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par

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Titre: **"Application du stress-test des risques climatiques pour 2022-2027 sur une compagnie d'assurance"**

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RESUME

Dans le contexte mondial actuel d'intensification du changement climatique et d'incertitude croissante, les secteurs de la finance et de l'assurance sont confrontés à des défis sans précédent en matière de risque climatique systémique au niveau mondial et européen mais aussi national. En réponse, l'Autorité de Contrôle Prudentiel et de Résolution (ACPR) a développé un ensemble de modèles quantitatifs et de lignes directrices pour évaluer le risque climatique. Ceux-ci visent à mesurer avec soin les impacts potentiels de divers scénarios de transition climatique et des politiques connexes sur les institutions financières et d'assurance. Notre étude, qui utilise le cas d'une compagnie d'assurance vie, consiste en une analyse empirique approfondie du cadre de test de stress climatique de l'ACPR, affirmant la nécessité et l'urgence de surveiller de près les risques liés à la transition climatique dans ce secteur de l'assurance. Au cours de sa mise en œuvre, nous avons été confrontés à de nombreux défis, notamment la sélection des scénarios climatiques, l'étalonnage des données, la construction et les méthodes des chocs, et la compatibilité du système, pour lesquels nous avons proposé une série de solutions et d'améliorations. Ce mémoire vise à améliorer l'opérabilité et l'adaptabilité des tests de stress climatiques au sein des entreprises d'assurance, afin d'assurer le développement durable du secteur de l'assurance à la pointe du risque climatique.

Mots Clés : Risque Climatique, Risque de Transition Climatique, ORSA, Scénarios Climatiques, Tests de Stress Climatique, Métriques de Solvabilité II, Calibration des Données, Programmation de Choc, Compagnie d'Assurance d'Épargne.

ABSTRACT

In the current global context of escalating climate change and increasing uncertainty, the finance and insurance industries are confronted with unprecedented systemic climate risk challenges at the global, European, and national levels. In response, the Autorité de Contrôle Prudentiel et de Résolution (ACPR) has developed a set of quantitative models and guidelines to assess climate risk, aimed at thoroughly measuring the potential impacts of various climate transition scenarios and related policies on financial and insurance institutions. Our study, using a life insurance company as a case study, conducts an in-depth empirical analysis of ACPR's climate stress test framework, affirming the necessity and urgency of closely monitoring climate transition risks in the insurance industry. During implementation, we faced multiple challenges including climate scenario selections, data calibrations, shock constructions and methods, and system compatibility, for which it proposed a series of solutions and enhancements. This thesis aims to improve the operability and adaptability of climate stress test within insurance industry, further ensuring the insurance industry's sustainable development at the forefront of climate risk.

Key Words: Climate Risk, Climate Transition Risk, ORSA, Climate Scenarios, Climate Stress Tests, Solvency II Metrics, Data Calibration, Shock Programming, Saving Insurance Company.

SYNTHÈSE

A l'heure de la reconnaissance d'une crise climatique aux niveaux international, européen et national, le secteur français de l'assurance est confronté à l'interprétation de nombreux textes et à de multiples exercices quantitatifs. Ceux-ci ont pour but d'avoir une meilleure compréhension du risque climatique dont la réalisation, si elle est indéniable, reste incertaine dans ses modalités et ses impacts.

S'appuyant majoritairement sur le Sixième Rapport d'évaluation (AR6) du Groupe d'experts intergouvernemental sur l'évolution du climat (GIEC), de nombreux experts et décideurs ont une compréhension quantifiée plus multidimensionnelle de l'état actuel et des tendances projetées du changement climatique mondial (climat, écologie, et société humaine). Le dernier rapport du GIEC souligne l'urgence d'une action immédiate et décisive face au changement climatique. Entre 2011 et 2020, les activités humaines ont incontestablement créé une augmentation des températures de surface dans le monde de 1,1°C par rapport à l'époque préindustrielle (1850-1900), le dernier demi-siècle ayant été témoin de la plus rapide augmentation de la température. Cette accélération du changement climatique, soulignant l'impact croissant de l'homme sur le système climatique, a suscité une préoccupation internationale généralisée, exposant les menaces significatives existantes pour les écosystèmes naturels et mettant au défi les structures économiques et financières mondiales.

En réponse, l'Union européenne (UE) a promulgué le Règlement 2021/1256 le 21 avril 2021, obligeant les compagnies d'assurance à intégrer les risques de durabilité dans leur évaluation interne des risques et de la solvabilité (ou ORSA). Entrant en vigueur le 2 août 2022, ce règlement marque une étape cruciale dans l'intégration des risques durables dans la gestion des risques et les évaluations de solvabilité dans l'industrie de l'assurance.

Les compagnies d'assurance sont confrontées aux doubles défis du changement climatique : les risques physiques, tels que l'augmentation des taux de mortalité, des fréquences de réclamation et des dommages matériels ; les risques de transition, y compris dans la prise en compte de l'inflation, de la volatilité de marché boursier et des fluctuations des taux d'intérêts. Il est à noter que, dans cette approche, les risques physiques et de transition sont interdépendants. La mise en œuvre de politiques climatiques plus strictes mais aussi plus efficaces pourrait mener à un déplacement de l'équilibre risque / durabilité / profitabilité vers des risques de transition plus prononcés avec des conditions plus encadrées d'exercice de l'activité d'assurance.

Affronter ces défis émergents nécessite que les compagnies d'assurance possèdent la capacité d'identifier, de mesurer et de gérer les risques climatiques. Intégrer ces risques dans des cadres de gestion des risques standards et contrôler efficacement leurs impacts devient un objectif stratégique. Dans un souci de mise en exergue de ce rôle stratégique du risque climatique y compris au sein d'une entreprise d'assurance vie, ce mémoire aborde trois questions critiques :

- Comment l'évaluation des risques de transition climatique peut-elle être intégrée dans le système de gestion des risques d'une compagnie d'assurance?

- Quels défis peuvent apparaître dans la mise en œuvre des évaluations des risques climatiques et de la solvabilité y afférant et quelles sont les solutions viables pour mieux les maîtriser?

- Quels efforts supplémentaires sont requis dans le secteur de l'assurance pour une évaluation plus effective et plus exacte des risques climatiques?

Ce mémoire d'actuariat est composé principalement de deux parties. La Partie I (constituée des chapitres 1 et 2) explique principalement le contexte scientifique et réglementaire du stress test climatique. La Partie II (comprenant les chapitres 3 à 5) expose d'une part les défis rencontrés en pratique lors de la réalisation du stress test comme prescrit par le premier exercice pilote de l'ACPR et, d'autre part, les résultats et analyses découlant de l'application pratique du test de stress climatique.

Le chapitre 1 donne un aperçu de l'état actuel du risque climatique, des défis et des réponses internationales au changement climatique mondial. Sur la base du Sixième Rapport d'évaluation du GIEC, nous analysons l'impact des émissions de gaz à effet de serre sur les températures mondiales et soulignons les conséquences négatives étendues du changement climatique sur l'environnement naturel et les sociétés humaines. De plus, ce chapitre explore le rôle important de la Convention-cadre des Nations Unies sur les changements climatiques (CCNUCC) et ses accords significatifs dans la gouvernance climatique mondiale. Il décrit les principales réglementations et choix politiques opérés par l'Union européenne et la France dans le secteur financier et dans le secteur de l'assurance pour faire face au changement climatique. Enfin, le chapitre se concentre sur le cadre réglementaire Solvabilité II dans le contexte des défis climatiques, y compris à travers le prisme des trois piliers de Solvabilité II et de la nécessité d'intégrer les risques climatiques dans un secteur déjà pluri réglementé. Ce chapitre vise également à donner un aperçu du traitement politique et réglementaire du changement climatique, des actions internationales et des stratégies de réponse possibles du secteur de l'assurance au regard du capital à mobiliser pour l'intégration de ce risque qui s'accentue de jour en jour.

Le chapitre 2 examine les spécifications techniques et les propositions de mesures des risques climatiques à travers différents scénarios menées succinctement par le GIEC, le Réseau pour le verdissement du système financier (NGFS) et l'ACPR. Ces différents travaux requièrent un examen fin des complexités et des nuances des scénarios de test de stress climatique développés. En comparant ces scénarios, nous constatons que les scénarios de risques climatiques de l'ACPR peuvent être utilisés comme base principale pour les études ultérieures en raison de leur précision plus importante dans les données fournies et de leur caractère opérationnel laissant présager une application prochaine via une réglementation nationale contraignante. Ensuite, le chapitre explore davantage les scénarios de test de stress climatique proposés par l'ACPR, analysant les impacts des scénarios allant d'une transition ordonnée à des transitions retardées et soudaines sur la macroéconomie et la macro-finance. Enfin, le chapitre fournit une introduction détaillée aux méthodes d'application des scénarios de test de stress climatique de l'ACPR, offrant des conseils solides pour les compagnies d'assurance sur la mise en œuvre des tests de stress climatique.

Le chapitre 3 présente dans un premier temps la logique d'entrée de données et le flux de travail de la plateforme de modélisation Addactis, construite en conformité avec le cadre Solvabilité II. Ensuite, nous abordons brièvement le contexte spécifique de l'entreprise d'assurance vie pour laquelle les tests de stress climatique de l'ACPR sont appliqués. L'accent de ce chapitre est mis sur le fait d'adresser des défis qui pourraient survenir lors de la mise en œuvre de la version 2019 des tests de stress climatique de l'ACPR dans l'entreprise d'assurance choisie sur la base de ses données à la fin 2022. Notons que, lors de l'application de chocs aux actifs des fonds d'actions, l'ACPR exige un niveau plus élevé de granularité des chocs que celui offert par la plateforme existante de modélisation Addactis. Aussi, nous avons dû prévoir l'écriture supplémentaire d'un programme de choc avec une granularité plus élevée. En décomposant et en abordant la logique adoptée pour la construction du stress et les défis dans l'établissement du programme de choc, nous avons créé un programme de choc pour les actifs des fonds d'actions répondant aux exigences de l'ACPR. Par la suite, en termes de taux sans risque et de taux d'inflation, face à des problèmes tels que l'insuffisance des données et l'obsolescence dans les tests de stress climatique de l'ACPR 2019, nous avons résolu différents problèmes en adoptant des méthodes raisonnables d'extrapolation et de calibrage des données. Ces travaux fournissent à présent une base solide pour la mise en œuvre des tests de stress climatique de l’exercice pilote de l’ACPR, même s’ils sont spécifiques aux portefeuilles étudiés et ne permettent pas de répondre à l’ensemble des problématiques liées à une approche macro prudentielle et de très long terme.

Le chapitre 4 compare et analyse les résultats de simulation de trois scénarios basés sur les tests de stress climatique de l'ACPR pour les années 2022-2027 : Baseline, Delayed Transition et Sudden Transition. L'analyse révèle que même sous le scénario de base dit Baseline, qui a le plus faible risque de transition climatique, le ratio de solvabilité de l'entreprise est réduit de 14 points de pourcentage par rapport au résultat attendu du test de stress ORSA conventionnel, ce qui représente un impact notable dès 5 ans. Du point de vue du ratio de solvabilité, la solvabilité en appliquant les scénarios dits « de Transition Retardée » et « de Transition Soudaine » n'est que de 2 points inférieure par rapport au scénario Baseline. Cependant, à mesure que la période d'analyse s'étend et évolue, les scénarios de Transition Retardée et de Transition Soudaine peuvent de plus en plus rencontrer des problèmes de solvabilité. Par conséquent, une surveillance à long terme des risques climatiques est essentielle.

Le chapitre 5 commence par mettre en lumière les limites de cette étude dans trois domaines : les hypothèses d'actifs, les hypothèses de passif et les résultats des tests. Ensuite, ce chapitre explore les nouvelles exigences et les changements de scénario de la nouvelle version 2023 du test de stress climatique de l'ACPR. Cette section révèle les avantages de combiner les tests de stress climatique à court terme et à long terme dans l'évaluation des risques climatiques, tout en soulignant les limitations persistantes de cette nouvelle version du test de stress climatique. La publication en 2023 de nouveaux jeux de stress tests climatiques par l'ACPR confirme non seulement l'importance accrue de mesurer les risques climatiques de manière fréquente et en cohérence avec l’environnement financier mais matérialise aussi l'imminence d’une évolution contrainte des méthodes d'évaluation des risques fortement guidées par les autorités de supervision. En outre, ce chapitre propose des axes d’adaptation pour les outils de modélisation actuarielle telles qu’Addactis, en réponse aux lacunes identifiées dans cette étude. Il présente également un cadre de macro-modélisation répondant aux exigences des tests de stress climatique de l'ACPR. L'objectif est d’améliorer les capacités d'évaluation des impacts à long terme du climat sur le secteur de l'assurance en anticipant les exigences des autorités de contrôle pour mieux répondre au besoin de leurs clients. Enfin, le chapitre souligne la nécessité d'efforts complets et minutieux par divers départements au sein des compagnies d'assurance face aux risques climatiques. Grâce à des efforts collectifs multidimensionnels au sein du secteur de l’assurance mais aussi plus largement, du secteur financier, l’adaptation de l'activité d’assurance à la fois à travers ses investissements mais aussi grâce à ses mesures de risque et de solvabilité pourrait permettre d’adresser efficacement les défis de plus en plus complexes du changement climatique, en répondant aussi bien aux exigences politiques qu’aux attentes des assurés.

INTRODUCTION

At a time when the climate crisis is recognized at the international, European, and national levels, the French insurance sector faces the interpretation of numerous texts and multiple quantitative exercises. These are aimed to provide a better understanding of climate risk, the realization of which, while undeniable, remains uncertain in its modalities and impacts.

Drawing predominantly from the Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (AR6), numerous experts and decision-makers gain access to a more multidimensional quantitative understanding (climate, ecology, and human society) of the current states and projected trends of global climate change. The latest IPCC report underscores the urgency of immediate and decisive action in response to climate change. Between 2011 and 2020, human activities have indisputably led to a 1.1°C increase in global surface temperatures compared to pre-industrial levels (1850-1900), with the past half-century witnessing the most rapid temperature rise. This acceleration of climate change, highlighting the growing human impact on the climate system, has sparked widespread international concern, exposing significant existing threats to natural ecosystems and challenging global economic and financial structures.

In response, the European Union (EU) enacted Regulation 2021/1256 on April 21, 2021, mandating insurance companies to incorporate sustainability risks into their Own Risk and Solvency Assessment (ORSA). Effective from August 2, 2022, this regulation marks a pivotal step in integrating sustainable risks into risk management and solvency evaluations in the insurance industry.

Insurance companies face the dual challenges of climate change: physical risks, such as increased mortality rates, claim frequencies, and property damages; transition risks, including inflation, stock market volatility, and interest rate fluctuations. It is worth noting that, in this approach, physical and transition risks are interdependent. The implementation of stricter yet more effective climate policies could lead to a shift in the risk / sustainability / profitability balance towards more pronounced transition risks with more regulated conditions for insurance activities.

Confronting these emerging challenges requires insurance companies to possess the ability to identify, measure, and manage climate risks. Integrating these risks into standard risk management frameworks and effectively monitoring their impacts becomes a strategic objective. With a focus on highlighting this strategic role of climate risk, including within a life insurance company, this thesis addresses three critical questions:

- How could the evaluation of climate transition risks be integrated into an insurance company's risk management system?
- What challenges might arise in implementing climate risk assessments and solvency evaluations, and what viable solutions exist to better manage them?

- What additional efforts are required in the insurance sector for a simpler and more efficient assessment of climate risks?

This actuarial thesis primarily consists of two parts. Part I (consisting of Chapters 1 and 2) primarily explains the scientific and regulatory context of climate stress test. Part II (consisting of Chapters 3 to 5) outlines the challenges encountered in practice during the implementation of stress test as prescribed by the ACPR's first pilot exercise and the results and analyses resulting from the practical application of climate stress test.

Chapter 1 provides an overview of the current state of climate risk, challenges, and international responses to global climate change. Based on the Intergovernmental Panel on Climate Change's Sixth Assessment Report, we analyze the impact of greenhouse gas emissions on global temperatures and highlight the extensive negative consequences of climate change on the natural environment and human societies. Additionally, this chapter explores the significant role of the United Nations Framework Convention on Climate Change (UNFCCC) and its agreements in global climate governance. This chapter also describes the main regulations and policy choices made by the European Union and France in the financial sector and insurance sector to address climate change. Finally, the chapter focuses on the Solvency II regulatory framework in the context of climate challenges, including through the lens of its three pillars and the need to integrate climate risks into an already multi-regulated sector. This chapter aims to provide an overview of the policy and regulatory treatment of climate change, international actions, and possible response strategies of the insurance sector regarding the capital mobilization required for the integration of this escalating risk.

Chapter 2 examines the technical specifications and proposed measures for climate risks through various scenarios conducted succinctly by the IPCC, the Network for Greening the Financial System (NGFS), and the ACPR. These different works require a thorough examination of the complexities and nuances of the developed climate stress test scenarios. By comparing these scenarios, we observe that the climate risk scenarios of the ACPR can be used as the main basis for further studies due to their greater accuracy in provided data and their operational nature, which suggests imminent application through binding national regulations. Subsequently, the chapter further explores the climate stress test scenarios proposed by the ACPR, analyzing the impacts of scenarios ranging from an orderly transition to delayed and sudden transitions on macroeconomics and macrofinance. Finally, the chapter provides a detailed introduction to the methods of implementing ACPR climate stress test scenarios, offering comprehensive guidance for insurance companies on the implementation of climate stress tests.

