | Reduction in trend capacity output (FRYCAP) | 2027Q3 to Q4 : -0.09% | Historical values for 2021-2022 outbreak in France (Briand et al., 2022) |
| | Avian influenza outbreak : tourism losses due to fear of contamination to human | Reduction in trend capacity output (FRYCAP) | 2027Q3 to Q4 : -0.06% | Historical values (tourism decline in Mexico in 2008, Rassy and Smith, 2013) |
| **Multiple Breadbasket failure** | International production losses : up to 10% loss in global cereals | Reduction in trend capacity output (YCAP for 16 countries[4]) | 2028Q3: -0.21% for France | Scenario-based values (Lloyd's of London, 2015, Gaupp et al., 2020) |

Continued below

[4]The countries considered include Argentina, Australia, Austria, Brazil, China, France, Germany, Hungary, India, Indonesia, Italy, Poland, Romania, Russia, UK and US.

**Table 5 continued from previous page**

| Risk | Transmission Channel | Impact (NiGEM variable names in parentheses) | Shock Value | Sources |
|---|---|---|---|---|
| | International agricultural losses : increase of crop commodity prices | Increase in global food prices (WDPFDV) | 2028Q3: +5.0% | Historical values for 2007-2008 food crisis (Fan and Headey, 2008) |
| **Geopolitical instability** | Food insecurity induced geopolitical instability | Investment risk premia increase (IPREM for all countries) | 2029Q1: country-specific shocks based on historical data | 2x standard deviation of historical IPREM |
| **Chronic pollinator decline** | Health decline due to reduced intake of fruits and vegetables : Loss of labour productivity | Reduction in labour augmenting technical progress (TECHL for all countries) | 2025Q1 : 0% then linear increase to 2035Q1 : -0.68% | Projected losses (Smith et al., 2015), converted to labour productivity (Lyeonov et al., 2025) |
| | Agricultural losses : Production losses | Reduction in trend capacity output (YCAP for all countries) | Linear interpolation from 2027Q1 to reach -0.31% in 2031Q4 | Projected losses (Potts et al. (2016)) |
| | International agricultural losses : increase of crop commodity prices | Increase in global food prices (WDPFDV) | Linear interpolation from 2027Q1 to reach +9.1% in 2031Q4 | Projected losses (Feuerbacher et al., 2025) |
| **Soil Health Decline** | Agricultural losses : Production losses | Reduction in trend capacity output (FRYCAP) | Not very material | Projected values (Panagos & al. articles) |
| **Pests and Pathogens** | Agricultural losses : Production losses | Reduction in trend capacity output (FRYCAP) | 2027Q3 to Q4: -0.88% | Wegner et al.(2025) |

To operationalize the narrative, the 2027 domestic biosecurity shock is modeled as a joint occurrence of agricultural and livestock pathogens. Specifically, the avian influenza episode is treated as a direct disruption to domestic productive capacity. Between 2027Q3 and Q4, this shock lowers trend capacity by an estimated 0.15%. Part of this decline reflects a straightforward supply effect, as large-scale culling halts production in the livestock sector due to slaughterings (assessed to be around 0.09% of aggregate productive capacity)[5]. The impact is moreover

[5]This estimate is consistent with recent literature, albeit at the lower end of the range suggested by Morel et al. (2026), who estimate potential GDP losses between 0.06% and 0.9% resulting from Highly Pathogenic Avian Influenza (H5N1) disruptions in the U.S. dairy sector.

amplified by the impact on tourism that could also lead to reduction in capacity due to the closure of hotels and restaurants. Drawing on evidence from the 2008 swine flu episode, heightened concern over zoonotic transmission leads households to cut back on travel, dining, and other service-sector activities. This effect represents another 0.05% decline in capacity output. While such shocks can exhibit significant persistence due to lasting changes in consumer behavior or reputational damage to specific regions, we maintain a more transitory calibration here to avoid overlapping with long-term structural trends and to remain conservative in the absence of sector-specific dynamics within the NiGEM framework.

This local instability acts as a precursor to a systemic global failure in 2028. We calibrate a multiple breadbasket failure as a synchronized exogenous shock to the trend capacity output across sixteen major producing countries (see footnote of Table 5). The magnitude is set to reflect a 10% loss in global cereal production, a severe tail risk supported by climate-agronomic projections. This leads to a decline in capacity output for the countries considered (see Table 5). For France, this is equivalent to a decline by 0.21% of trend GDP. Moreover, we also account in our calibration for an increase in crop commodity prices leading to an increase in global food prices of +5%. This calibration is inspired by the dynamics of the 2007–2008 food crisis, where supply-side constraints led to extreme price volatility. While the FAO Food Price Index recorded a nominal increase of 41% during this period, we deliberately calibrate our shock based on the underlying supply disruptions identified by Fan and Headey (2008). This approach allows us to isolate the structural productivity loss from the 'noise' of temporary market fluctuations – such as speculative trading and energy price volatility – which frequently amplify short-term price indices far beyond the scale of the initial biophysical impact.

To capture the non-linear transformation of ecological risk into financial instability, the model links food insecurity directly to financial market sentiment through a geopolitical feedback loop. The surge in commodity prices is assumed to trigger social unrest and trade protectionism, which we quantify via a shock to the investment risk premia. By applying a penalty of two standard deviations to the historical risk premia for all countries, the model reflects a "flight-to-quality" and a contraction in liquidity in response to heightened international tensions. By comparison, the increase in quarterly credit spreads during the Global Financial Crisis peaked at roughly five standard deviations above the historical mean. Calibrating our shock at two standard deviations therefore represents a severe but plausible stress scenario, remaining conservative relative to the extremes of 2008.

In addition to those acute shocks, we assume a chronic deterioration in environmental conditions, driven by declining pollinator populations which leads to reducing yields and a decrease in the supply of nutrient-dense foods. As diets deteriorate over time, labor productivity weakens and mortality rises. As these risks are not included in the model's baseline, they are proxied by a decline in labor-augmenting technical progress, which falls to -0.68% by 2035, along with a decline in total population.

#### 4.2.3 Results of the Agriculture-Related Scenario

Figure 13 presents the cumulative impact of the international agriculture crisis scenario on France's GDP, which shows strong amplification effects when multiple nature-related shocks materialise simultaneously, leading to significant and persistent macroeconomic losses. The first domestic shock, occurring between Q3 2027 and Q1 2028, triggers a limited but material effect on GDP (-0.3%) during the first year of the simulation. The largest short-run contraction is then driven by a sharp decrease in trend capacity output for 16 countries combined with an increase in the world food price index due to a multiple breadbasket failure, which generates a pronounced negative supply shock together with a demand shock through higher import prices and reduced real incomes. Concurrently, pollinator loss amplifies output losses through a combination of exogenous capacity constraints and lower productivity of workers. Geopolitical instability, captured through an increase in risk premia, weighs on investment and consumption, contributing to the negative deviation of the GDP which peaks around -2.7% at Q3 2029. Additional supply-side pressures stem from livestock diseases, and pest and pathogen outbreaks, all modelled as negative trend capacity output shocks that further reduce productive capacity. A year after the shock ends (Q1 - Q4 2030), a rebound effect temporarily pushes GDP above the baseline, but the recovery in activity remains incomplete in the medium term, as low trend capacity output due to pollination loss still weighs on supply.

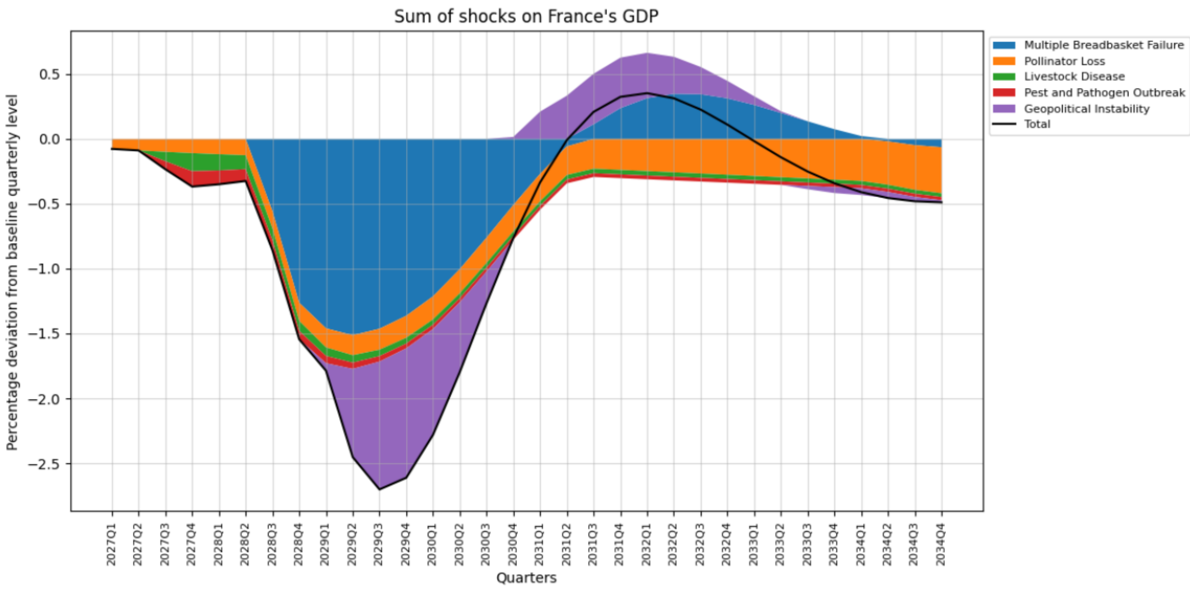



Figure 13: Multiple breadbasket failure scenario – Impact on GDP in France (percentage deviation from baseline)
*Note:* This figure shows the GDP profile of the multiple breadbasket failure scenario and the contributions of the shock drivers that are part of the scenario.

Figure 14 illustrates the strong role of international transmission channels in the inflationary effects of this scenario. Inflation remains limited following the initial domestic shocks (around 0.2pp after one year), then rises sharply starting from mid-2028 peaking at around 1.5 percentage points above baseline, largely driven by the decrease of trend capacity output due to the agriculture crisis in main producing countries. This global food price shock transmits rapidly to domestic prices through higher import costs and food price pass-through, dominating all other channels in the first phase of the scenario. Additional upward pressure on inflation arises from pollinator loss, which combines exogenous capacity constraints with lower technological efficiency and adverse labour supply effects in agriculture, as well as from other supply-side shocks linked to livestock diseases, and pest and pathogen outbreaks, all modelled via trend capacity output. In the medium term, inflation turns temporarily negative relative to baseline as the contraction in economic activity and real income reduces demand (-1.2pp after 4 years). This disinflationary phase is amplified by geopolitical instability, captured through higher risk premia, which tightens financial conditions and dampens price pressures. However, this disinflationary effect in the second half of the horizon is mostly driven by lower aggregate demand and may not capture the specific dynamics of the agricultural sector, where supply shortages can trigger sharp food price spikes that could generate more persistent inflationary pressures. Over the longer horizon, inflation gradually returns towards baseline but remains affected by persistent global food price pressures.