Chapter 3 initially presents the data input logic and workflow of the Addactis modeling platform, built in compliance with the Solvency II framework. Subsequently, this chapter briefly addresses the specific context of the life insurance company for which the ACPR climate stress tests are applied. The focus of this chapter is on addressing challenges that may arise during the implementation of the 2019 version of the ACPR climate stress tests in the chosen insurance company based on its data as of end-2022. Note that the ACPR requires a higher level of shock granularity when applying shocks to equity fund assets, and the existing Addactis modeling platform does not meet this requirement, necessitating the additional writing of a shock program with higher granularity. Also, by decomposing and addressing the logic adopted for stress construction and challenges in establishing the shock program, we have created a shock program for equity fund assets that meets the ACPR's requirements. Subsequently, in terms of risk-free rates and inflation rates, facing issues such as data insufficiency and obsolescence in the 2019 ACPR climate stress tests, we have addressed various problems by adopting reasonable methods of data extrapolation and calibration. These efforts now provide a solid foundation for the implementation of the ACPR pilot exercise climate stress tests, even though they are specific to the portfolios studied and do not address all issues related to a macroprudential and long-term approach.

Chapter 4 compares and analyzes the simulation results of three scenarios based on the ACPR climate stress tests for the years 2022-2027: Baseline, Delayed Transition, and Sudden Transition. The analysis reveals that even under the Baseline scenario, which has the lowest climate transition risk, the company's solvency ratio is reduced by 14 percentage points compared to the expected result of conventional ORSA stress test, representing a notable impact within 5 years. From the solvency ratio perspective, the solvency under the scenarios of 'Delayed Transition' and 'Sudden Transition' is only 2 points lower compared to the Baseline scenario. However, as the analysis period extends and evolves, the scenarios of Delayed Transition and Sudden Transition may increasingly encounter solvency issues. Therefore, long-term monitoring of climate risks is essential.

Chapter 5 first identifies the limitations of this study in three aspects: asset assumptions, liability assumptions and test results. Next, this chapter explores the new requirements and scenario changes of the new 2023 version of the ACPR climate stress test. It reveals the benefits of combining short-term and long-term climate stress tests in climate risk assessment, while highlighting the continuing limitations of this new version of the climate stress test. The publication in 2023 of new sets of climate stress tests by the ACPR not only confirms the increased importance of measuring climate risks frequently and consistently with the financial environment, but also materializes the imminence of a constrained evolution in risk assessment methods strongly guided by supervisory authorities. In addition, this chapter proposes areas of adaptation for actuarial modeling tools such as Addactis, in response to the shortcomings identified in this study. The chapter also develops a macro-modeling framework that satisfies the requirements of the ACPR's climate stress tests. The aim is to improve the ability to assess the long-term impact of climate on the insurance sector, by anticipating the requirements of the supervisory authorities to better meet the needs of their clients. Finally, the chapter underlines the need for comprehensive and meticulous efforts by various departments within insurance companies in the face of climate risks.

With collective efforts at multiple levels within the insurance industry, also more broadly within the financial sector, the adaptation of the insurance business both through its investments and through its risk and solvency measures could effectively address the increasingly complex challenges of climate change, meeting both political requirements and policyholder expectations.

PART 1: BACKGROUNDS

Chapter 1 : Global Climate Change: Challenges, Actions and Responses

1.1 Global Climate Change Status and Challenges

According to the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC),[1] people have gained a comprehensive understanding of the current state and future trends of global climate change. The report underscores the urgency of taking immediate and decisive action. From 2011 to 2020, human activities, primarily greenhouse gas emissions, have indisputably caused an increase in global surface temperature by 1.1°C compared to the pre-industrial era (1850-1900), with a more significant average rise of 1.59°C on land compared to 0.88°C in the oceans. The acceleration of climate change, evidenced by the fastest temperature rise in the past 50 years, reflects the intensifying human impact on the climate system.

The report also highlights the substantial disparity in historical and current greenhouse gas emissions. Approximately 35% of the global population resides in areas where per capita emissions exceed 9 tons of CO_2 equivalent, while 41% live in areas with emissions less than 3 tons of CO_2 equivalent. This uneven distribution of emissions exacerbates the vulnerability of populations, with an estimated 3.3 to 3.6 billion people living in environments highly sensitive to climate change.

Climate change has already had widespread and profound adverse impacts on the natural environment and human society, leading to losses and damages across systems, regions, and industries. Particularly in climate-sensitive sectors such as agriculture, forestry, fisheries, energy, and tourism, economic losses due to climate change have become a detectable reality. Individual livelihoods have been severely affected by the destruction of homes and infrastructure, loss of property and income, and the deterioration of human health and food security, further impacting gender and social equity. In urban settings, climate change is especially intense, with frequent extreme heat events. Urban infrastructure, including transportation, water resources, sanitation, and energy systems, has been compromised by extreme and gradual climate events, leading to economic losses, service disruptions, and a decrease in residents' well-being. These adverse impacts are particularly pronounced among economically and socially marginalized groups, highlighting the inequality issues brought about by climate change.

These data collectively underscore the urgency of global action in adopting mitigation and adaptation strategies. Despite progress in adaptation planning and implementation across various sectors and regions, significant gaps remain, especially in developing countries with limited

[1] https://www.ipcc.ch/assessment-report/ar6/

financial resources. In terms of mitigation, the current trajectory of greenhouse gas emissions, as per the national commitments of October 2021, indicates a high likelihood of exceeding a 1.5°C temperature rise within the 21st century, further intensifying the urgency to bridge the gap between policy and implementation. The global temperature evolution trends from 1900 to 2100 is shown in Figure 1.

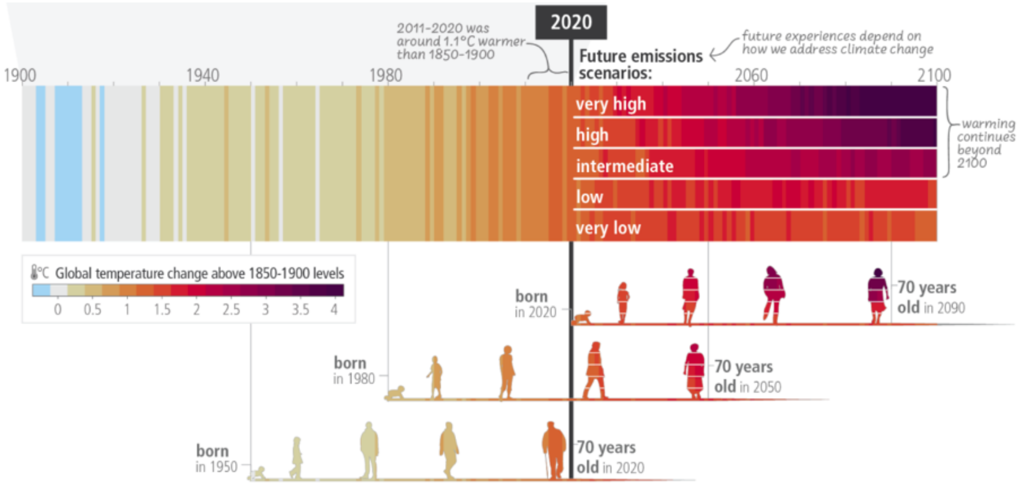

Figure 1: Trends in Global Temperature Evolution from 1900 to 2100

Source: The IPCC Sixth Assessment Report

1.2 The International Actions in the Background of the Climate Challenge

Against the backdrop of global climate governance, the United Nations' early attention to and action on climate change has been significant. As the impact of climate change on Earth's natural ecosystems and human societies becomes increasingly severe, the international community has come to realize that addressing this global challenge requires cooperation and action on a global scale. In this context, the establishment of the United Nations Framework Convention on Climate Change (UNFCCC) as the first major international agreement on climate change issues marks a significant milestone in the global response to climate change. The UNFCCC, adopted at the United Nations Conference on Environment and Development in 1992, also known as the Rio Earth Summit, represents a collective response to the substantial challenge of climate change at a global level. The summit was epoch-making in the history of international environmental governance and ushered in a new era where issues of environment and sustainable development gained widespread attention globally.

The primary objective of the UNFCCC is to stabilize greenhouse gas concentrations in the atmosphere, aiming to prevent potential threats to the climate system caused by human activities. Since its entry into force in 1994, the Convention has been ratified by nearly all United Nations member states, reflecting a universal consensus and an urgent need for action on climate change issues. Additionally, the UNFCCC serves not only as a global policy framework but also as an important platform for nations to negotiate, discuss, and shape subsequent agreements on climate change. Under its guidance, a series of important agreements, such as the Kyoto Protocol in 1997 and the Paris Agreement in 2015, have been established, strengthening the international community's commitment to climate action, and playing a key role in global climate governance.

Furthermore, the United Nations Framework Convention on Climate Change (UNFCCC) has established multiple institutions to promote and implement its objectives, with the most important being the Conference of the Parties (COP). The COP, as the supreme decision-making body of the Convention, is responsible for reviewing the implementation of the Convention, assessing the progress of countries in reducing greenhouse gas emissions and addressing climate change, and reaching a consensus on new global climate actions.

COP meetings are a key platform for global climate action, providing opportunities for national leaders, policymakers, scientists, non-governmental organizations, and the public to discuss, negotiate, and formulate strategies to address climate change. Since the first meeting in 1995, COP has convened multiple times, focusing each time on the current climate challenges and strategies to address them. The following is a comprehensive summary of the content of significant COP meetings:

Conference	Achievements and Decisions
COP1 (1995, Berlin)	The 'Berlin Mandate' was adopted, initiating negotiations for the Kyoto Protocol and affirming the leadership role of developed countries in reducing greenhouse gas emissions.
COP3 (1997, Kyoto)	The Kyoto Protocol was adopted, setting quantified greenhouse gas emission reduction targets for developed countries and introducing international emission trading mechanisms.
COP7 (2001, Marrakech)	The 'Marrakech Accords' were established as the operational details of the Kyoto Protocol, including emissions trading, Clean Development Mechanism (CDM), and Joint Implementation (JI).
COP11 (2005, Montreal)	Witnessed the entry into force of the Kyoto Protocol and initiated negotiations for the post-Kyoto period (post-2012) action roadmap.
COP15 (2009, Copenhagen)	The Copenhagen Accord was adopted, recognizing the need to limit global temperature rise to within 2 degrees Celsius and providing important guidance for climate financing.

Table 1: The Summary of the Significant COP Meetings[2]

[2] https://unfccc.int/process/bodies/supreme-bodies/conference-of-the-parties-cop

Conference	Achievements and Decisions
COP17 (2011, Durban)	Establishment of the Green Climate Fund to support climate action in developing countries and agreed to reach a comprehensive climate agreement by 2020, laying the groundwork for the Paris Agreement.
COP21 (2015, Paris)	The Paris Agreement was reached, a global framework for climate action aimed at limiting global temperature rise to well below 2 degrees Celsius, striving not to exceed 1.5 degrees Celsius.
COP24 (2018, Katowice)	Finalized the implementation details of the Paris Agreement, the 'Katowice Rulebook', providing specific guidance for the implementation of the Paris Agreement.
COP26 (2021, Glasgow)	Emphasized the urgency of enhancing countries' emissions reduction commitments (NDCs) and strengthened commitments to climate finance, especially regarding funding flows to developing countries.

Table 1 (Continued)

Source: Conference of the Parties (COP)

Within the broader context of international climate policy and action, the interaction between the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Framework Convention on Climate Change (UNFCCC) plays a decisive role in shaping and driving global climate policy. Since its establishment in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), the IPCC has been committed to providing scientific evidence and assessments for the global dialogue on climate change. Its primary responsibilities include evaluating existing scientific knowledge on climate change, exploring its impacts on natural environments and human societies, and proposing adaptation and mitigation strategies to address climate change.

Before the establishment of the UNFCCC, which was adopted at the United Nations Conference on Environment and Development in 1992, the IPCC's first assessment report, published in 1990, laid the scientific foundation for subsequent negotiations and the formulation of the UNFCCC. Subsequent IPCC assessment reports have continually provided scientific support to the UNFCCC, playing a crucial role in the development of key climate agreements such as the Kyoto Protocol and the Paris Agreement.

Since its inception, each assessment report released by the IPCC has provided a comprehensive analysis of various aspects of global climate change, including scientific foundations, impact assessments, adaptation measures, and mitigation strategies. These reports have laid a solid scientific foundation for global climate policy, supporting the international community's decision-making and actions in addressing climate change. The following is a comprehensive summary of the main content of the first six assessment reports.[3]

[3] https://www.ipcc.ch/reports/

Report	Key Findings
First Assessment Report (AR1) - 1990	Identified human-caused greenhouse gas increases as the main reason for global warming, predicting a rise of about 0.3°C to 0.7°C in global average temperatures by 2025 from 1980, with sea levels rising 15 to 95 cm.
Second Assessment Report (AR2) - 1995	Strengthened evidence of the link between human activities and climate change, predicting a 1.0°C to 3.5°C increase in global average temperatures by 2100, with sea levels rising 15 to 95 cm, emphasizing the need for mitigation and adaptation measures.
Third Assessment Report (AR3) - 2001	Presented a view that climate change is occurring faster than previously anticipated, predicting a 1.4°C to 5.8°C increase in global average temperatures by 2100, with sea levels rising 9 to 88 cm, highlighting the urgency of greenhouse gas emissions reduction.
Fourth Assessment Report (AR4) - 2007	Clearly indicated the widespread impacts of climate change on natural and human systems, predicting a 1.1°C to 6.4°C increase in global average temperatures by the end of the 21st century from 1980-1999, with sea levels rising 18 to 59 cm.
Fifth Assessment Report (AR5) - 2014	Further emphasized the importance of limiting global average temperature increases to well above 2 degrees Celsius, predicting in the best-case scenario a 0.3°C to 1.7°C rise by 2100, and in the worst-case scenario a 2.6°C to 4.8°C rise, with sea levels rising 26 to 82 cm.
Sixth Assessment Report (AR6) - 2021	Issued a more explicit warning that the impacts of climate change are more profound and rapid, predicting a 1.0°C to 5.7°C increase in global temperatures by 2100 based on different emission scenarios, with sea levels rising 28 to 55 cm in the best-case and 63 to 101 cm in the worst-case.

Table 2: The Summary of the Six Assessment Reports of IPCC

Source: The Climate Assessment Reports of IPCC

1.3 The Financial Actions from European Union and France

Faced with the intensifying situation of global climate change, the European Union (EU) has taken a series of pioneering steps by introducing numerous key regulations to actively address this challenge. As the international community's understanding of climate change and its impact on global society and economy deepens, along with the continuous accumulation of scientific evidence, the EU has increasingly recognized the critical importance of acting in the financial sector to mitigate the effects of climate change.

Against this international environmental and policy backdrop, the EU has rolled out a range of key regulations to strengthen its climate actions and sustainability measures in the financial domain. These regulations not only demonstrate the EU's active role in global climate governance but also reflect its strategic thinking in financial and environmental policies. These regulations include, but are not limited to, the plan on sustainable finance, taxonomy for sustainable activities, and sustainable financial disclosure requirements, aimed at enhancing investment transparency and directing capital flows towards more sustainable projects and practices. The following is a summary of the key climate-related regulations introduced by the EU:

Initiative	Description
EU Action Plan on Sustainable Finance (2018)[4]	This action plan marks the EU's emphasis on sustainability in finance, aiming to enhance investment transparency and direct capital towards sustainable projects to combat climate change.
EU Taxonomy for Sustainable Activities (2018)[5]	By defining what constitutes a 'sustainable activity', this taxonomy provides clear guidance for investors and companies to promote environmentally friendly investments.
Sustainable Finance Disclosure Regulation (SFDR, 2019)[6]	The SFDR requires financial institutions to disclose sustainability characteristics and impacts of their products, enhancing transparency in sustainable investments.
Revision of the Non-Financial Reporting Directive (NFRD, 2021)[7]	This revision strengthens the obligations of large companies in disclosing climate-related information, highlighting the importance of transparency in climate action.
EIOPA's Guidelines and Frameworks on Climate-Related Risks (2023)[8]	The European Insurance and Occupational Pensions Authority (EIOPA) has developed a range of guidelines and frameworks aimed at helping the insurance and pension industry better understand and manage climate-related risks.

Table 3: The Summary of the Key Climate-Related Regulations of EU

France, as a core member state of the European Union (EU), has not only played an active role in the EU's overall strategy to address climate change but has also developed a series of distinctive laws and strategies based on its environmental characteristics and economic needs. These measures align with the EU's climate objectives while showcasing France's pioneering thoughts and practices in environmental protection and sustainable development. French initiatives in climate action include, but are not limited to, the introduction of the French Energy Transition Law, the Green Finance Strategy, the French Climate Energy Law, and the ACPR Climate Stress Test. The following is a summary of the key climate-related regulations introduced by France:

[4] https://finance.ec.europa.eu/sustainable-finance/overview-sustainable-finance_en
[5] https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en
[6] https://finance.ec.europa.eu/regulation-and-supervision/financial-services-legislation/implementing-and-delegated-acts/sustainable-finance-disclosures-regulation_en
[7] https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/654213/EPRS_BRI(2021)654213_EN.pdf
[8] https://www.eiopa.europa.eu/publications/application-guidance-climate-change-materiality-assessments-and-climate-change-scenarios-orsa_en

Initiative	Description
French Energy Transition Law (2016)[9]	Aims to guide France's transition to a low-carbon economy, emphasizing disclosure responsibilities of financial institutions and companies on climate change, aligning with EU's overall objectives, and reflecting France's specific concerns.
French Green Finance Strategy (2018)[10]	Responds to the EU's Sustainable Finance Action Plan, demonstrating France's innovation and leadership in promoting the green bond market and sustainable investments in the private sector.
French Energy and Climate Law (2019)[11]	Reaffirms France's goals for carbon neutrality and biodiversity protection, showcasing its ambition and commitment in alignment with the EU.
ACPR Climate Stress Test (2020)[12]	Highlights the importance of assessing and managing climate-related risks in the financial sector, echoing the EU's broader concerns about financial stability.