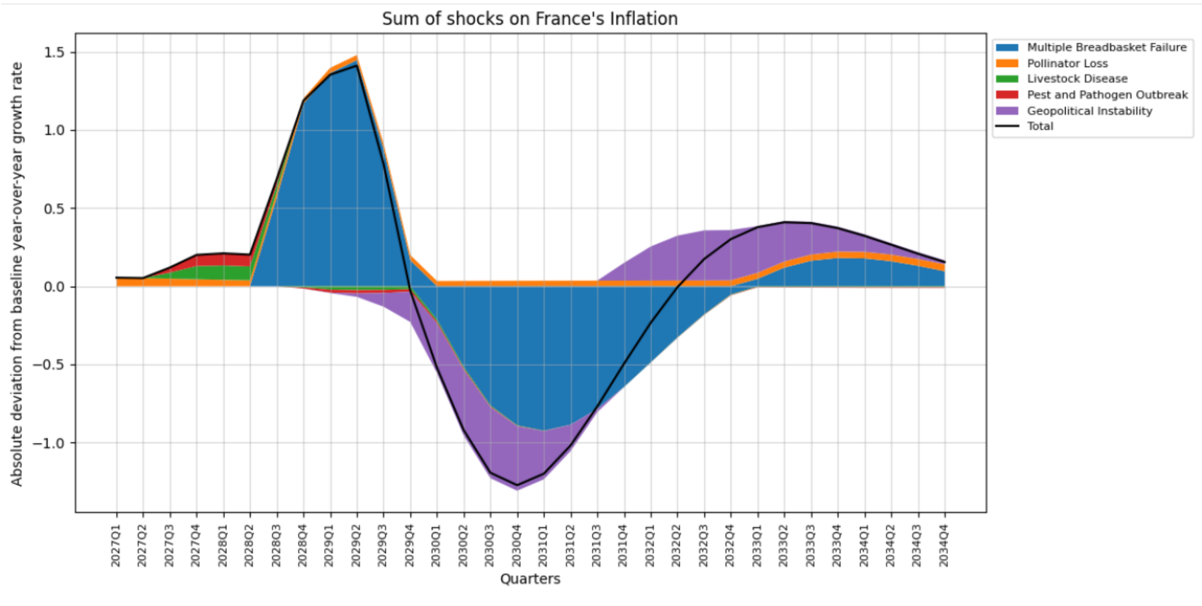



Figure 14: Multiple breadbasket failure scenario – Impact on inflation in France (percentage deviation from baseline)
*Note:* This figure shows the inflation profile of the multiple breadbasket failure scenario and the contributions of the shock drivers that are part of the scenario.

The disaggregation of these macroeconomic effects reveals a deep and synchronized contraction in private demand. Consumption (Figure 22 in Appendix) experiences a persistent slump, reaching a trough of approximately -1.7% in mid-2029. This decline is largely driven by the erosion of purchasing power following the peak in food-driven inflation and the simultaneous rise in uncertainty. The impact on business investment (Figure 23) is even more pronounced and volatile, plummeting by over 8% relative to the baseline. This sharp contraction reflects both the heightened risk premia associated with geopolitical instability and a ”wait-and-see” approach by firms facing significant supply-side capacity constraints.

The labor market reacts with a visible lag, as unemployment (Figure 24) rises steadily as the demand-side contraction takes hold, peaking at over 1 percentage point above the baseline in 2030. While the labor market begins to recover as GDP rebounds, the persistence of the supply-side shocks—particularly the long-term effects of pollinator loss—prevents a rapid return to full employment. Finally, monetary policy (Figure 25) faces a classic "supply-shock dilemma." Initially, the short-term interest rate rises by nearly 1 percentage point to counter the sharp spike in inflation. However, as the massive contraction in consumption and investment begins to dominate the price outlook, the policy stance reverses sharply, with rates falling more than 1 percentage point below the baseline by 2031 to support low demand. This sharp reversal from a restrictive to an accommodative stance underscores the transition of the crisis from a pure supply-side price shock to a broader, demand-driven economic downturn.

# 5 Conclusion

This paper provides a first macroeconomic assessment of nature-related risks through two complementary stress scenarios focusing on water-related shocks and an international agricultural crisis. The results indicate that environmental degradation can generate large and persistent macroeconomic effects, affecting output and inflation. By embedding nature-related shocks within a semi-structural global macroeconomic model, the analysis contributes to the growing literature seeking to quantify the macroeconomic relevance of biodiversity loss and ecosystem degradation.

From a methodological perspective, the exercise also highlights important modelling challenges. NiGEM is not specifically designed to capture nature-related risks, and several transmission channels are necessarily introduced through reduced-form or exogenous shocks. In particular, the absence of an explicit sectoral structure and of endogenous input-output linkages limits the representation of sectoral interdependencies and supply chain propagation mechanisms. This constraint leads to an underestimation of our impacts on agriculture and food systems, where production processes are strongly integrated into global value chains (Johnson et al., 2021). As a result, international spillovers related to import dependence, upstream input shortages, and foreign production shocks are only partially captured.

Besides, the scenarios rely on historical relationships and available forward-looking projections, which may underestimate the economic impact of future nature-related shocks. Biodiversity loss and ecosystem degradation are characterised by non-linear dynamics, threshold effects, and the potential for compound shocks (Steffen et al., 2015), which are difficult to represent within standard macroeconomic frameworks. These features suggest that the estimated impacts should be interpreted as conservative lower-bound estimates, abstracting from amplification mechanisms that could arise in the presence of simultaneous or cascading environmental disruptions.

These limitations point to several promising avenues for future research. First, combining macroeconomic models with international sectoral input-output models would allow for a more realistic representation of global supply chains and trade dependencies, particularly for critical commodities such as agricultural inputs for food and manufacturing production processes. Second, the development of more global macroeconomic scenarios could help capture the systemic nature of environmental degradation, moving beyond country-specific or region-specific shocks. However, more granular, ecosystem-level approaches could also benefit to macro models by improving the mapping between biophysical degradation and economic outcomes, thereby strengthening the microfoundations of nature-related macroeconomic scenarios (NGFS, 2023a).