Table 4: The Summary of the Key Climate-Related Regulations of France

[9] https://www.ecologie.gouv.fr/sites/default/files/Energy%20Transition%20for%20Green%20Growth%20Act%20in%20action%20-%20Regions%2C%20citizens%2C%20business%20%28%2032%20pages%20-%20juillet%202016%20-%20Versions%20anglaise%29.pdf
[10] https://www.banque-france.fr/en/banque-de-france/engaged-central-bank/climate-change-sustainable-finance
[11] https://www.tresor.economie.gouv.fr/Articles/2021/06/08/publication-of-the-implementing-decree-of-article-29-of-the-energy-climate-law-on-non-financial-reporting-by-market-players
[12] https://acpr.banque-france.fr/scenarios-et-hypotheses-principales-de-lexercice-pilote-climatique

1.4 The Solvency II in the Context of Climate Challenges

1.4.1 A Brief Introduction of Solvency II

The Solvency II Directive, implemented in the European Union in 2016, represents a significant overhaul in insurance regulation. The genesis of this directive was the re-evaluation of the stringency of insurance market regulations and the capability of risk management following the global financial crisis. Its purpose was to establish a unified EU insurance regulatory framework to enhance the financial soundness of insurance companies and overall market transparency. Solvency II is primarily composed of three pillars as shown in Figure 2:

- Pillar 1 (Quantitative Requirements): The core of this pillar is the Standard Capital Requirement (SCR). The objective of SCR is to ensure that insurance companies could withstand significant adverse events that occur annually, thus stipulating the minimum capital level that insurers must hold. The calculation of SCR is based on a 99.5% confidence level, meaning that insurers must possess sufficient capital to cover losses in 99.5% of the worst-case scenarios. The SCR calculation involves assessing various types of risks, including market risk, credit risk, life underwriting risk, non-life underwriting risk, and operational risk.
- Pillar 2 (Risk Management and Supervisory Review Process): Under this pillar, insurance companies are required to establish a comprehensive risk management system. A key component is the Own Risk and Solvency Assessment (ORSA), which requires companies to evaluate their current and future business strategies under various risk scenarios. ORSA emphasizes that companies need to determine capital requirements based on their specific risk profile and risk-bearing capacity, integrating this information into their strategic planning and long-term sustainability considerations.
- Pillar 3 (Market Discipline and Transparency): This pillar mandates the disclosure of key information by insurance companies about their capital status, risk exposures, risk management, and capital management practices. The aim is to enhance market discipline and transparency of insurance companies, allowing investors and policymakers to better understand the companies' financial health and risk management capabilities.

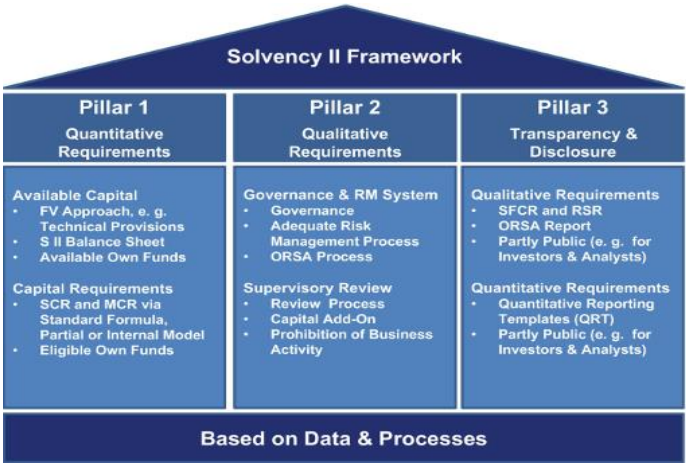

Figure 2: Solvency II Framework[13]

Source: Solvency II in the Insurance Industry

The transition from Solvency I to Solvency II marks a fundamental transformation in the European Union's regulatory framework for the insurance industry. This shift is characterized not only by increased complexity and refinement in regulation but also by significant changes in the structure of insurance companies' balance sheets. The implementation of the Solvency II framework, particularly the introduction of its three pillars, has significantly enhanced the insurance industry's understanding and management of risk. In this new regulatory environment, several key financial metrics have been introduced, aimed at more accurately reflecting the financial health and risk exposure of insurance companies. The following is a brief comparison of Solvency I and Solvency II from various perspectives:

Aspect	Solvency I	Solvency II
Regulatory Framework	Baseline framework established before 2004. Simple and generalized.	Comprehensive and advanced framework implemented in 2016. Tailored to risk and individualization.
Capital Requirements	Capital requirements based on simple fixed ratios.	Capital requirements based on the actual risk profile of the insurance company, e.g., using risk-sensitive formulas for market risk, credit risk, etc.
Risk Management	Basic risk management, without explicit requirements for a risk management framework or processes.	Requires detailed risk management framework, including risk assessment, risk tolerance, and mitigation strategies (e.g., ORSA).
Transparency and Reporting	Reporting focused mainly on financial status with less emphasis on risk disclosure.	Highlights transparency in risk and capital management, including regular detailed risk reporting and capital status disclosure.
Focus	Emphasis on ensuring sufficient capital levels to protect policyholders from extreme scenarios.	Focuses on comprehensive risk management, including risk evaluation, capital planning, and ongoing supervision to ensure long-term financial health.

Table 5: The Comparison of Solvency I and Solvency II

[13] Heep-altiner, M. (2018). Solvency II in the Insurance Industry. Springer.

Under the Solvency II framework, insurance companies are required to comply with more stringent capital and risk management requirements, as well as to adapt to significant adjustments in their balance sheet structures. Within this framework, core indicators like the Asset (market value), Solvency Capital Requirement (SCR), Risk Margin, Best Estimate Liability (BEL) and Own Funds are pivotal for measuring and reporting financial status as shown in Figure 3. More specifically, the balance sheet of Solvency II introduces the SCR, which allows for a more precise quantification and consideration of the multi-risk types that insurance companies face. Also, on the liability side, Solvency II mandates the calculation of the Risk Margin to ensure that the capital required when an insurance company transfers its obligations to another entity and, by incorporating the BEL, Solvency II thoroughly contemplates the time value and uncertainty of expected cash flows, thereby realizing a more accurate assessment of liabilities. Lastly, on the equity side, the introduction of Own Funds is aimed at ensuring that insurance companies possess sufficient financial strength to cover potential risks and losses, thereby maintaining financial market stability.

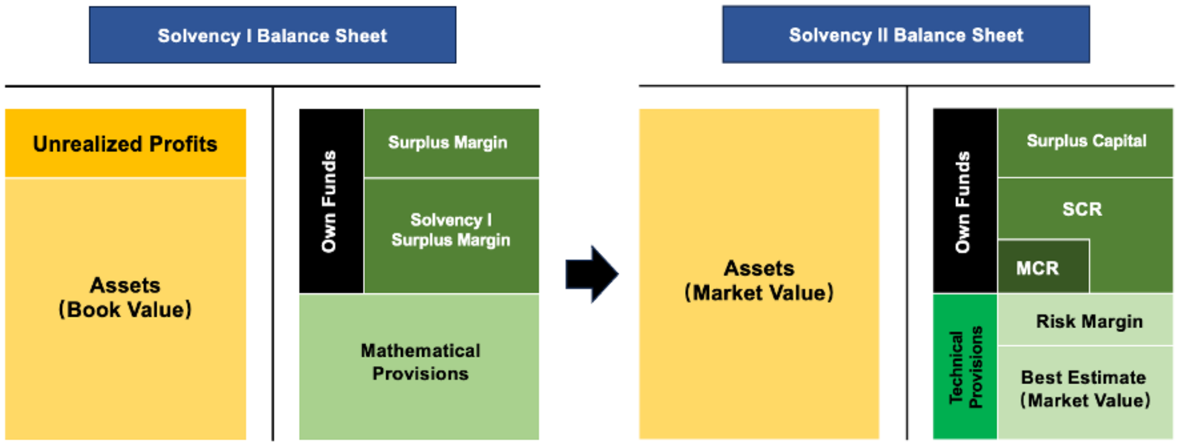

Figure 3: The Comparison of the Balance Sheet of Solvency I and Solvency II[14]

Source: InsuranceSpeaker - Wavestone

Additionally, the Own Risk and Solvency Assessment (ORSA) has become a key process within insurance companies for internal assessment and management of risks. ORSA requires insurance companies to regularly assess their risk-bearing capacity, ensuring that they could meet capital and solvency requirements even in adverse situations. This necessitates that companies not only calculate the SCR but also continuously monitor and assess their risk profile, developing adaptive risk management and capital management strategies.

Understanding the meanings, functions and calculation methods of SCR, Risk Margin, Best Estimate Liability, and ORSA is crucial for a deeper insight into the operations of insurance companies under the Solvency II framework.

[14] https://www.insurancespeaker-wavestone.com/2014/03/solvabilite-2-enjeux-et-contraintes/solva2-bilan/

1.4.1.1 Solvency Capital Requirement (SCR), Risk Margin & Best Estimate Liability (BEL)

Definition: The Solvency Capital Requirement (SCR) refers to the minimum amount of capital that an insurance company must hold to withstand significant adverse events within a year under the Solvency II Directive. It is a key indicator measuring the financial health and risk-bearing capacity of an insurance company. The calculation of SCR is based on a 99.5% confidence level, which means that it is only in the worst 0.5% of scenarios that the insurance company might fail to meet its obligations.

Calculation Method: Under the Solvency II framework, the calculation of the Standard Capital Requirement (SCR) first involves the individual assessment of each risk sub-module as shown in Figure 4. This includes independent calculations for market risk, credit risk, life underwriting risk, non-life underwriting risk, and operational risk. The SCR calculation for each sub-module reflects the impact of the corresponding type of risk on the capital requirements of the insurance company. After completing these individual calculations, the SCRs of these risk sub-modules are integrated to derive the overall SCR.

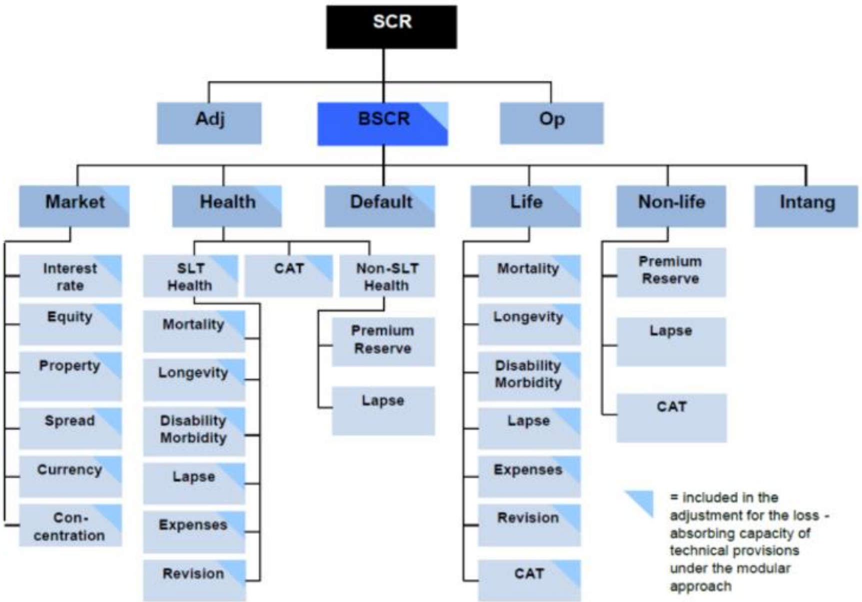

Figure 4: SCR Calculation Structure[15]

Source: Préparation à Solvabilité II

Calculation Standard Formula:

Sub-module Solvency Captial Requirement (Sub-module SCR) formula:

$$\text{Sub-moduleSCR} = \sqrt{\sum_{i=1}^{n}\left(\text{Sub-module Risk}_i^2 + \sum_{j=1, j\neq i}^{n} \text{Corr}(i,j) \times \text{Sub-module Risk}_i \times \text{Sub-module Risk}_j\right)}$$

[15] https://acpr.banque-france.fr/sites/default/files/20140806_traduction_hypotheses_sous-jacentes_formule_standard.pdf

where:

Risk Sub-module i: Represents the SCR for the ith risk category under that risk sub-module

Corr (i,j): Represents the correlation between different risk categories

n: The total number of risk categories within the risk sub-module.

Basic Solvency Captial Requirement (BSCR) formula:

$$\text{BSCR} = \sqrt{\sum_{i,j} \text{Corr}\,(i,j) \cdot SCR_i \cdot SCR_j} + SCR_{\text{intangible}}$$

where:

SCR i: Represents the capital requirement for risk type i and SCR intangible refers to the capital requirement related to intangible assets.

We have:

$$SCR = Adj + BSCR + Op$$

where:

Adj: Adjustment for the loss absorption capacity of deferred taxes and technical provisions

Op: Solvency Capital Requirement for operational risk.

Best Estimate (BE):

Definition: Under the Solvency II framework, the Best Estimate Liability (BEL) refers to the unbiased estimation of the current value of expected cash flows (including payments to policyholders for claims and expenses) for all insurance contracts held by an insurance company. This represents the value of liabilities that an insurance company expects to incur and is used on the balance sheet to reflect insurance obligations.

Calculation Method: Under the Solvency II framework, the Best Estimate Liability is the current value of the expected payouts and related expenses by the insurance company. This calculation is based on the forecast of future cash flows, considering various probabilities and discounting using a risk-free rate. The risk-free rate is used to reflect the time value of money, ensuring that the liability assessment is consistent with market conditions.

Calculation Standard Formula:

$$\text{Best Estimate} = \Sigma(\text{ Expected Cash Flows } \times \text{ Probability } \times e^{-rt})$$

where：

Expected Cash Flows: The future anticipated payments and related expenses

Probability: The likelihood of each cash flow occurring

r: The risk-free rate for the corresponding period

t: The number of years from the current time to when the cash flow is expected to occur.

Risk Margin (RM)

Definition: Within the Solvency II framework, the Risk Margin (RM) is an additional capital requirement calculated on top of the Best Estimate Liability. It is designed to ensure that insurance companies have sufficient funds to cover the uncertainty of their insurance obligations. The Risk Margin is intended to represent the cost of transferring insurance liabilities to another insurance company.

Calculation Method: The calculation of the Risk Margin involves estimating the capital costs required to support insurance liabilities until they are settled. The calculation is based on the cost of holding the capital (SCR) needed to meet these liabilities, as well as these capital requirements under different future scenarios.

Calculation Standard Formula:

$$\text{Risk Margin} = \text{Capital Cost Ratio} \times \sum_{t=1}^{T} (\mathrm{SCR_t} \times e^{-rt})$$

where:

Capital Cost Ratio: Represents the rate of cost for holding capital, typically set by regulatory authorities, generally at 6%

$\mathrm{SCR_t}$*: Represents the Solvency Capital Requirement for the t-th year*

r: The risk-free rate for the corresponding period

t: The number of years from the current time to when the cash flow is expected to occur.

1.4.1.2 Own Risk and Solvency Assessment (ORSA)

Own Risk and Solvency Assessment (ORSA) is a key requirement of the second pillar of the Solvency II framework. ORSA aims to associate and integrate the significant risks faced by a company with the required internal capital, focusing on a dynamic self-assessment of risk and solvency. The core concept is to balance and manage risk, capital, and value, and fully reflect this in the company's business strategy, decision-making, performance assessment, and communication with stakeholders. It requires insurance companies to self-assess their risk profile and solvency, considering various future scenarios that may arise. The ORSA assessment process should include the following three dimensions:

- Overall Solvency: In calculating the capital required for an insurance company's solvency, factors such as regulatory capital, economic capital, target risk profile, risk appetite/tolerance approved by the board, business strategy, budget plans, and changes in the external environment should be comprehensively considered.
- Ongoing Assessment and Compliance: Insurance companies should establish a continuous assessment and review process to monitor changes in risk capital requirements and capital adequacy levels. This process should include a series of scenario analyses and stress tests, and proactive capital planning and capital replenishment mechanisms should be in place.
- Risk Profile: Assessing the risk profile involves examining whether the basic assumptions for calculating solvency capital requirements and the target risk profile deviate significantly from the company's actual risk corridor and adjusting the assessment methods and capital measurement models accordingly.

1.4.2 Necessity of Integrating Climate Risk into ORSA

The increasing severity and long-term impacts of climate issues have raised their profile in the insurance industry. The World Economic Forum (WEF) listed up the failure of climate action as the biggest long-term threat to the world, with devastating economic effects in the next decade. From the perspective of the insurance industry, the most significant impact of climate change is the natural disaster damages. For example, damages caused by natural disasters are projected to increase by 93% by 2050 compared to the period from 1989 to 2019. The financial status of the insurance companies and their long-term existence is at risk. Moreover, the impact of climate change on human health has intensified the risks in public health insurance. The World Health Organization (WHO) has declared climate change as the greatest global health threat of the 21st century.

In response to this trend, the delegated regulation (EU) 2021/1256 issued by the EU on April 21, 2021, mandates that insurance companies must incorporate sustainability risks into their overall solvency requirements and assess them in ORSA. This regulation, effective from August 2, 2022, signifies that the insurance industry would for the first time integrate sustainability risks into its primary risk assessment, actuarial functions, and the ORSA process. This change marks a significant step forward in the industry's risk management and solvency assessment capabilities.

In summary, integrating climate risk into ORSA is not only a response to regulatory requirements but also an inevitable choice for insurance companies in managing risks in a complex environment. This integration not only reflects a deeper understanding of risk management complexity in the insurance industry but also aligns with the global financial regulatory trend towards higher transparency and more refined risk sensitivity.