From a policy standpoint, the scenarios demonstrate that nature-related risks can have material macroeconomic consequences and therefore justify their integration into central banks' risk assessments. Improving modelling frameworks to jointly account for climate- and nature-related risks is a necessary step toward a more comprehensive assessment of the implications of environmental degradation for price and financial stability, which are directly relevant for monetary policy and supervisory authorities' core mandate.

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## 6 Online Supplementary Material

This paper is accompanied by online supplementary material, which includes:

- Risk ID cards summarising, for each risk, qualitative evidence on potential macroeconomic and financial materiality and likelihood at the French and international levels
- Averaged materiality and likelihood scores for each risk, unweighted and weighted by uncertainty scores
- The pairwise correlation matrix and the Python script used to extract information from it

This online supplementary material is available in a dedicated Zenodo repository at `https://doi.org/10.5281/zenodo.19222624`

# Appendix A Nature-Related Risk Inventory

Table 6: Nature-related risk inventory for France

| **Risks** | **Chronic / acute** | **Domestic / international** |
|---|---|---|
| Water shortages | Chronic & acute | Domestic & international |
| Freshwater pollution | Chronic | Domestic |
| Algal blooms in water ecoystems | Acute | Domestic & international |
| Flooding due to deforestation and soil damage | Acute | Domestic & international |
| Soil and freshwater salinization | Chronic | Domestic & international |
| Degradation of coral reefs and impacts on coastal population | Chronic | Domestic & international |
| Livestock disease | Acute | Domestic & international |
| Loss of pollination service | Chronic | Domestic & international |
| Fishery collapse due to overfishing | Chronic & acute | Domestic & international |
| Aquaculture collapse due to pollution and water acidification | Chronic | Domestic & international |
| Agriculture pest or pathogen outbreak | Acute | Domestic & international |
| Aquaculture pest or pathogen outbreak | Acute | Domestic & international |
| Tree pest outbreak | Acute | Domestic & international |
| Soil health decline | Chronic | Domestic & international |
| Multiple breadbasket failure | Acute | International |
| Global food security repercussions | Chronic & acute | International |
| Invasive species impacts | Acute | Domestic & international |
| Direct damage from wildfires | Acute | Domestic |
| Air pollution from wildfires | Acute | Domestic |
| Air pollution due to economic activities | Chronic | Domestic |
| Risk to tourism from nature damage | Chronic | Domestic |
| Critical resource supply chain disruption | Chronic & acute | International |
| Micro-plastic contamination in food and water | Chronic | Domestic & international |
| Amazon forest and ecosystem tipping points | Chronic & acute | International |
| Anti-microbial resistance | Chronic & acute | Domestic & international |
| Zoonotic disease | Acute | Domestic & international |
| Decline in medicinal resources from biodiversity | Chronic | Domestic & international |
| Biodiversity access and mental health | Chronic | Domestic |

# Appendix B Expert survey

Table 7: Profiles and affiliations of the experts involved in the survey

| **Institutions** | **Main expertise of involved experts** | **Type** | **Number of experts** |
|---|---|---|---|
| French Foundation on Research for Biodiversity (FRB) | Ecology | Foundation | 3 |
| French National Research Institute for Agriculture, Food and the Environment (INRAE) | Ecology | National public institution | 1 |
| WWF France | Ecology | Non-governmental organisation | 8 |
| World Bank | Ecological economics | International institution | 1 |
| Paris School of Economics | Ecological economics | Academia | 2 |
| French Development Agency (AFD) | Ecological economics | National public institution | 1 |
| OECD | Finance | International institution | 1 |
| Center for Research in Economics and Statistics (CREST) - Ecole Nationale de la Statistique et de l'Administration Economique | Finance | Academia | 2 |
| Center for Applied Mathematics (CMAP) - Ecole Polytechnique | Finance | Academia | 3 |

# Appendix C Clustering analysis

**Methodology for clustering of risk groups** For each pair of risks, experts indicated whether they considered the two hazards to be related, assigning a value of 1 if the risks if so and 0 otherwise. For each pair, binary responses were averaged across experts, producing a correlation matrix with entries between 0 and 1 (see the online Supplementary Material).

We then apply a hierarchical clustering algorithm to this matrix. Risks are grouped according to a distance linked to the correlation between them. Distance between risks $i$ and $j$ is defined as:

$$d_{i,j} = \frac{\sqrt{2.(1 - corr(i,j))}}{min(M_i^w L_i^w, M_j^w L_j^w)} \tag{1}$$

Where $corr(i,j)$ denotes the correlation between risks $i$ and $j$, and $M_i^w L_i^w$ and $M_j^w L_j^w$ are the products of uncertainty-weighted materiality and likelihood for risks $i$ and $j$. This specification reduces the influence of correlations involving risks assessed as less material or less likely, preventing them from disproportionately shaping early cluster formation.

Hierarchical clustering can be sensitive to the choice of linkage criterion used to compute distances between clusters:

- Under complete linkage, the distance between two clusters is defined as the maximum distance between any pair of risks across the two clusters. This approach tends to produce relatively compact and homogeneous clusters, as risks are only grouped together when all constituent elements are sufficiently close.
- Under single linkage, the distance between two clusters is defined as the minimum distance between any pair of risks belonging to the two clusters. This criterion emphasises local connections by creating long chains of risks, even when overall similarity is limited.
- Under average linkage, the distance between two clusters is defined as the average of all pairwise distances between risks across the two clusters. This criterion represents a compromise between single and complete linkage.

While the detailed resulting dendrogram structure varies across linkage methods (see Figures 15, 16 and 17), several groupings are robust. On this basis, we identify six non-exclusive groups of interrelated nature-related physical risks related to (i) water cycle disruption, (ii) threatened crops, (iii) animal health and biosecurity, (iv) coastal vulnerabilities, (v) acute extreme events, and (vi) global systemic risks.