Chapter 2 : Climate Scenarios Introduction, Analysis and Application Policy

2.1 Background and Introduction of Climate Scenarios

Given the rapidly changing nature of climate risk, its high degree of uncertainty and wide range of impacts, rather than attempting to make accurate predictions, climate risk should be more accurately measured from a multi-dimensional scenario analysis.

As the problem of climate change intensifies and climate risks increase, governments, organizations, and financial institutions across the globe have intensified their focus in this area. In this section the work of the IPCC, NGFS, and ACPR on climate risk assessment will be introduced.

2.1.1 Background and Introduction of the Climate Scenario from IPCC

Based on the contents of the Synthesis Report of the Sixth Assessment Report of the IPCC (AR6), experts use modeling scenarios and pathway approaches to delve into future carbon emission trends, climate change, its associated consequences and potential risks, and mitigation and adaptation measures to address these changes. The modeling is based on a set of integrated assumptions, covering socio-economic factors and mitigation strategies. It is important to note that the modeling provides quantitative scenario analysis rather than specific forecasts.

The IPCC consists of three core working groups:

- Working Group I (WGI) focuses on the physical science basis of climate change;
- Working Group II (WGII) is concerned with the impacts and risks of climate change on ecosystems and socio-economic systems;
- Working Group III (WGIII) examines mitigation strategies for climate change.

In its assessment of climate risk, the IPCC is neutral on the underlying assumptions of the scenarios. WGI assessed five example scenarios based on shared socio-economic pathways (SSPs), which cover the range of potential future anthropogenic climate change drivers to develop. SSP-based scenarios are referred to as SSPx-y, where 'SSPx' refers to the Shared Socioeconomic Pathway describing the socioeconomic trends underlying the scenarios, and 'y' refers to the level of radiative forcing (in watts per square meter, or Wm^2) resulting from the scenario in the year 2100.

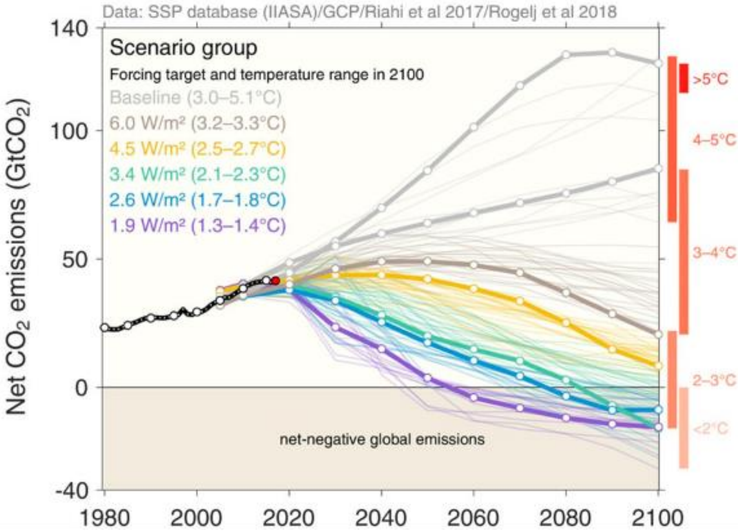

Figure 5: The Evolutionary Path of the IPCC's SSP Scenarios[16]

Source: Global Carbon Budget

The trajectories in Figure 5 cover a wide range of scenarios, from a very optimistic scenario in which CO_2 emissions fall sharply to reach carbon neutrality by 2050 and go negative in the second half of the century (SSP1-1.9), to one in which CO_2 emissions continue to rise sharply to double current levels by 2050, and more than triple current levels by 2100 (SSP5-8.5).

Based on the graphs of the evolution of their CO_2 emissions, each of the SSP scenarios chosen by the IPCC to conduct the study is listed below:

- SSP 1-1.9 scenario is rooted in sustainable development, setting its sights on limiting global temperature increase to within +1.5°C. Against this backdrop, the global community has become more inclined towards environmental protection and cooperation and has actively sought to reduce social inequalities, emphasizing broad-based well-being rather than blind economic growth.
- The SSP 1-2.6 scenario also emphasizes the importance of sustainable development. CO_2 emissions from this scenario are also significantly reduced, though at a slightly slower rate than the previous scenario, and carbon neutrality is projected to be achieved after 2050. This scenario aligns with the socio-economic trajectory of SSP 1-1.9, championing sustainable growth and reduced inequalities, but expects a temperature rise of approximately 1.8°C by 2100.
- SSP 2-4.5 proposed an intermediate strategy. Its efforts to reduce CO_2 emissions are not significant and show volatility. Overall, social change under the program is not significant and only modestly mitigates socio-economic risks. Progress in sustainable development has been gradual, with a clear gap between economic growth and income growth. If this trend continues, global temperatures are estimated to rise by 2.7°C by the end of the century.

[16] https://www.globalcarbonproject.org/carbonbudget/archive/2019/GCP_CarbonBudget_2019.pdf

- SSP 3-7.0 presents a pessimistic vision triggered by regional rivalries. It paints a bleak picture of a society deeply divided by regional fragmentation and the breakdown of international cooperation. Competition among nations for limited resources fosters antagonism and greatly undermines global cooperative efforts. Under these circumstances, commitments to reduce greenhouse gas emissions remain unfulfilled and global temperatures continue to rise. By the end of the century, temperatures could rise by 3.6°C, while CO_2 emissions could double.
- SSP 5-8.5 Provides a grim view of a fossil fuel-driven world. In this context, society's primary driver is economic growth, while concerns about climate change are sidelined. Industrial operations and societal functions are deeply rooted in fossil fuels and high consumption, severely hampering their resilience to global warming. Projections indicate that the global average temperature would rise by more than 4°C by 2100.

WGI and WGII have also integrated Representative Concentration Pathways (RCPs) to evaluate the potential impacts and risks of regional climate change. RCP-based scenarios are referred to as RCPy, where 'y' refers to the level of radiative forcing (in watts per square metre, or Wm^2) resulting from the scenario in the year 2100. The SSP scenarios cover a broader range of greenhouse gas and air pollutant futures than the RCPs. They are similar but not identical, with differences in concentration trajectories. The evolutionary path of the IPCC's RCP scenarios is shown in Figure 6.

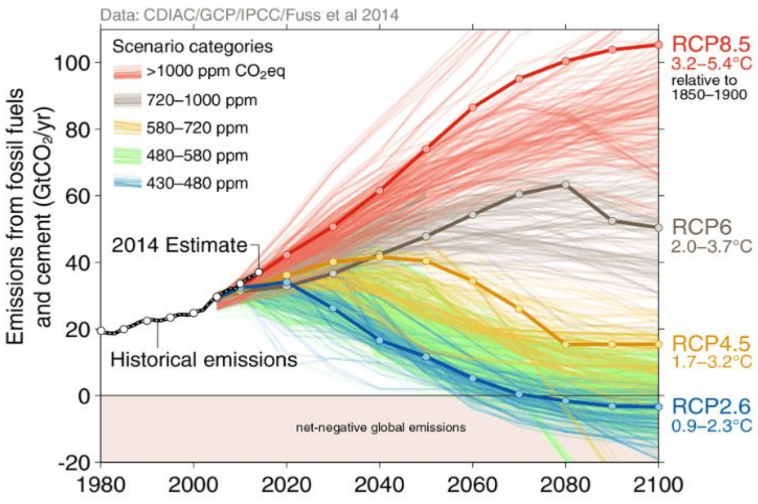

Figure 6: The Evolutionary Path of the IPCC's RCP Scenarios[17]

Source: Fuss, S. and al (2014). Betting on Negative Emissions. Nature Climate Change.

According to the graphical representation, it is observable that depending on society's collective response, CO_2 emissions might undergo a range of evolutions. Within these potential future scenarios, the IPCC specifically emphasizes four pivotal trajectories: RCP 2.6, 4.5, 6.0, and 8.5. These four trajectories provide a structured framework for outlining the emission trends for each

[17] https://doi.org/10.1038/nclimate2392

scenario and their associated temperature rise impacts.

Among these key trajectories:

- The RCP 2.6 scenario is the only pathway that is consistent with the Paris Agreement goal of limiting global temperature rise to +1.5°C or +2°C by 2050.This pathway projects significant reductions in greenhouse gas emissions, with a peak in the 2020-2030 period, followed by carbon neutrality and a clear linear decline in emissions by 2100.
- RCP 4.5 represents a medium emission scenario with relatively ambitious mitigation measures. This scenario expects GHG emissions to rise until 2040 and then stabilize at a relatively low level by mid-century, but not to meet the commitments set out in the Paris Agreement.
- RCP 6.0 represents a trajectory from high to moderate emissions, with GHG emissions projected to peak around 2060 and then stabilize by the end of the 21st century, despite relatively high levels of emissions.
- RCP 8.5 is the most pessimistic scenario, assuming business as usual with no changes in emissions reduction policies or initiatives. Emissions are projected to continue to grow linearly at the current rate.

In summary, these representative emission pathways offer a comprehensive perspective on potential developments in climate change, underscoring the urgency of corresponding strategies and actions and their profound implications.

Table 6 provides a summary of the climate scenarios for the three working groups:

Category in WGIII	Category description	GHG emissions scenarios (SSP x-y) in WGI & WGII	RCPy in WGI & WGII
C1	Limit warming to 1.5°C (>50%) with no or limited overshoot	Very low (SSP1-1.9)	
C2	Return warming to 1.5°C (>50%) after a high overshoot		
C3	Limit warming to 2°C (>50%)	Low (SSP1-2.6)	RCP2.6
C4	Limit warming to 2°C (>50%)		
C5	Limit warming to 2.5°C (>50%)		
C6	Limit warming to 3°C(>50%)	Intermediate (SSP2-4.5)	RCP 4.5
C7	Limit warming to 4°C (>50%)	High (SSP3-7.0)	
C8	Exceed warming to 4°C (>50%)	Very high (SSP5-8.5)	RCP 8.5

Table 6: Comparison of Climate Scenarios for WGI, WGII and WGIII[18]

Source: The IPCC Sixth Assessment Report

[18] https://www.ipcc.ch/assessment-report/ar6/

Both RCP and SSP scenarios are delineated based on the projected radiative forcing levels by the year 2100. However, when viewed solely from the perspective of radiative forcing, there isn't a direct comparability between them. These scenarios integrate visions of greenhouse gas reductions with data on transitional adaptation and societal impacts, offering a more comprehensive and nuanced understanding. It is noteworthy that the SSP scenarios differ from the RCPs in several dimensions. Firstly, SSP scenarios provide climate models with higher-resolution and more detailed input data. Secondly, they enable the exploration of combinations not covered by the RCPs. From a financial standpoint, SSPs offer unique insights into potential fluctuations in asset values within investment portfolios.

In WGIII, an in-depth examination and evaluation of numerous global emission pathways were undertaken. It emerges that 1,202 emission pathways are categorized based on their anticipated global warming levels for the 21st century, spanning scenarios from a limited warming of 1.5°C to exceeding 4°C. Concurrently, it is imperative to recognize that, in terms of richness of assumptions and measurement metrics, these pathways are not as comprehensive as those in WG I and WG II.

In conclusion, while both RCP and SSP scenarios provide invaluable insights into future climate trajectories, they vary across multiple dimensions and warrant careful consideration when analyzed and utilized.

2.1.2 Background and Introduction of the Climate Scenario from NGFS

The Network for Greening the Financial System (NGFS) is a collaborative alliance encompassing central banks and financial regulators globally, instituted in 2017. Its core mission is to foster environmental sustainability within the global financial architecture, considering the influences of global climate risks on both economic and financial equilibria. The inception of NGFS symbolizes an escalating global financial attention to climate change and environmental hazards. This consortium amalgamates 116 central banks and regulatory entities, along with 19 observers, intending to curate a platform for dialogue and the dissemination of best practices. It endeavors to propel advancements in the domain of climate and environmental risk management within the financial sector and ardently advocates for the mainstream financial system's active engagement in the transition towards a sustainable economy.

To furnish a robust foundation for the analysis of climate risks within the economic and financial frameworks, the NGFS has cultivated an array of scenario analyses. These scenarios are devised to serve as evaluative instruments, delving deeply into prospective future risks and formulating preparatory strategies for anticipated risk impacts. Distinct from conventional predictive models, NGFS scenarios are more inclined towards exploring the dichotomy of extreme situations that might arise in financial risk assessments.

Acknowledging the inherent uncertainties when simulating climate-associated macroeconomic and financial risks, the NGFS employs a diverse array of models within its scenarios, encompassing extensive examinations across varying regions and industries. As the sands of time shift, there is an iterative refinement and augmentation in the NGFS scenarios. In its third iteration, these scenarios have integrated pledges from various nations towards achieving net-zero emissions. They have been enriched further through intricate industrial categorizations and granular representations of physical risks.

To adeptly quantify the impacts of climate risks within the economic and financial frameworks, the NGFS has systematically orchestrated dual transmission channels encompassing both transition and physical risks as shown in Figure7:

Transition risk: the sources of transition risk may involve policies and regulations, technological developments, and consumer preferences. Transition risk not only affects the profitability of companies and the financial situation of households but could also put significant financial pressure on lenders and investors. In addition, changes in the trajectory of investment, changes in the scale of production and changes in relative prices could have an impact on the overall structure of the economy.

Physical risks: it comes from two major sources. Firstly, the acute impacts of extreme weather events, such as floods and storms, which could swiftly disrupt commercial operations and damage property. Secondly, the enduring shifts in climate, including temperature increases and sea-level rise, which are set to profoundly influence labor, capital allocation, and natural resources, compelling a spectrum of adaptive adjustments across various sectors.

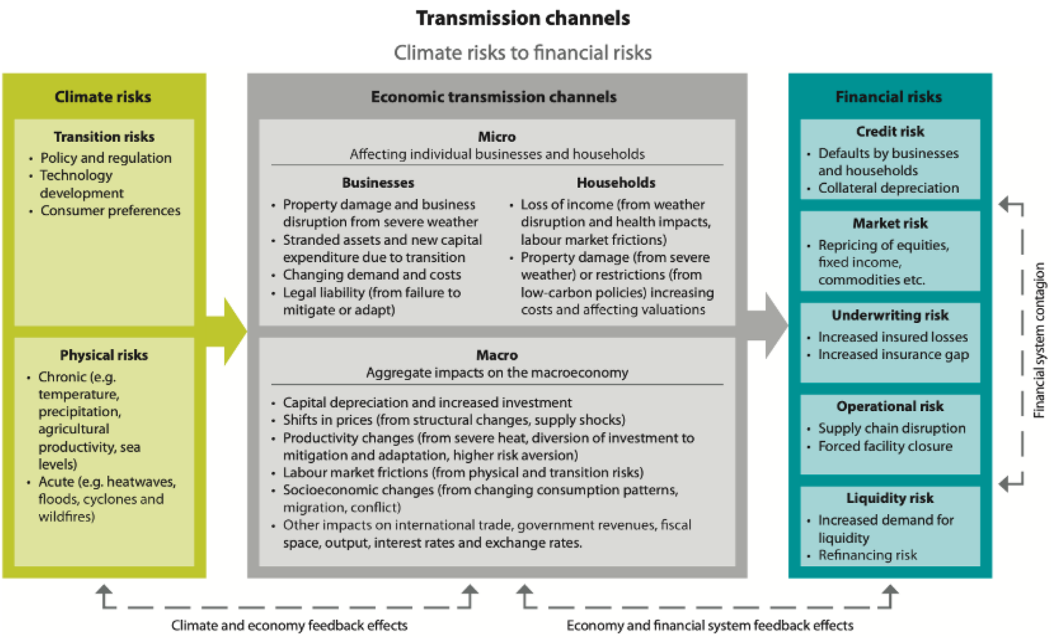

Figure 7: The Transmission Channels Applied by NGFS[19]

[19] https://www.ngfs.net/sites/default/files/medias/documents/ngfs_climate_scenarios_for_central_banks_and_supervisors_.pdf.pdf

Source: NGFS Scenarios for central banks and supervisors

The NGFS presents a comprehensive set of scenario analyses to delve into transition risks, physical risks, and their potential ramifications on the global economy, all derived from a highly synchronized and coherent suite of modeling tools. Researchers committed to in-depth examination of transition and economic variables could access the NGFS scenario database managed by the IIASA (International Institute for Applied Systems Analysis). This database is constructed in collaboration with three major Integrated Assessment Model (IAM) teams: Firstly, the PIK (Potsdam Institute for Climate Impact Research) employs the REMIND-MAgPIE model to study prospective global economic trajectories, energy sector advancements, and their climatic implications. Secondly, IIASA utilizes the MESSAGEix-GLOBIOM model, a dynamic system optimization modeling framework specially designed to analyze competitions in land use among agriculture, forestry, and bioenergy sectors, thereby providing robust backing for the research. Lastly, the University of Maryland (UMD) explores the macroeconomic impacts of climate changes and strategies using the Global Change Analysis Model (GCAM). Meanwhile, the NIESR (National Institute of Economic and Social Research) takes on the responsibility of constructing economic variables using the NiGEM model. The model structure applied by NGFS is shown in Figure 8.