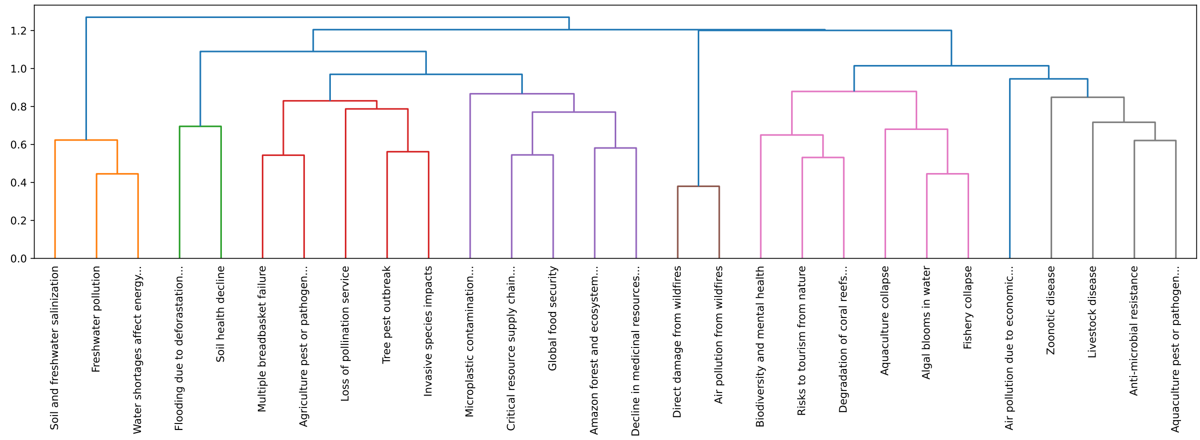


Figure 15: Hierarchical clustering of nature-related physical risks, ’complete’ grouping

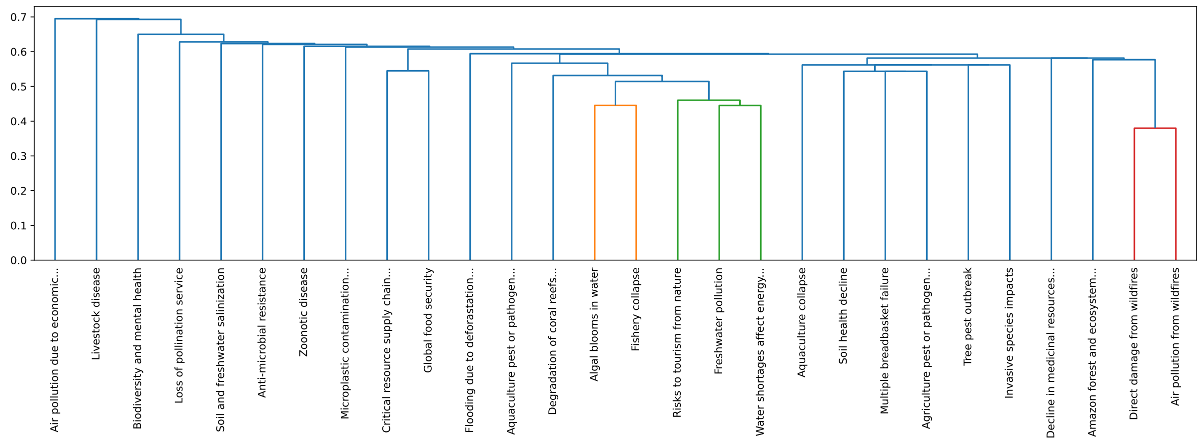


Figure 16: Hierarchical clustering of nature-related physical risks, ’single’ grouping

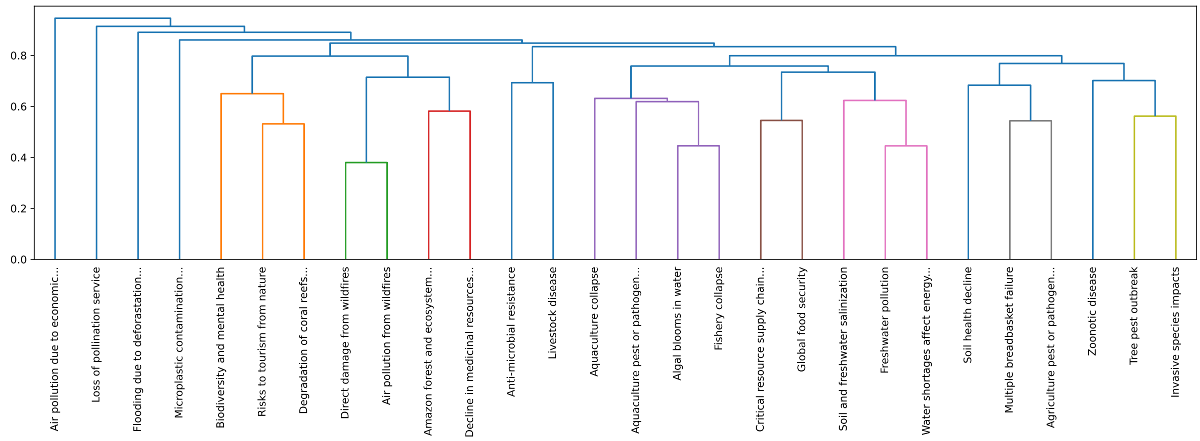


Figure 17: Hierarchical clustering of nature-related physical risks, 'average' grouping