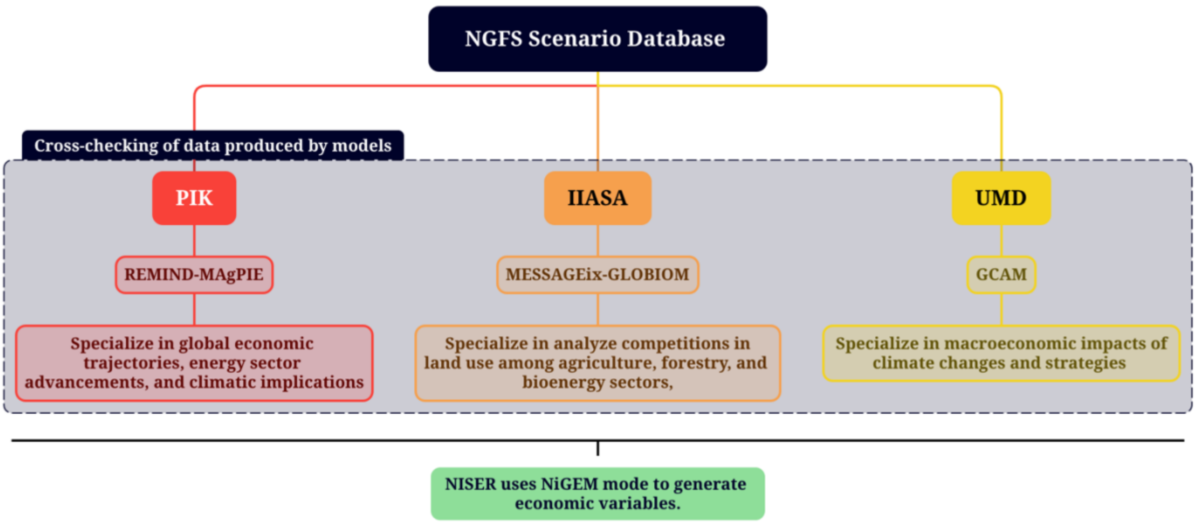

Figure 8: The Model Structure Applied by NGFS

The third-phase scenarios of the NGFS have established the following six climate stress scenarios:

Orderly：

- Net Zero 2050 aims to achieve net-zero global carbon dioxide emissions by around 2050 through rigorous climate policies and innovations that limit global warming to 1.5°C. Some jurisdictions, such as the United States, the European Union, the United Kingdom, Canada, Australia, and Japan, have achieved net-zero emissions of all greenhouse gases.
- Below 2°C gradually increases the stringency of climate policies, resulting in a 67% chance of limiting global warming to less than 2°C.

Disorderly：

- Divergent Net Zero reaches net zero around 2050 but at a higher cost due to the different policies adopted by the sectors, leading to an accelerated phase-out of oil use.
- Delayed transition assumes annual emissions do not decrease until 2030. Strong policies are needed to limit warming to below 2°C. Negative emissions are limited.

Hot House world：

- Nationally Determined Contributions (NDCs) includes all pledged targets even if these targets are not yet supported by effective policies already in operation.
- Current Policies assumes that only currently implemented policies are preserved, which would result in a very high real risk.

The figures below show the The Scenarios Framework of NGFS and the scenarios comparison of NFGS:

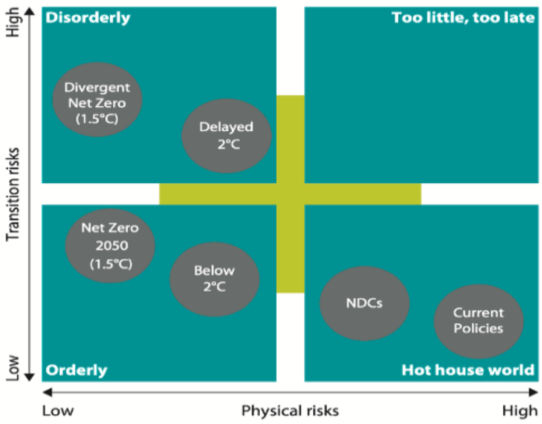

Figure 9: The Scenarios Framework of NGFS[20]

Source: NGFS Scenarios for Central Banks and Supervisors

		Physical risk	Transition risk			
Category	**Scenario**	**Policy ambition**	**Policy reaction**	**Technology change**	**Carbon dioxide removal -**	**Regional policy variation +**
Orderly	Net Zero 2050	1.4°C	Immediate and smooth	Fast change	Medium-high use	Medium variation
	Below 2°C	1.6°C	Immediate and smooth	Moderate change	Medium-high use	Low variation
Disorderly	Divergent Net Zero	1.4°C	Immediate but divergent across sectors	Fast change	Low-medium use	Medium variation
	Delayed Transition	1.6 °C	Delayed	Slow / Fast change	Low-medium use	High variation
Hot house world	Nationally Determined Contributions (NDCs)	2.6°C	NDCs	Slow change	Low-medium use	Medium variation
	Current Policies	3°C +	Non-currente policies	Slow change	Low use	Low variation

Figure 10: The Scenarios Comparison of NFGS[21]

Source: NGFS Scenarios for Central Banks and Supervisors

[20] https://www.ngfs.net/sites/default/files/medias/documents/ngfs_climate_scenarios_for_central_banks_and_supervisors_.pdf.pdf

[21] https://www.ngfs.net/sites/default/files/medias/documents/ngfs_climate_scenarios_for_central_banks_and_supervisors_.pdf.pdf

2.1.3 Background and Introduction of the Climate Scenario from ACPR

ACPR acknowledges that while short-term financial stress tests are undoubtedly valuable, a comprehensive understanding and assessment of the enduring resilience of the financial system to climate variations necessitates scenario analyzes over a more extended temporal horizon. Addressing this need, ACPR has formulated a theoretical framework up to 2050, amalgamating the multi-country macroeconomic model NiGEM with the high-level reference scenarios set by NGFS, offering deep insights into the policy responses for greenhouse gas emissions reduction for professionals in banking and insurance sectors.

Although the high-level scenarios from NGFS furnish information about transition policies, emissions, temperature, and GDP in major economic sectors, assessing the implications of climate change for financial stability demands granular data on pivotal macro-financial variables and a more intricate sectoral breakdown. ACPR's modeling approach integrates a variety of modular tools, including Integrated Assessment Models (IAMs), the multi-country macroeconomic model (NiGEM), internally crafted sector-specific models, credit rating models of Banque de France, and a unique financial module. Primary data, predominantly stemming from IAMs, furnishes key figures like GDP trajectories, carbon prices, and greenhouse gas emissions for major economies, encompassing the EU, the US, and other nations. While NiGEM offers a rich tapestry of macroeconomic and financial data, the sectoral models focus on transition scenarios for specific regions and sectors. Leveraging this sectoral data, Banque de France's credit rating model is further deployed to evaluate financial performance at the firm level. To furnish a more holistic analysis, ACPR also devised a financial module, adept at translating economic forecasts across scales into tangible financial metrics, such as corporate bond yield curves, asset prices, and spreads. The ACPR Climate Stress Test model structure is shown in Figure 11.

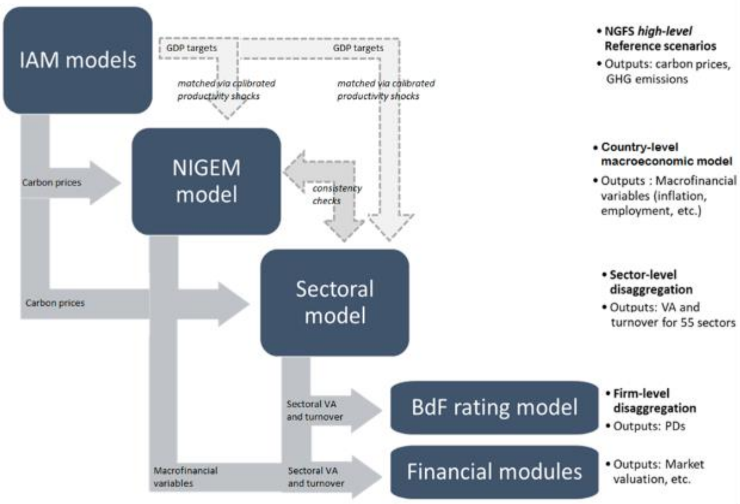

Figure 11: The ACPR Climate Stress Test Model Structure[22]

Source: Climate-Related Scenarios for Financial Stability Assessment

[22] https://publications.banque-france.fr/en/climate-related-scenarios-financial-stability-assessment-application-france

Under the reference framework of the NGFS, the climate risk researchers at ACPR have meticulously crafted three scenario narratives with a primary focus on transition risks to cater specifically to the needs of Banque de France and its regulatory body, ACPR. These scenarios span the time horizon from 2020 to 2050 and are differentiated into a baseline scenario and two increasingly adverse variants. The ACPR Climate Stress scenarios evolutionary pathways is shown in Figure 12.

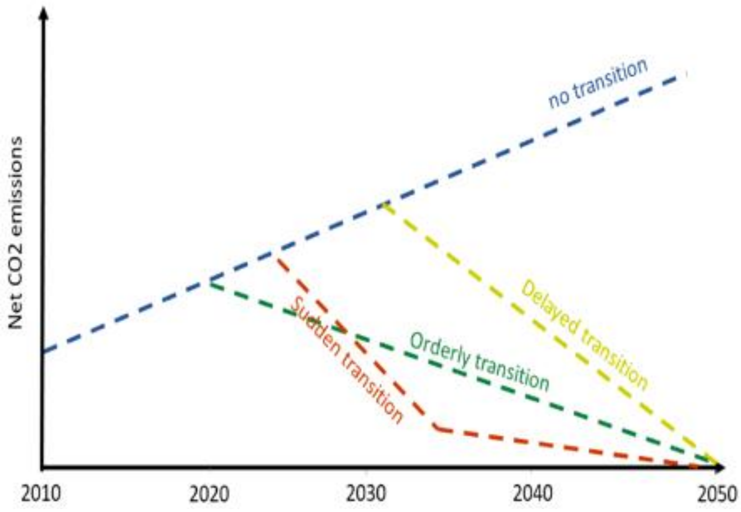

Figure 12: The ACPR Climate Stress Scenarios Evolutionary Pathways[23]

Source: Climate-Related Scenarios for Financial Stability Assessment

- Baseline scenario: The baseline scenario refers to an orderly transition. It assumes that an optimal carbon price is introduced immediately at the start of the climate stress tests. This price increases by about \$10 per ton of CO_2 per year until the end of 2050. Because the carbon price is introduced earlier and increases steadily over time, the actual physical and transition risks remain low, and the 2°C climate target can be achieved by 2100.
- Negative scenario 1: Delayed policy transition scenario. This scenario implies a delay in policy action and mainly describes a situation where a carbon tax is introduced late. According to the NGFS narrative, it is assumed that the 2030 GHG reduction target is not met, and that carbon capture and storage technology is not mature. To be consistent with the goal of reaching carbon neutrality by 2050, the government decides to revise the carbon price. The revision of the carbon price implies a series of shocks over the period, jumping steadily from \$87 per ton of CO_2 in the baseline to \$219 in 2035 (in the EU). This implies an overall increase in energy prices, although the actual increase in each price depends on the carbon content of each energy product.
- Negative scenario 2: Sudden policy transition scenario. The second negative scenario describes a sudden, earlier-than-expected transition situation that is made worse by the

[23] https://publications.banque-france.fr/en/climate-related-scenarios-financial-stability-assessment-application-france

immaturity of technological innovations. It combines an early increase in the carbon price with a productivity shock. In this scenario, the carbon price adjusts unexpectedly and is assumed to reach $184 per ton of CO_2 in 2030, consistent with the carbon trajectory set for a disorderly transition in the NGFS reference scenario. At the same time, it is assumed that low-carbon energy production technologies are less mature than expected in 2025, and the required investment translates into lower productivity gains compared to the baseline scenario.

The following table summarizes the 3 scenarios of the ACPR Climate Stress Test compared to the NGFS scenarios:

	Orderly Transition	**Delayed Transition**	**Sudden Transition**
Carbon price	Input from the NGFS representative scenario for an orderly transition	Input from the NGFS representative scenario for a disorderly transition	Input from the NGFS alternative scenario for a disorderly transition with a 5-year delay to start in 2025
Productivity	Adjustment variable calibrated to match the NGFS GDP figures – translate into productivity gains	Adjustment variable calibrated to match the NGFS GDP figures – translate into productivity gains	No productivity gain assumed – Negative shock compared to baseline
GDP	Matched to GDP targets of the NGFS representative scenario for an orderly transition	Matched to GDP targets of the NGFS representative scenario for a disorderly transition	Generated endogenously by the models

Table 7: The Comparison of NGFS and ACPR Climate Scenarios[24]

Source: Climate-Related Scenarios for Financial Stability Assessment

2.2 Scenarios Comparison and Conclusion

In delving into the intricate climate stress scenarios published by the IPCC, NGFS and ACPR, our work discerns the complexity and subtle nuances among these frameworks. Despite variances in their predictive models and underlying assumptions, these institutions share a unified goal: to assess and quantify the potential impact of climate change.

When analyzing these scenarios, the IPCC offers global climate projections grounded in scientific research, underscoring long-term trends and possible global impacts of climate change. The NGFS, from a financial stability perspective, investigates the direct and indirect effects of climate change on macroeconomics and financial markets. ACPR, on the other hand, focuses more narrowly on

[24] https://publications.banque-france.fr/en/climate-related-scenarios-financial-stability-assessment-application-france

individual financial institutions, evaluating their potential climate-related risks and guiding them in formulating appropriate risk management strategies.

Comparing these scenarios, the correlations are shown below:

IPCC Scenarios	NGFS Scenarios	ACPR Scenarios (2020)
Very low (SSP1-1.9)	Net Zero 2050	
	Below 2°C	Baseline scenario
	Delayed transition	Delayed policy transition
	Divergent Net Zero	Sudden policy transition

Table 8: IPCC, NGFS and ACPR Scenarios Related Relationships

In scrutinizing the climate stress scenarios presented by major international organizations, correlations and similarities are discernible across the climate stress scenarios published by them. For instance, the IPCC's "Very low (SSP1-1.9)" scenario and the NGFS's "Net Zero 2050" both depict an ideal trajectory of limiting global temperature rise to 1.5°C and smoothly transitioning to carbon neutrality around 2050. However, when compared with ACPR's models, it is notable that the latter does not present a similar counterpart scenario.

Further, the NGFS's "Below 2°C", "Delayed transition", and "Divergent Net Zero" scenarios correspond to ACPR's "Baseline scenario", "Delayed policy transition", and "Sudden policy transition" scenarios. Yet, it is crucial to acknowledge that while they exhibit a degree of correspondence at a macro level, each institution has tailored its scenarios to specific interests and model requirements in terms of implementation pathways and assumptions.

Upon a comprehensive analysis of the climate stress scenarios put forward by IPCC, NGFS, and ACPR, our research aims to select a scenario with practical applicability for our subsequent research work. The primary criterion for this selection is the ease of application of the scenario, which primarily involves the granularity and type of the scenario's output data. This criterion is not only linked to the operability of the scenario but also directly affects the depth and breadth of our research. The following table provides a detailed comparison of the output data granularity and types of climate stress scenarios from each institution, offering data support and a visual reference for the selection:

	IPCC Climate Scenarios	NGFS Climate Scenarios	ACPR Climate Scenarios
Data Granularity	Global + Regional	Global + Regional	Regional+Sectoral
Output Data	Precipitation, Mortality, Sea Level, Agricultural Production, etc.	GDP, Unemployment, Inflation, Interest Rates, etc.	GDP, Unemployment, Inflation, Interest Rates, Stock Indices, etc.

Table 9: The Comparison of IPCC, NGFS and ACPR's Model Output

The examination of climate stress scenarios from the IPCC, NGFS, and ACPR reveals notable disparities in data granularity and typologies across the provided scenarios.

Initially, both the IPCC and NGFS climate scenarios offer data with granularity down to the regional level, but they diverge in terms of the types of output data. The IPCC's data tends to measure and quantify the broader ecological impacts of climate change, whereas NGFS focuses more on macroeconomic and financial data.

Further examination reveals that although both NGFS and ACPR scenarios provide macroeconomic and financial data, such as Gross Domestic Product (GDP), unemployment rates, and inflation, ACPR's data extends further in granularity, encompassing economic sector subdivisions. This aligns well with the current understanding that "different economic sectors experience varying impacts during climate transition," and fits the direction of sustainable finance legislation recently pursued by the European Union and France.

Considering these factors, ACPR's climate scenario excels in terms of operability. Additionally, the integration of data from the Banque de France within the ACPR scenario model adds a higher degree of credibility and practicality to climate stress test efforts. Consequently, our research has selected ACPR's climate scenario as the primary basis for our subsequent research and analysis.

2.3 ACPR Climate Stress Test Scenarios Analysis

Within the framework based on the ACPR model, this part delves deeply into the two adverse scenarios diverging from the orderly transition – the "delayed" transition (Scenario 1) and the "sudden" transition (Scenario 2). Through a comprehensive simulation analysis of four major geographic blocs (France, the rest of the European Union, the United States, and the rest of the world) and 55 industry sectors, ACPR demonstrates the deviations of these two scenarios compared to the orderly transition baseline. This provides the insurance industry with targeted risk assessments and strategic recommendations.

2.3.1 Macroeconomic Impact Under Climate Transition Risk

In the two adverse transition scenarios examined, significant increases in carbon pricing lead to escalated production costs for businesses and a decline in households' purchasing power. While there is a redistribution of carbon tax revenues, its benefits are insufficient to fully offset the adverse effects on households' real income due to the general rise in consumer prices. Simulations indicate that, under either scenario, real GDP would face setbacks by 2050. Specifically, in Europe and the United States, under the delayed transition scenario, the anticipated long-term GDP loss is projected to be between 2% and 3%. In the sudden transition scenario, the losses are more pronounced, reaching 6% to 7%.

For the rest of the world, the anticipated economic impact is expected to be more significant, primarily driven by various structural transformations. There is substantial heterogeneity in economic impacts across countries. Developing countries, due to their higher dependency on energy, may confront more severe challenges. Notably, countries like China, with a high reliance on energy, are projected to experience GDP losses of 6% and 12% under the delayed and sudden transition scenarios respectively. This trend underscores an evident energy efficiency shortfall in China compared to developed economies such as the United States or Europe. However, it is noteworthy that these adverse effects are relatively moderate in the short term, with GDP remaining stable until between 2035 and 2040, after which its declining trend becomes more evident.