**Additional risk group obtained from the clustering analysis and not included in the two scenario narratives**

Table 8: Group of risks related to coastal vulnerabilities

| Risks | Primary transmission channels |
|---|---|
| Algal blooms in water ecosystems | Fishing industry, tourism |
| Freshwater pollution | Agriculture, industry, fishing/aquaculture, water treatment |
| Risks to tourism from nature damage | Tourism |
| Fishery collapse due to overfishing | Fishing industry |
| Degradation of coral reefs | Fishing/aquaculture, real estate, tourism |
| Soil and freshwater salinization | Agriculture, human health |

Table 9: Group of risks related to acute extreme events

| Risks | Primary transmission channels |
|---|---|
| Direct damages from wildfires | Real estate, business interruption, tourism |
| Air pollution from wildfires | Human health, business interruption, public expenditure |
| Soil health decline | Agriculture, water treatment |
| Flooding due to deforestation and soil damage | Agriculture, real estate |
| Freshwater pollution | Agriculture, industry, fishing/aquaculture, water treatment |

Table 10: Group of global systemic risks

| Risks | Primary transmission channels |
|---|---|
| Global food security | Migration, human health |
| Amazon forest and ecosystem tipping points | Agriculture, food prices, wood industry, climate, migration |
| Zoonotic disease | Human health, public expenditure, business interruption, tourism |
| Critical resource supply chain disruption | Industry, energy, business interruption |
| Multiple breadbasket failure | Agriculture, food industry |

# Appendix D Additional results

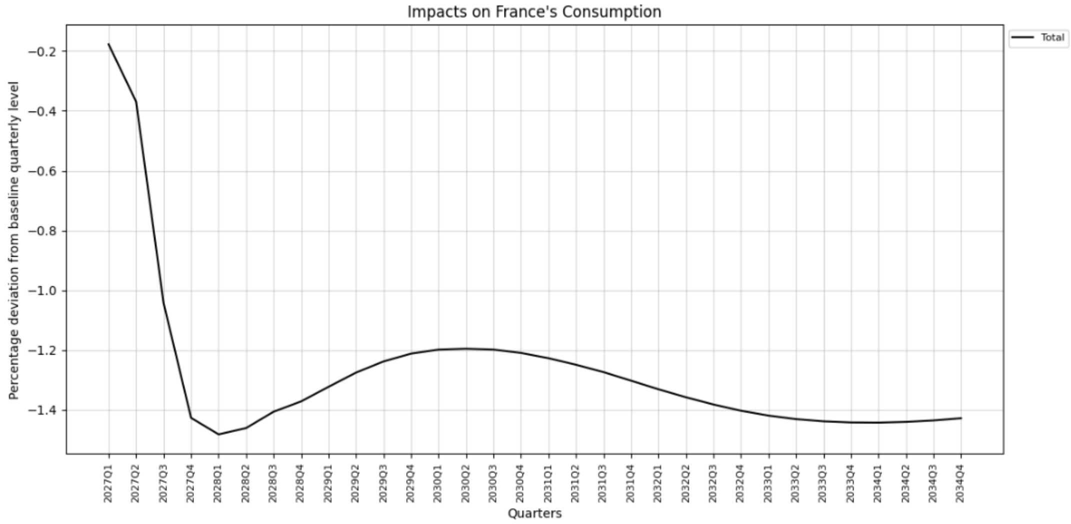


Figure 18: Aggregate Water-Related Scenario – Impact on Consumption in France (percentage deviation)

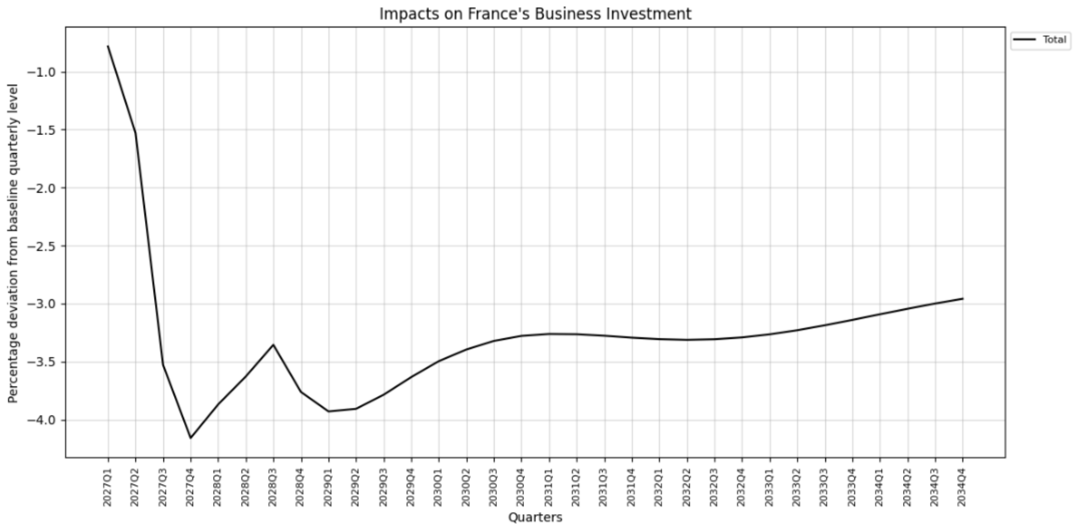


Figure 19: Aggregate Water-Related Scenario – Impact on Business Investment in France (percentage deviation)

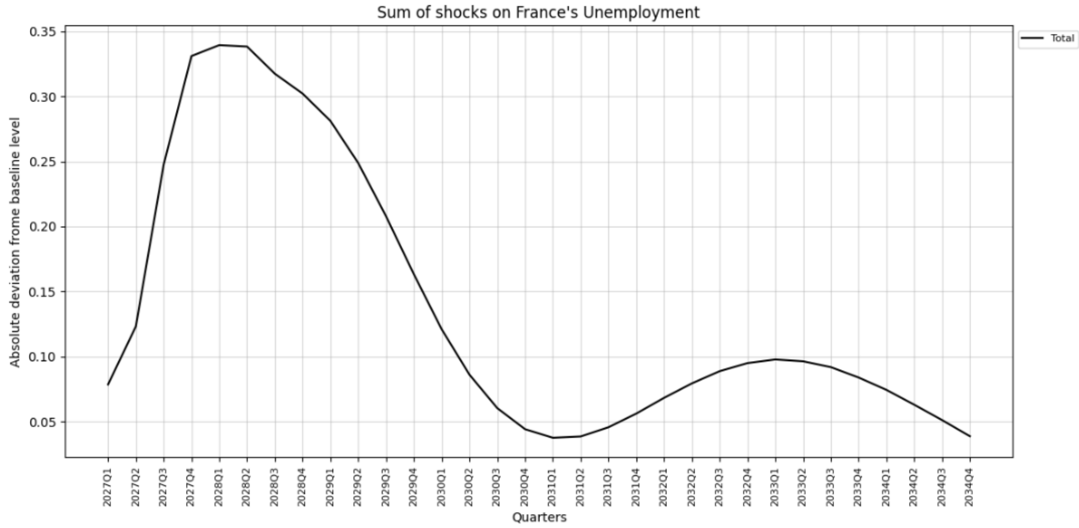


Figure 20: Aggregate Water-Related Scenario – Impact on Unemployment in France (percentage points deviation)

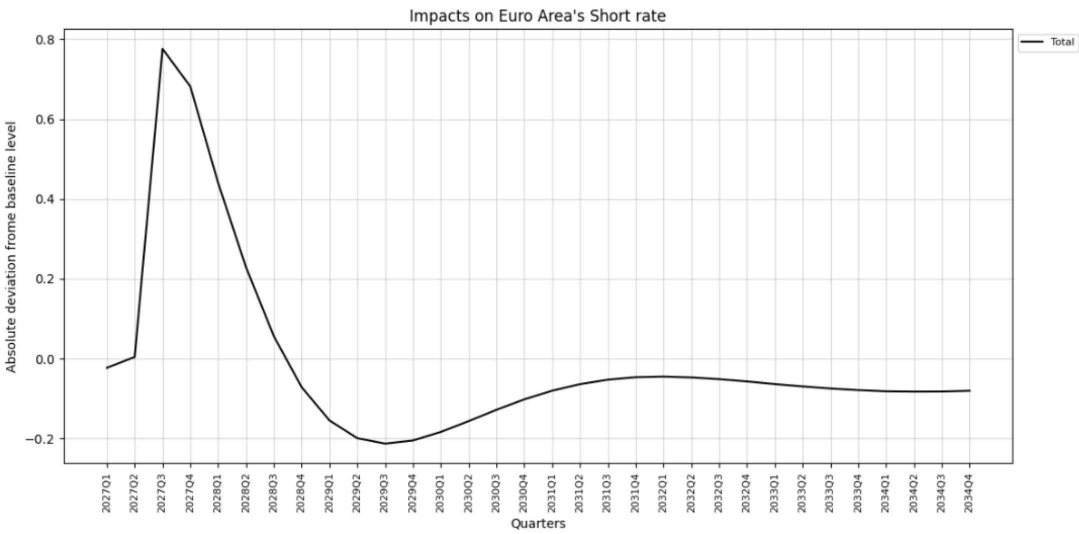


Figure 21: Aggregate Water-Related Scenario – Impact on Short-Term Interest Rates in the euro area (percentage points deviation)

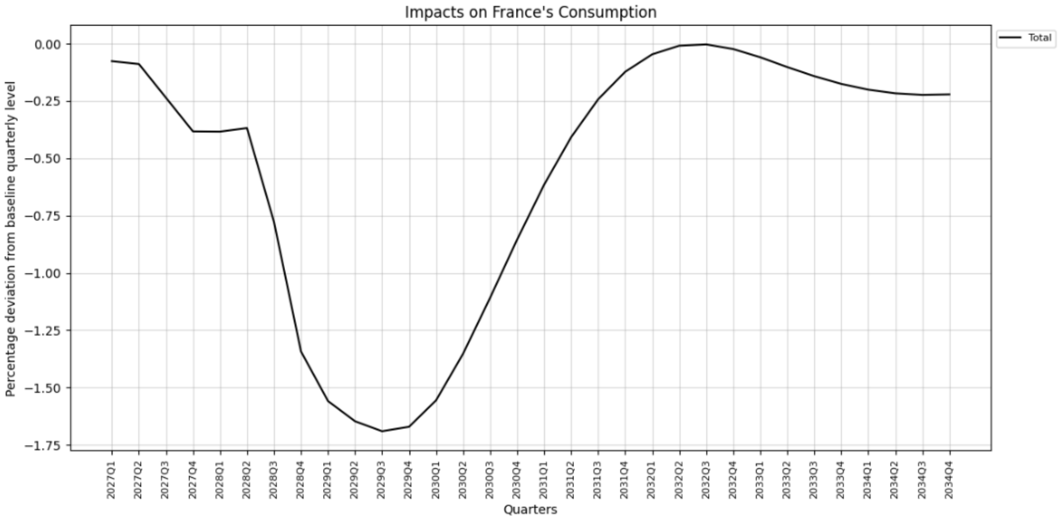


Figure 22: Multiple Breadbasket Failure Scenario – Impact on Consumption in France (percentage deviation)