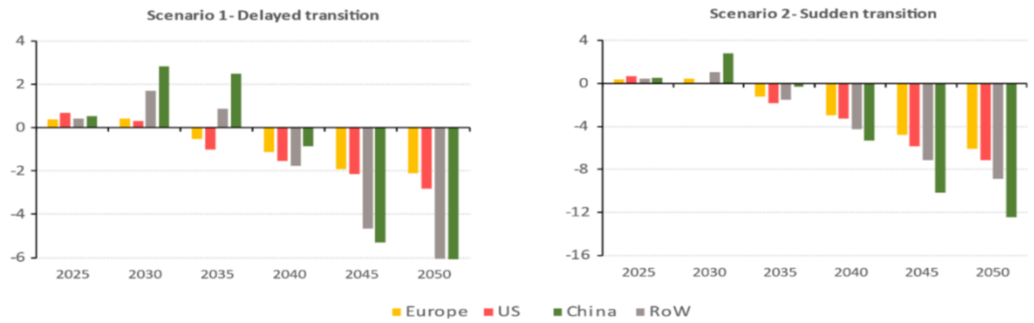

Figure 13: Impact of Adverse Scenarios of Real GDP (% Deviation from Baseline)[25]

Source: Climate-Related Scenarios for Financial Stability Assessment

In the two adverse transition scenarios examined, the manifested variances are not solely restricted to the trajectory of carbon pricing but are also tied to assumptions related to productivity advancements. Concurrently, assumptions about how tax revenues are redistributed to economic entities have had a pronounced impact on economic activity. In the delayed transition scenario (Scenario 1), the growth in carbon pricing emerges as the principal driver of economic downturn, while the redistribution of taxes offsets this negative influence on some extent, continuing until 2045. As time progresses, the benefits from tax revenues diminish due to structural shifts in economic activities, making them the dominant factor behind the recession towards the end of the scenario. Overall, such productivity shocks help to reduce GDP losses by nearly a percentage point before 2050, limiting the ultimate loss to 2%. In contrast, the sudden transition scenario (Scenario 2) is characterized by the diminishing positive effects of tax redistribution over time, particularly after 2040, where multiple elements contribute to the negative shock on GDP. By 2050, 60% of the GDP loss could be attributed to the rise in carbon taxation, 20% to the deterioration in public fiscal conditions, with the remaining portion explained by adverse productivity shocks. Specifically, for France, under Scenario 1, there is an anticipated reduction in economic activity by about 2% by 2050 compared to the baseline scenario. However, this decline only becomes evident from 2035 onwards—the time when carbon prices surge. Prior to this, due to carbon prices being below the baseline, the impact on economic activity is relatively positive. Under Scenario 2, French economic activities exhibit a sharp declining trend, resulting in a 5.5% GDP reduction by 2050 compared to the baseline. This decline is influenced by the dual factors of rising fossil fuel prices and a lower productivity gain compared to the baseline.

[25] https://publications.banque-france.fr/en/climate-related-scenarios-financial-stability-assessment-application-france

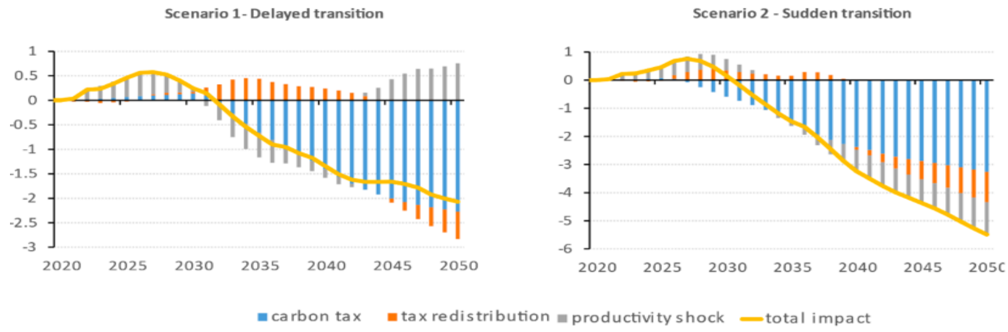

Figure 14: The Contribution of Factors to the GDP in France (% Deviation from Baseline)[26]

Source: Climate-Related Scenarios for Financial Stability Assessment

The discourse now delves into a series of macroeconomic shifts in France, notably concerning consumer prices and governmental budget impacts. The introduction of a carbon tax initially led directly to a surge in energy prices. This escalation indirectly inflated other costs, resulting in an overall rise in consumer prices. This trend was corroborated in the sudden transition of 2030 and the subsequent delayed transition, aligning with the swift ascent of carbon pricing. Up until this point, given the postponement of the carbon tax relative to the baseline, its predominant effect manifested as mild inflation. However, from 2030 onwards, due to the rapid climb in carbon pricing compared to the baseline (which had a more robust and lower trajectory), the inflationary effects intensified considerably. By the end of the scenarios, the cumulative impact on consumer prices stands at around 4.5% for the delayed transition (Scenario 1) and 10% for the sudden transition (Scenario 2). Dynamically, prices accelerated faster in the years following the carbon pricing shock, then slowed down due to counterbalancing inflationary pressures resulting from reduced activity. For the delayed transition (Scenario 1), the annual inflation rate, compared to the baseline, peaks post-2030 at 0.7 percentage points. Still, it averages an increase of 0.2 percentage points after 2035. In the sudden transition (Scenario 2), price growth is more dynamic and persistent, with the annual inflation rate averaging an increase of 0.6 percentage points from 2030 to 2040, and 0.3 percentage points from 2040 to 2050.

Additionally, the inflationary assault on household purchasing power partly negates the positive effects of tax redistribution post-2040 in the delayed transition and post-2035 in the sudden transition. The resultant reduction in real disposable income curtails private consumption and investment, leading to a downturn in labor demand and consequent unemployment rate hikes. Decreased employment rates further diminish individual income and consumption, in turn, impacting aggregate output. This slump in output and employment reduces governmental revenues, while the escalation in unemployment amplifies welfare-related governmental expenditures. Theoretically, while the carbon tax should bring about supplemental revenues for the government, these benefits are entirely redistributed to households, resulting in a prolonged

[26] https://publications.banque-france.fr/en/climate-related-scenarios-financial-stability-assessment-application-france

deterioration of the government's overall fiscal balance. Specifically, for France, in the delayed transition (Scenario 1), the average deterioration stands at 0.7 percentage points from 2040 to 2050, whereas in the sudden transition (Scenario 2), it is 1.5 percentage points.

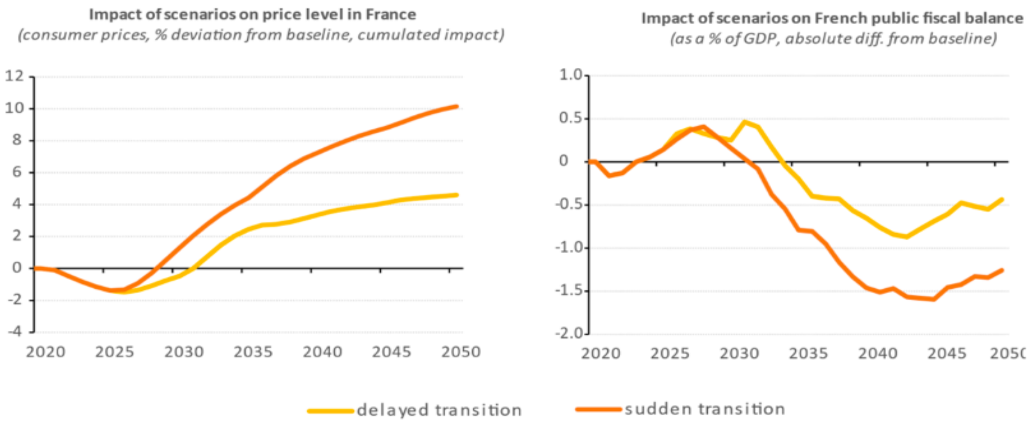

Figure 15: The Impacts of Adverse Scenarios on the Price level and Public Fiscal in France[27]

Source: Climate-Related Scenarios for Financial Stability Assessment

2.3.2 Macrofinancial Impact Under Climate Transition Risk

By 2025, under both the delayed and sudden transition scenarios, the expected changes in the EIOPA RFR (Risk-Free Rate) term structure appear relatively more optimistic, by approximately 20 basis points, compared to an orderly transition, as shown in Figure 16. This trend is likely attributable to the robust economic growth witnessed during the initial period. However, over a longer projection horizon, as economic activity gradually shows signs of decline and successfully neutralizes inflationary pressures, the anticipated changes shift into negative territory. More notably, under the sudden transition scenario, relative to the delayed transition, the significant downturn in economic activity induces a more pronounced negative shift in the EIOPA RFR term structure, which is particularly evident in absolute terms.

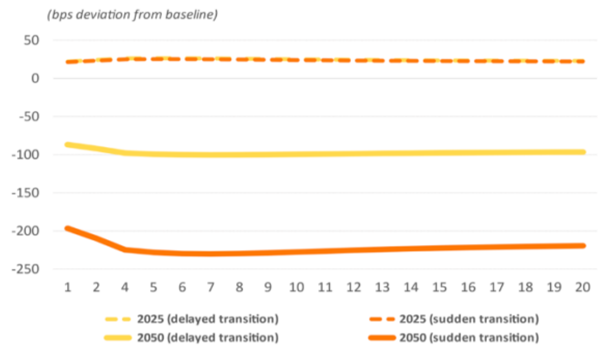

Figure 16: The Expected Changes in the EIOPA RFR Term Structure in 2025 and 2050[28]

Source: Climate-Related Scenarios for Financial Stability Assessment

While the simulated shocks show relatively moderate impacts on macroeconomic costs, the

[27] https://publications.banque-france.fr/en/climate-related-scenarios-financial-stability-assessment-application-france
[28] https://publications.banque-france.fr/en/climate-related-scenarios-financial-stability-assessment-application-france

magnitude and disparities of effects become especially pronounced when delving into sectoral levels. Different sectors exhibit varied response patterns under the impact of carbon pricing. These responses are closely tied not only to the sector's total emissions but also to its position in the production network, available substitution options, and other factors. For instance, the mining and industrial sectors are noticeably more affected compared to the service sector. Specifically, the refined petroleum and coke sector—hereafter referred to as the "petroleum" sector—as well as the agricultural and mining sectors, bear the most significant losses. Taking France as an example, under the delayed transition scenario, by 2050 the output of its petroleum sector would drop approximately 47% compared to the baseline. In a sudden transition scenario, this decrease could reach nearly 60%.

Concurrently, as producers have the option to substitute petroleum with electricity and natural gas—subsequently referred to as "electricity"—an energy structure shift is observed. Specifically, under the delayed transition scenario, the output for the electricity sector increased by 5.7% by 2050, while in the sudden transition scenario, the growth rate stood at 5.6%. This further underscores the non-linear and diverse response patterns exhibited by different sectors when faced with carbon pricing shocks.

Notably, prior to the introduction of carbon policies, i.e., before 2030, sectors with the highest carbon intensity were relatively wealthy. However, from 2035 onwards, these sectors gradually faced unfavorable circumstances, primarily due to the increased economic costs attributed to the carbon tax. As producers adopted optimization measures to reduce costs by substituting intermediate inputs with options that had lower tax costs and less pollution, the price of sectoral output consequently increased.

The carbon tax regime, by imposing taxes on the intermediate consumption of fossil fuels, evidently drove sectors towards more environmentally friendly energy choices. For example, during the delayed transition from 2025 to 2050, the proportion of fossil fuels in the sectoral energy structure dropped from 65% to less than 35%, paper products from 11% to 0.5%, and road transportation from 85% to 60%. However, sectors heavily reliant on fossil fuels, such as aviation and maritime transportation, due to their limited potential to switch to green energy, had a stable energy structure but a significant reduction in overall output.

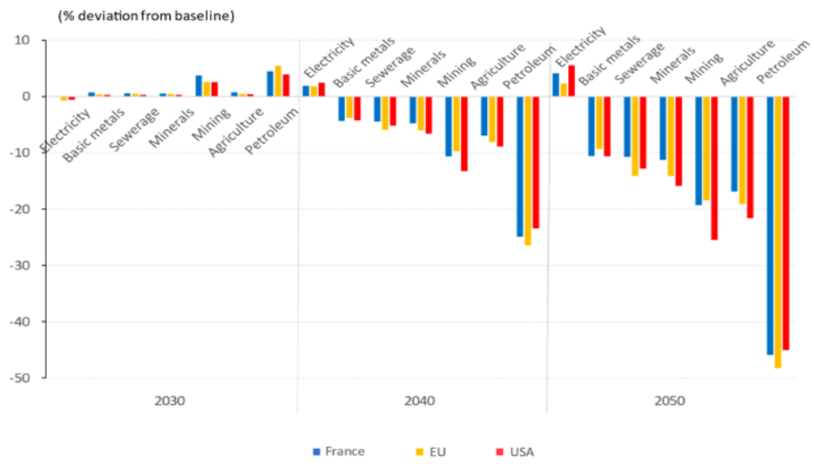

Figure 17: Impacts on Value Added Index – Delayed Transition[29]

Source: Climate-Related Scenarios for Financial Stability Assessment

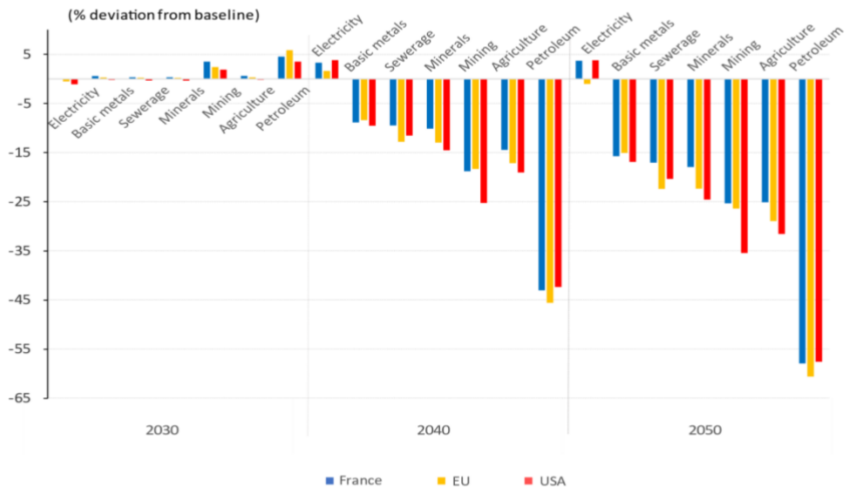

Figure 18: Impacts on Value Added Index – Sudden Transition[30]

Source: Climate-Related Scenarios for Financial Stability Assessment

2.4 ACPR Climate Stress Test Scenarios Application Policy

On July 16, 2020, ACPR published a guidance document for the application of climate stress test scenarios titled "Modalités techniques pour l'exercice pilote climatique – Assurances."

This guidance document unfolds from a macro perspective, initially presenting the overall framework of the project, encompassing the scope of the stress test, regulatory and accounting framework, timeline steps of the stress test, along with dynamic assumptions and organizational response functions.

Subsequently, the document delves into the application of climate stress scenarios to market risks, delineating from general rules, equities, and bonds. Following, the application of climate stress scenarios to technical risks is delineated as the third major segment, commencing from general

[29] https://publications.banque-france.fr/en/climate-related-scenarios-financial-stability-assessment-application-france
[30] https://publications.banque-france.fr/en/climate-related-scenarios-financial-stability-assessment-application-france

provisions, and then guiding on the application of stress scenarios to risks associated with natural disasters and health. Post presentation of these three significant segments, the guidance document outlines the format of the balance sheets that need to be submitted.

Lastly, the document enumerates the timetable and submission procedures for the climate stress test, providing more detailed process and method references for insurance companies participating in the test.

Table 10 is the summarization of the key content from the guideline document for applying stress tests:

General Principle	Stress Test Range	• At least 80% of the technical provisions for life entities, with health activities to be retained within the scope, even if they represent only a limited part of the entity's activity. • At least 80% of the premiums for non-life entities, with coverages related to natural disasters and health being prioritized within the scope of the exercise.
	Time Horizon	• The exercise covers a time horizon consistent with the materialization horizon of the transition risk, that is, with an end of period situated on December 31, 2050.
	Dynamic Hypothesis	• No assumption adjustments allowed for 2019-2025. • Adjustable assumptions for investment share, risk management strategy, reinsurance share, business distribution, etc. from 2026-2050 onwards.
Market Risks	General Rules	• ACPR requires organizations to assess the impact of representative transition risk scenarios on their equity and bond market exposures, applying the shocks provided in the scenario tables. The amounts for other asset categories (e.g. real estate) should remain unchanged and be multiplied only by the inflation rate. • Assets are valued in accordance with Solvency 2. Organizations are not expected to submit asset-by-asset data. The minimum granularity is expected to be the nature of the assets by business line. If possible, further granularity could be based on the country of issuance of the assets.
	Equity	• Equity held by the company is adjusted by year, 4 regions, and 55 sectors based on changes in the VA index (shocks are instantaneous). • The VA index represents the change in the intrinsic value of the company (price change + dividends), presented by year/sector/geographic region.
	Bonds	• Bonds should be valued using the EIOPA risk-free yield curve (which incorporates a volatility adjustment) and the corporate and sovereign spreads provided.

Table 10: The Summary of the Key Contents from the ACPR Guideline

Technical Risks （More about Liability side in the balance sheet）	General Rules	• The reported "(investment fees and other costs associated with asset management)/total assets" would increase with inflation throughout the period. • Customer acquisition costs and administrative expenses would increase at least with inflation. Finding new clients or developing new insurance products is thought to increase these costs. • For activities that are not affected by climate change scenarios, consideration should be given to maintaining a constant activity that takes inflation into account. • For life insurance activities like savings, the annuity sharing rate schedule provided by the insurer should be clarified by scenario in the methodology note.

Table 10: (Continued)[31]

Source: Modalités Techniques pour L'exercice Pilote Climatique

[31] https://acpr.banque-france.fr/sites/default/files/media/2020/09/23/modalites_techniques_banques_21092020.pdf

PART 2: APPLICATIONS

Chapter 3: Preparation for Implementing the ACPR 2019 Climate Stress Test

3.1 Addactis Modeling System Introduction

To meet the risk management needs under the Solvency II regulatory framework, APICIL Group has elected to employ Addactis Modeling as its computational platform. Addactis Modeling, a software developed by Addactis Group, is widely utilized in the global insurance and reinsurance sectors. The software was designed from its inception to cater to industry professionals' needs across various regulatory environments, particularly under the Solvency II framework.

As the European standard for insurance regulation, Solvency II provides clear guidance on risk management, model validation, and capital requirements for insurance firms. Under such circumstances, Addactis Modeling offers a comprehensive solution set to assist insurers in navigating the technical and regulatory challenges. Specifically, the software features tools for Solvency II, QIS exercises and standard model computations, empowering firms to fulfill the capital and reporting mandates of the European Union.

Addactis Modeling's custom model initialization files for Groupe APICIL are structured as follows:

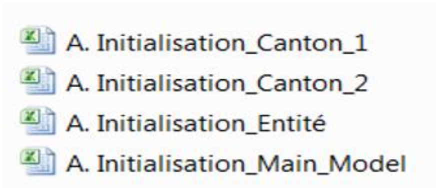

Figure 19: The Initialization Files for Addactis Modeling

The functionalities of the documents are as follows:

- The file named "A. Initialisation_Canton" is designated for inputting assets (investments and ALM), liabilities (initial investment portfolio and new business for each division), as well as the balance sheet and income statement inputs.
- The file named "A. Initialisation_Entité" includes forecast assumptions common to all portfolios and their divisions, as well as detailed information of the consolidated balance sheets and income statements, tax items, and equity of various layers of entities representing all the portfolios and their respective divisions.
- The file named "A. Initialisation_Main_Model" contains the shock amounts that are part of the standard formula, along with the matrices pertinent to risk sub-modules. For instance, matrices related to market risks when interest rates rise or fall can be found in this file as shown in Figure 20.

II. Corrélations du risque de marché

II.i. Corrélations du risque de marché en cas de hausse des taux

Interest	Equity	_Property	Spread	_Currency	Concentration	Counter_Cyclical_Premium
1	0	0	0	0,25	0	0
0	1	0,75	0,75	0,25	0	0
0	0,75	1	0,5	0,25	0	0
0	0,75	0,5	1	0,25	0	0
0,25	0,25	0,25	0,25	1	0	0
0	0	0	0	0	1	0
0	0	0	0	0	0	1

II.ii. Corrélations du risque de marché en cas de baisse des taux

Interest	Equity	_Property	Spread	_Currency	Concentration	Counter_Cyclical_Premium
1	0,5	0,5	0,5	0,25	0	0
0,5	1	0,75	0,75	0,25	0	0
0,5	0,75	1	0,5	0,25	0	0
0,5	0,75	0,5	1	0,25	0	0
0,25	0,25	0,25	0,25	1	0	0
0	0	0	0	0	1	0
0	0	0	0	0	0	1

Figure 20: Correlation Matrices related to Market risks in Addactis

Key assumptions such as inflation rate, risk-free rate, fund return, etc. can be set in "CourbeInflation", "CourbeTaux" and "RendementAction" files as shown in Figure 21. More specifically, the files contained in Figure 45 allows for the following data to be entered:

- The "RendementAction" file allows to enter equity returns.
- The "CourbeTaux" file allows to enter the risk-free rate from EIOPA.
- The "CourbeInflation" file allows to enter the inflation rate.
- For files with "up" and "down" in their names, they contain shock parameters for important assumptions based on the Solvency II standard formulas.

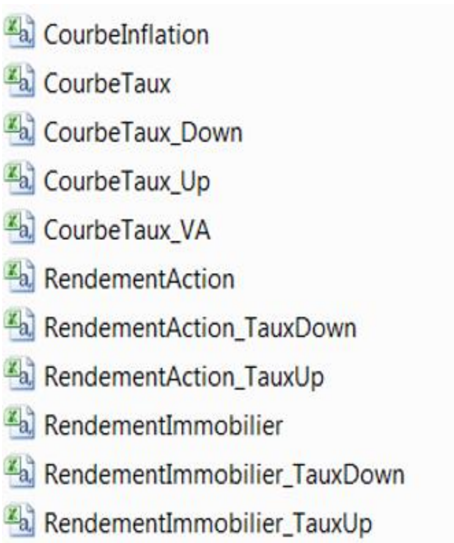

Figure 21: The Initialization Files for Important Assumptions in Addactis

3.2 Data Entry Logic and Workflow

For a typical stress test, to perform calculations under the Solvency II regulatory framework on the Addactis Modeling, two main categories of documents must be prepared:

- The initial investment portfolio for each division, balance sheet, and their significant assumption tables, which include files such as "A. Initialisation_Canton," "A. Initialisation_Entité," and "A. Initialisation_Main_Model."

- Assumption tables for macroeconomic and financial scenarios pertinent to stress test, which include files such as "CourbeInflation," "CourbeTaux," and "RendementAction."

Once done, the five-year stress test can start. The workflow is illustrated as shown in Figure 22:

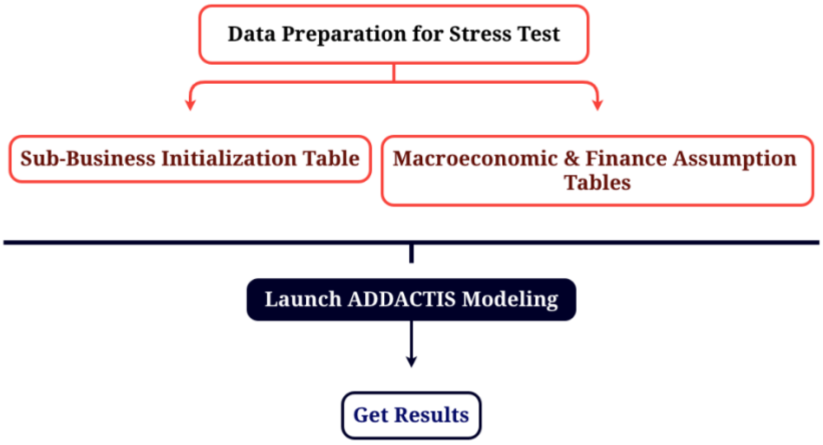

Figure 22: The Climate Stress Test Workflow

3.3 Company Background Introduction and Risk Mapping Materiality Analysis

Risk management is the process through which an organization or individual ensures the formulation and implementation of appropriate strategies to mitigate or control potential losses in the face of financial or other forms of risk. Insurance companies utilize risk management to safeguard capital and the interests of the insured. Below are the fundamental steps involved in the process of risk management:

- Risk Identification: The initial step involves the identification of potential risks, which may encompass market risk, credit risk, operational risk, liquidity risk, etc. Methods for identification could include the analysis of historical data, expert judgment, simulation tests, and more.
- Risk Assessment: Following the identification of risks, the next step is to evaluate their potential impact on the organization and the likelihood of their occurrence. This evaluation may be conducted using quantitative methods such as the eatimation of risk measures (e.g. Value at Risk - VaR), Stress Test, Scenario Analysis, and others qualitative approaches.
- Risk Quantification: Risks are quantified using statistical and mathematical models, helping organizations in gaining a more precise understanding of the potential magnitude of their losses.
- Risk Reporting: Regular risk reports are provided to senior management, regulatory bodies, or other stakeholders to ensure they are informed about the organization's risk profile.

- Risk Decisioning: Based on the assessment and quantification of risks, decisions are made regarding their management. Possible strategies include risk avoidance, reduction, or transfer, such as using financial instruments (e.g. derivatives) or reinsurance to lower or eliminate certain parts of risks.

Risk management is a complex yet critical domain that requires the collaboration of multiple departments within an organization. The right risk management strategy could help an organization protect its assets, increase profitability, and ensure long-term survival and success.

At the corporate level, identifying current and future risks associated with climate change involves the formalization of a risk map. This is part of constructing the Group's sustainable development risk map, which allows for an initial quantification of the impact and frequency of environmental and climate-related risks as identified internally, thus laying the groundwork for a more robust risk management strategy.

APICIL Epargne is a life insurance company under the APICIL Group, designing life insurance products and capitalization contracts for individuals and legal entities. As of December 31, 2022, the market value of the APICIL Epargne portfolio amounted to 9.196 billion euros. The portfolio is principally composed of 77.1% bonds, 6.4% equity funds, 4.6% real estate investments, 6.7% cash and cash equivalents, and 4.3% corporate holdings. The breakdown is as follows:

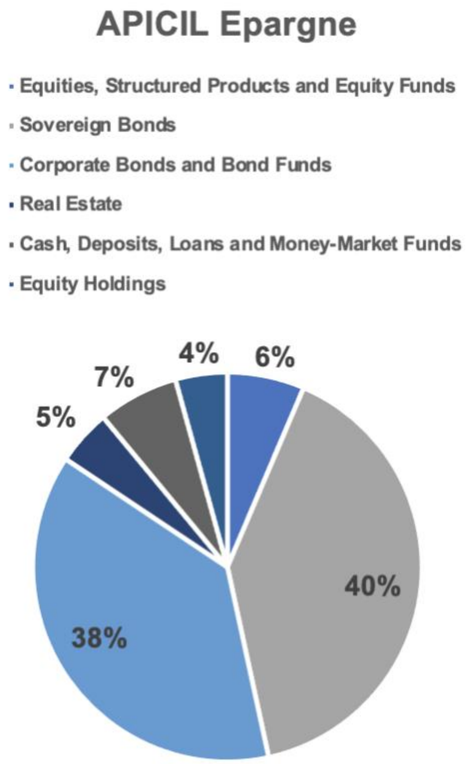

Figure 23: APICIL Epargne Portfolio Breakdown

The risk rating for each risk at APICIL is based on an assessment of two dimensions: the probability of occurrence and the impact on solvency capital. The scoring criteria for strategic risk, financial risk, underwriting risk, and sustainability risk are as follows:

Frequency		Impact as % of Own Funds	
Less Likely	Less than 1 every 10 years	Mild	0.5% or less
Moderate Probable	At least 1 time in 10 years	Moderate	Between 0.5% and 3%.
Probable	At least 1 time in 3 years	Severe	Between 3% and 12
Highly Probable	At least 1 time per year on average	Extremely Severe	12% or more

Table 11: The Scoring Criteria for Risk Rating

Source: APICIL Risk Department

Based on the two factors of probability and impact, risks are qualitatively assessed using a criticality grid with color coding: green (less likely/mild), yellow (medium or moderate probable/moderate), orange (probable/severe), and red (high probable/extremely severe).

This color-coded system, as shown in Figure 24, is a visual tool that allows stakeholders to quickly identify and prioritize risks based on their severity and likelihood. Risks that fall into the green category may require routine monitoring, while those that fall into the red category may need immediate action or more rigorous management strategies due to their potential to significantly affect solvency capital.

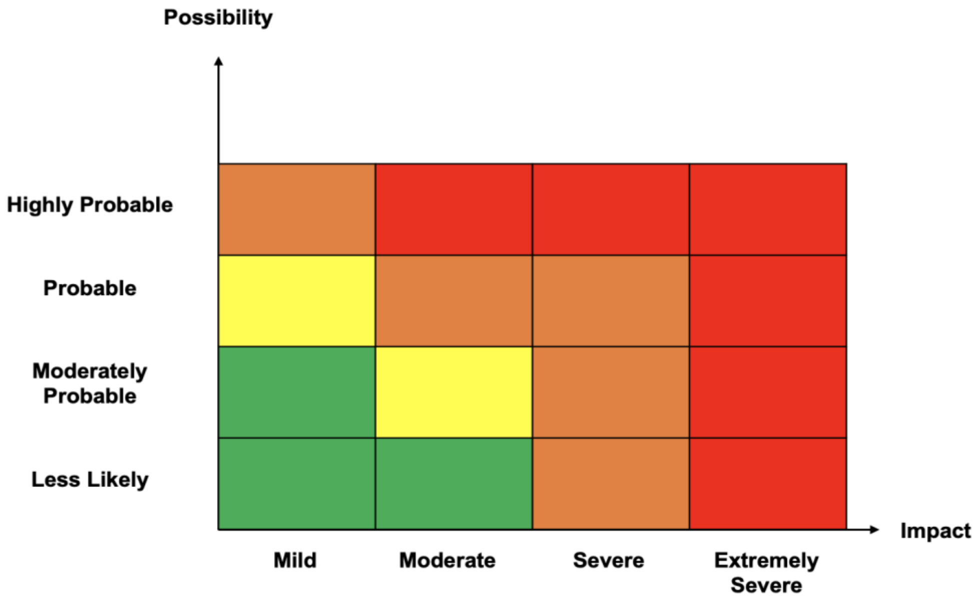

Figure 24: The Risk Positioning Map of the APICIL Group

Source: APICIL Risk Department

Firstly, our research analyzes the dimension of occurrence probability. According to information from the IPCC AR6 report, if the lifespan and operation pattern of existing and planned fossil fuel infrastructure are maintained, and if there is no increase in emission reductions, by 2100 there is at 83% probability that the global temperature increase would reach 2°C. Even with measures to limit carbon emissions, the probability that the global temperature increase would exceed 1.5°C by 2100 is still over 50%. Therefore, the probability on this dimension can be approximated between Probable and Highly Probable.

In terms of the impact on prudent capital, the climate Value at Risk needs to be estimated. For instance, under a disorderly 2°C scenario, APICIL Group estimated that the net impact of climate risk VaR on equities reached 20.6% as of December 31, 2022, up from 16.5% on December 31, 2021, indicating the necessity to continue integrating climate risks and opportunities into portfolio management.

Thus, in terms of investments, the climate risks can be categorized as:

- Risk of climate inaction (2°C rise): Probable, Severe Impact.
- Risk of disorderly climate transition (2°C rise): Highly Probable, Severe Impact.

Based on the above analysis, the risk map is shown as follows:

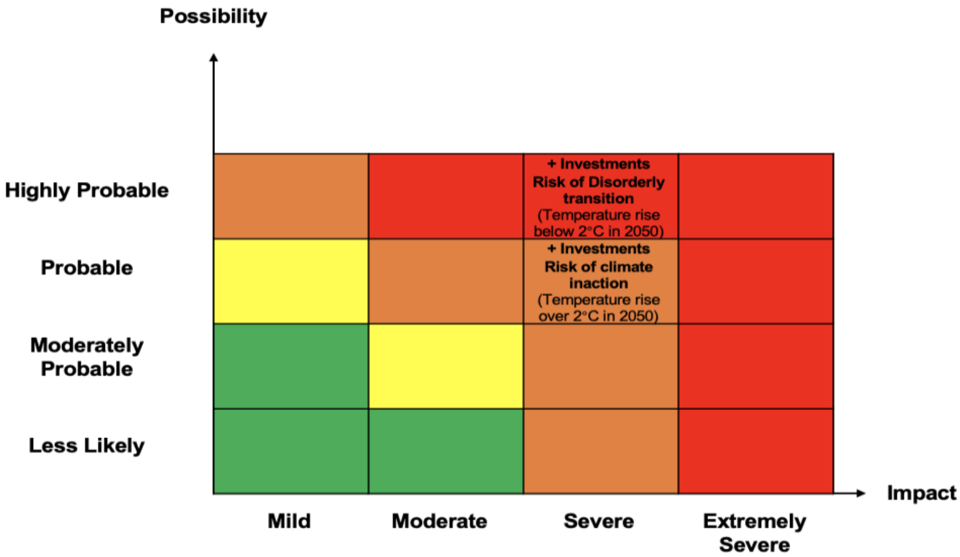

Figure 25: The Climate Risk Map of the APICIL Group

3.4 Financial Asset Data Calibration and Practical Application

Based on the guidance material from ACPR, the compilation of the materials to be used in conducting climate stress tests for APICIL Epargne and additional work need to be done are shown in Table 12. Next, we will address each of these points in turn:

	Data available	Additional Work Required
Entity	APICIL Epargne	• Obtain information on APICIL Epargne investment assets by geography, economic sector, and size of holdings (if available).
Inflation Rate	ACPR Climate Stress Test Scenario for 2020-2050 (five-year average)	• As the data given are not for consecutive years, data interpolation is required. • ACPR published the data in 2020 and the calibration process is required.
Risk Free Rate	ACPR Climate Stress Test Scenario ript for 2020-2050 (five-year average)	• Since the data given are not for consecutive years, additional calculations need to be made through the forward rate formula. • ACPR publishes data in 2020 and a calibration exercise is required. • The Addactis model requires the input of 120 years of RFRs, thus requiring an extended interest rate term structure.
Value Added Index	ACPR Climate Stress Test Scenario for 2020-2050 (five-year average)	• ACPR published the data in 2020 and the calibration process is required. *Note: The Value Added Index actually needs to be calibrated, but there are no relevant indices on the market for calibration. Therefore, our work chooses to apply it directly.* • Equity fund shocks need to meet the requirements for shocks in 4 regions and 55 sectors of economic activity.