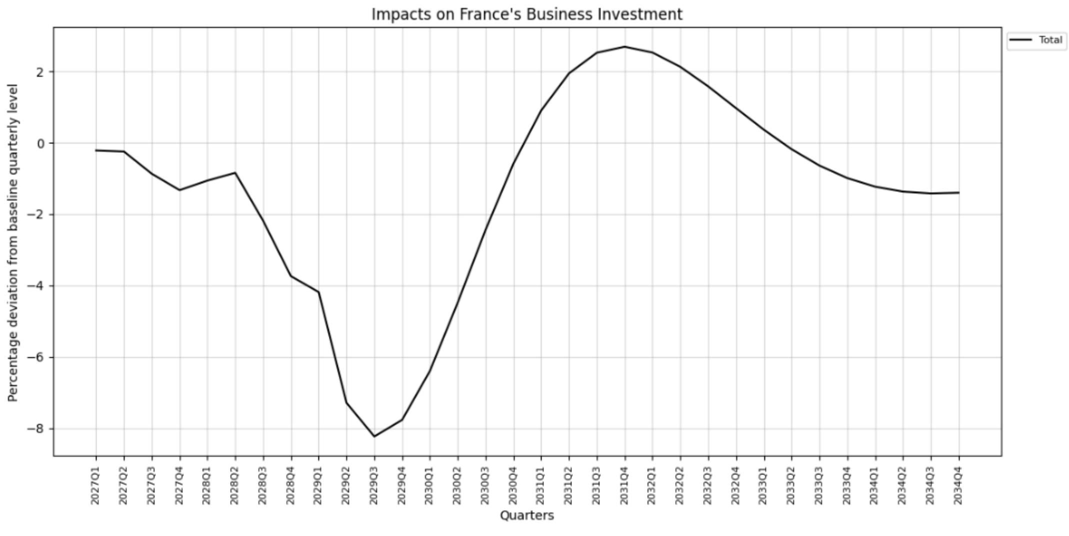


Figure 23: Multiple Breadbasket Failure Scenario – Impact on Business Investment in France (percentage deviation)

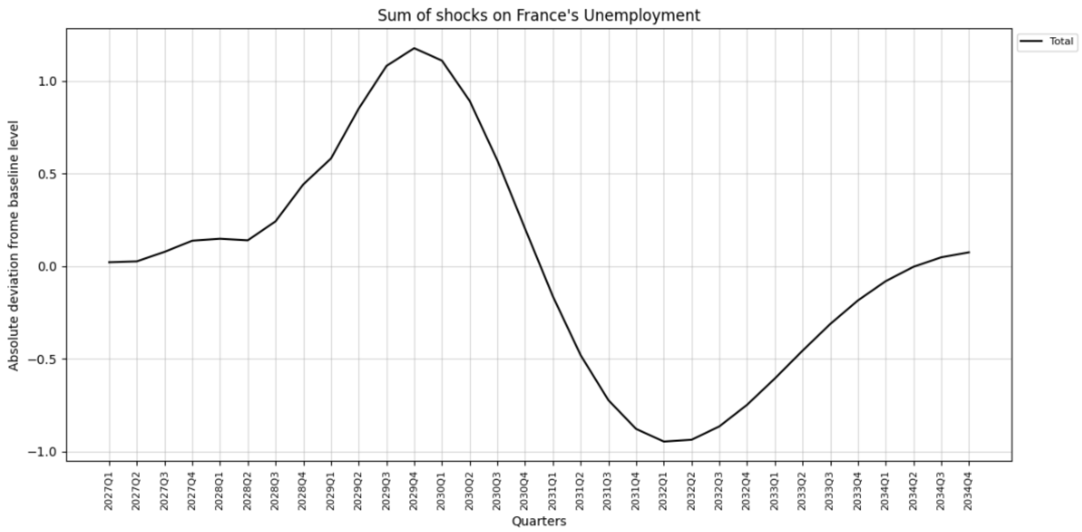


Figure 24: Multiple Breadbasket Failure Scenario – Impact on Unemployment in France (percentage points deviation)

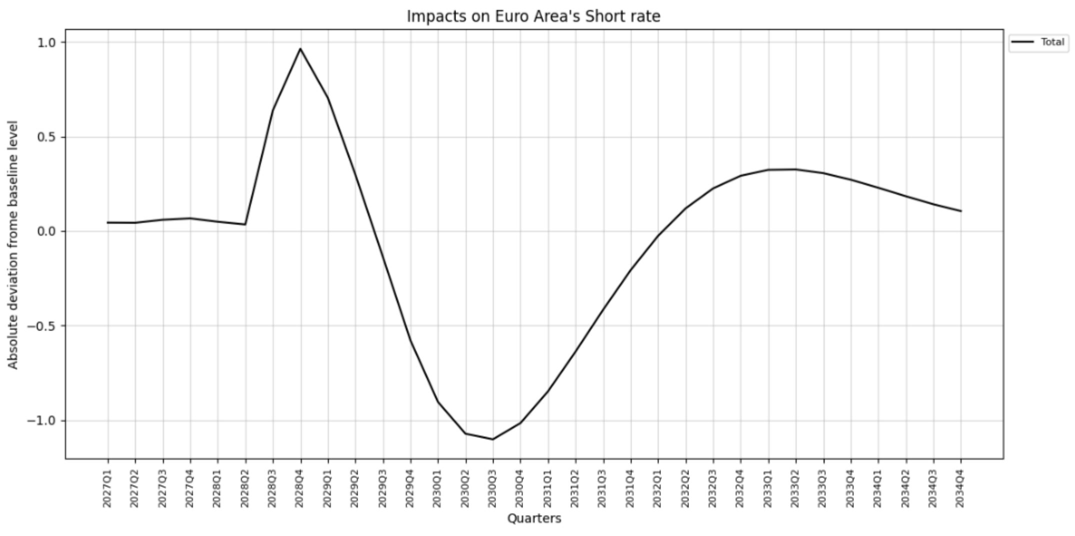


Figure 25: Multiple Breadbasket Failure Scenario – Impact on Short-Term Interest Rates in the euro area (percentage points deviation)