Table 12: The Materials and Additional work Required for the Climatic Stress Test

3.4.1 Application of Value Added Index on Equity

3.4.1.1 Explanation of the Meaning of Value Added Index

For the application of the Value Added (VA) index, we need to review again the ACPR Guidance Document on Climate Stress Test. Let us recall its definition given in：The VA index represents the change in the intrinsic value of the company (price change + dividends), presented by year, sector, geographic region. An example of a VA index figure for the French base metal manufacturing industry is shown below:

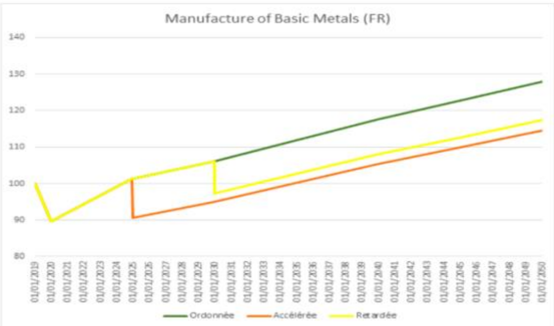

Figure 26: VA Manufacture of French Basic Metals [32]

[32] https://publications.banque-france.fr/en/climate-related-scenarios-financial-stability-assessment-application-france

Source: Climate-Related Scenarios for Financial Stability Assessment

Due to the abundance of the data and to better understand the VA notion, an example is provided: Company A falls under the economic category of “Electricity, gas, steam and air conditioning supply” according to the NACE classification and is in France. Hence, the company needs to employ the VA Index of “Electricity, gas, steam and air conditioning supply” in France to shock this asset. According to the ACPR climate stress test Baseline scenario, the index for “Electricity, gas, steam and air conditioning supply” in France is 100 in 2022, while it is 89.7 in 2023. If the company holds stocks of Company A amounting to € 100 in 2022, then the value of Company A stocks the company holds in 2023 would be € 89.7. The calculation standard formula is as follows:

$$\begin{aligned}&\text{New Market Value after Shock}\\&= \text{Value of Equity for the Previous Year} \times \frac{VA_{\text{This Year}}}{VA_{Previous\ Year}}\end{aligned}$$

When applying the VA Index to the ACPR climate stress test, the company's existing Addactis Modeling platform was not able to apply shocks in a detailed manner by geography and sector of economic activities. By looking at the Addactis’ shock files applied to equity funds in Figure 27 and Figure 28, the current system can only apply 6 different shocks, which is not sufficiently accurate for the ACPR Climate Stress Test requirement to apply shocks to 4 geographies and 55 sectors of economic activities.

RendementActionMR

SIMULATION	LINE	Indice1	Indice2	Indice3	Indice4	Indice5	Indice6
1001	1	0%	0%	0%	0%	0%	0,00%
1001	2	5,00%	5,00%	7,00%	6,00%	0,00%	0,00%
1001	3	3,00%	3,00%	5,00%	6,00%	0,00%	0,00%
1001	4	3,00%	3,00%	5,00%	6,00%	0,00%	0,00%
1001	5	3,00%	3,00%	5,00%	6,00%	0,00%	0,00%
1001	6	3,00%	3,00%	5,00%	6,00%	0,00%	0,00%
1001	7	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%

Figure 27: The Stock Shock Input File from Addactis

Figure 28: The Addactis Regular Stock Shock Process

Therefore, it is necessary to supplement the Addactis Modeling platform with a shock program that can be applied to 4 geographic regions and 55 sectors of economic activities to shock all the equity funds held by APICIL Epargne. Generally, in the equity side, the Addactis Modeling platform needs to be fed with stock returns to perform the stress test. The purpose of the supplemental program is precisely to get a uniform stock return that can be interfaced with the current Addactis Modeling platform as shown in Figure 29. After obtaining the fund returns for target years, these data will be input into the Addactis Modeling platform, thus realizing the shocks to the equity funds in accordance with the needs of the ACPR Climate Stress Test.

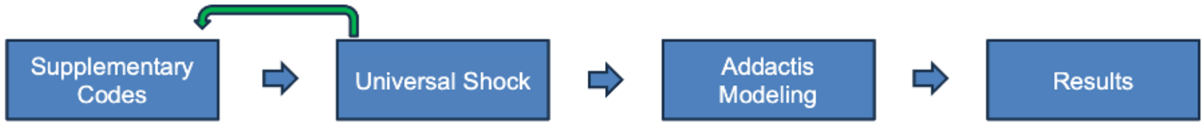

Figure 29: The Updated Stock Shock Process

Next, we will discuss the necessary steps for applying the VA Index's shock to equity funds, which will consist of the following two main parts:

1. Develop query programs for the Region and Economic Sector distributions to obtain information on the Region and Economic Sector distribution of the 86 equity funds held by APICIL Epargne.

2. Based on the information obtained in step 1, develop a program for applying the VA Index to shocks to equity funds to obtain different market values and return rates under ACPR climate stress test scenarios.

3.4.1.2 Equity's Region and Economic Sector Information Inquiring Program Design

In APICIL Epargne, the company that conducted the ACPR climate stress test, it holds a total of 86 equity funds in 12 portfolios. Since the APICIL Epargne purchased these funds, the purchased fund companies are obliged to disclose the fund positions. In the company's Risk Management department, a table of information on purchased fund 1 (an example) can be accessed, as exemplified below:

Portfolio ID	Market Exposure in Weight	Issuer Country	Economic Sector	Instrument Name
FR0000295230	2%	IE	K6419	Company A
FR0000295230	…	…	…	…
FR0000295230	1%	DE	J0000	Company C

Table 13: The Dataset Example of a Fund Detailed Information

To realize an effective shock to Equity, the Fund 1's region and economic sector as a percentage of that fund needed to be queried and calculated. Therefore, the program is to query the geographic distribution of stocks held in a fund.

To achieve an accurate assessment of the geographic distribution of the equity holdings within Fund 1, our work initially engaged with the relevant dataset, similar in nature to the example provided in Table 13. This dataset enumerated each stock's issuing country utilizing ISO 3166-1 alpha-2 codes, a two-letter country code standard established by the International Organization for Standardization (ISO). To ascertain the precise geographic location of these stocks, an API [33] interface that translated these two-letter codes into each country's official names and their

[33] https://gitlab.com/restcountries/restcountries.

corresponding continents is employed.

Subsequently, according to the geographic segmentation criteria set forth by the ACPR, a geographic category needed to be assigned to each stock. Specifically, the data retrieved via API were processed through a conditional logic statement. For instance, a stock issued by a country other than the "French Republic" but situated within Europe will be categorized as RoEU. This procedure ensured that every stock in Fund 1 was labeled in compliance with the ACPR's geographic classification standards.

After verifying the correct classification of each stock, we need to do the third phase of data processing. The aim at this juncture was to extract "Market Exposure Amount" data from the dataset and aggregate it according to the geographic categories established previously. To determine the market exposure percentage for each region, the aggregate "Market Exposure Amount" for each category was compared against the total current market value of Fund 1.

Following the processes, Fund 1's market exposure was successfully delineated across the four principal geographic categories: FR, RoEU, US, and RoW. The logical flow of the program is shown in Figure 30.

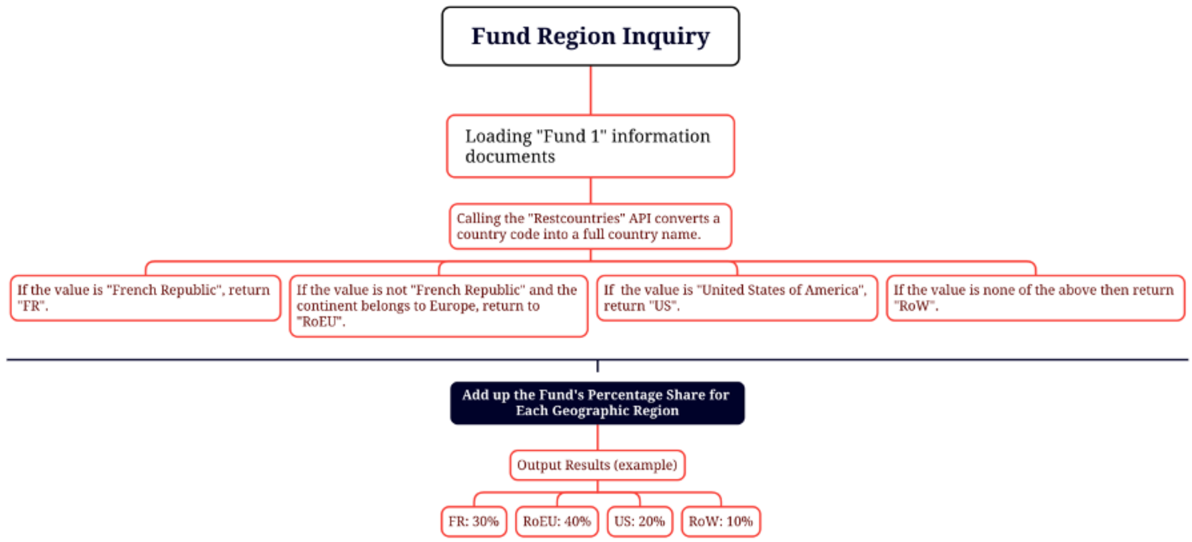

Figure 30: The Structure of the Fund's Region Inquiry Program

To conduct a granular analysis of Fund 1’s economic sector distribution, the dataset for Fund 1 was first retrieved. The focus was placed on stock data within the "Issuer Country" column identified with the "FR" regional code. It should be noted that during the Fund Region Inquiry procedure, the original data in "Issuer Country" had already been supersed.

To align the data set's "Economic Sector" codes with the ACPR's categorizations, a "Dictionary" needs to be established. The NACE codes, representing the European Community's classification standard for statistical activities, manifested across various sectors of economic activity, furnished us with a uniform standard for classification. This taxonomy allowed for a detailed penetration into specific business activity levels, as exemplified by the NACE code "C1001," which denotes

"Beverage Manufacturing." Here, "C" represents the manufacturing sector, "10" denotes food production, and "1001" corresponds to a more precise categorization.

After establishing the "Dictionary," the translation of the dataset's NACE codes into ACPR's standardized 55 economic sector categories commenced. An illustrative example is the correlation of "BXXXX" with "Mining and Quarrying," leading to a systematic transformation throughout the dataset.

Then, we proceeded to the specific stage of data compilation. For stocks within the same economic sector, their "Market Exposure Amounts" were aggregated to ascertain the total market exposure for each economic sector. Further, the total market exposure for a given sector was divided by the total market value of the fund within the "FR" region to determine the market exposure percentage for that sector.

In summary, our work delineated the market exposure distribution of Fund 1's stocks within the "FR" region, categorized by the ACPR's 55 standardized economic sectors as shown in Figure 31.

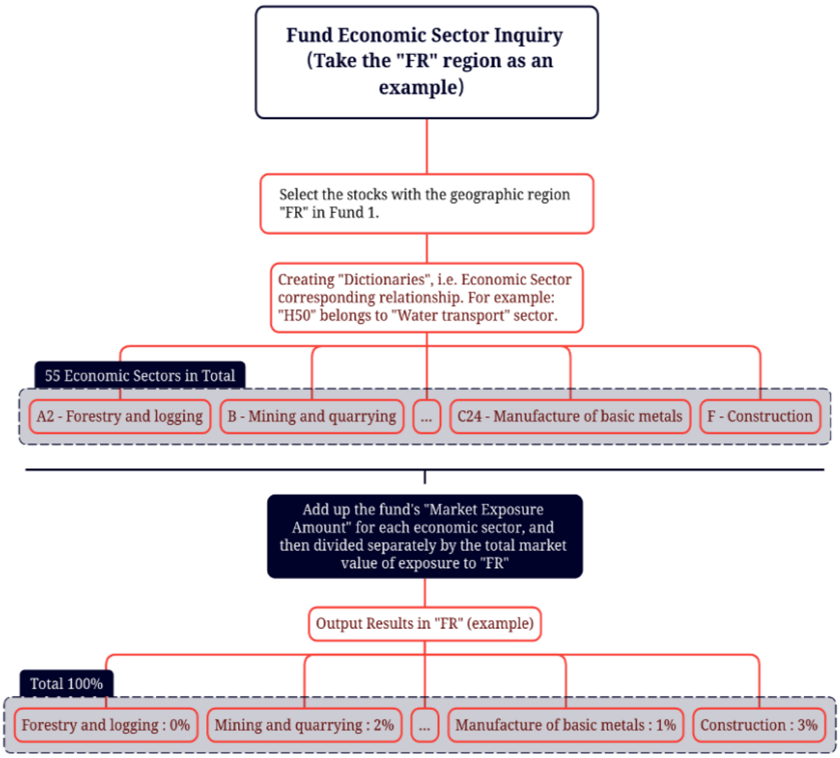

Figure 31: The Structure of the Fund's Economic Sector Inquiry Program

Upon completion of the Fund Region Inquiry and Fund Economic Sector Inquiry programs for Fund 1, we obtained a structured dataset, encompassing the following data elements:

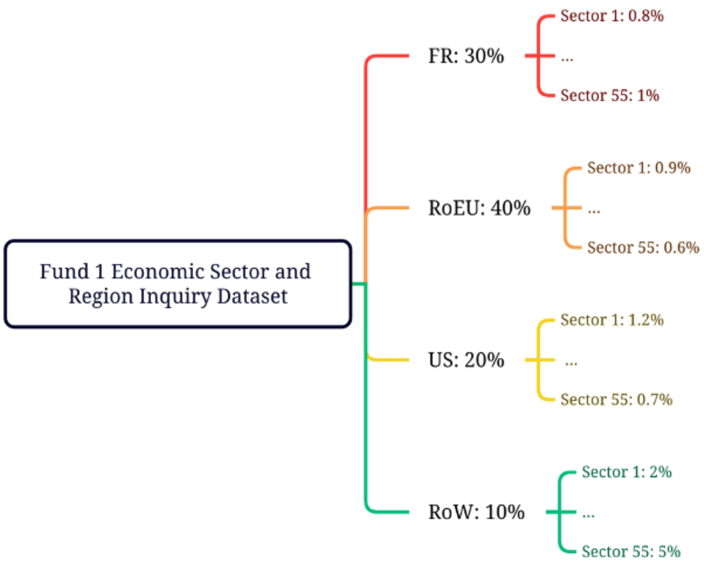

Figure 32: The Structure of the Fund's Economic Sector and Region Dataset

3.4.1.3 Equity's VA Index Shock Program Design

Upon the execution of both Fund Region Inquiry and Fund Economic Sector Inquiry procedures on all funds held by APICIL Epargne, the next stage is set to apply shocks to the values of these funds, aligning with the climate stress test scenarios outlined by ACPR. The logical framework of the Shock Program for Equity Funds is as follows:

The program hinges on three critical datasets that are required:

(i) A dataset encapsulating the base information (including fund code and market value) of all 86 funds held by APICIL Epargne for the year 2022

(ii) A detailed climate scenario (VA index) as outlined by ACPR

(iii) The Data on the regional distribution of all funds along with the Economic Sector data for each region

The program tackles each fund sequentially, commencing with Fund 1 and concluding with Fund 86. For each fund, the following computational steps are adopted as shown in Figure 33:

1. Retrieve the market value data for the fund as of 2022;
2. Appropriately allocate this market value in accordance with the fund's regional distribution;
3. Based on the allocation, further distribute value across the various Economic Sectors within each region;
4. In alignment with the ACPR climate scenarios, ascertain the shock parameters that correspond to the designated regions and Economic Sectors;
5. Calculate the post-shock value of all Economic Sectors within each region utilizing the shock

parameters and aggregate these values;

6. Synthesize the shocked values across all regions to forecast the fund's market value for the ensuing year;
7. Iteratively conduct the calculations to project the market value of the fund from 2023 to 2050.

It is essential to underline that the calculation procedure described above is tailored for an individual fund. To comprehensively compute all funds held by APICIL Epargne, 86 iterations of this process are needed as shonw in Figure 34.

Through the computational process delineated above, the market value fluctuations of the funds held by APICIL Epargne under the climate scenarios proposed by ACPR will be successfully simulated.

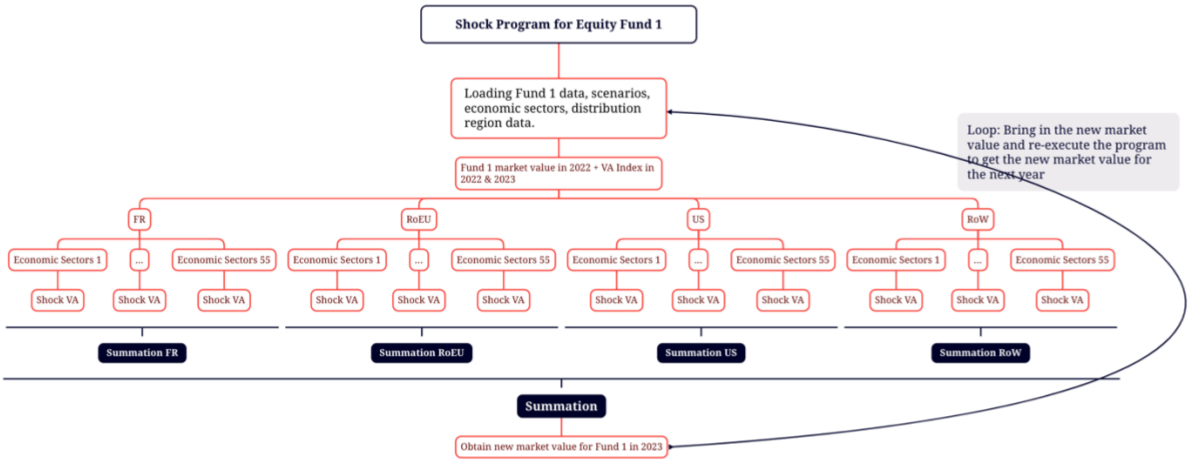

Figure 33: The Structure of the Shock Program for an Equity Fund

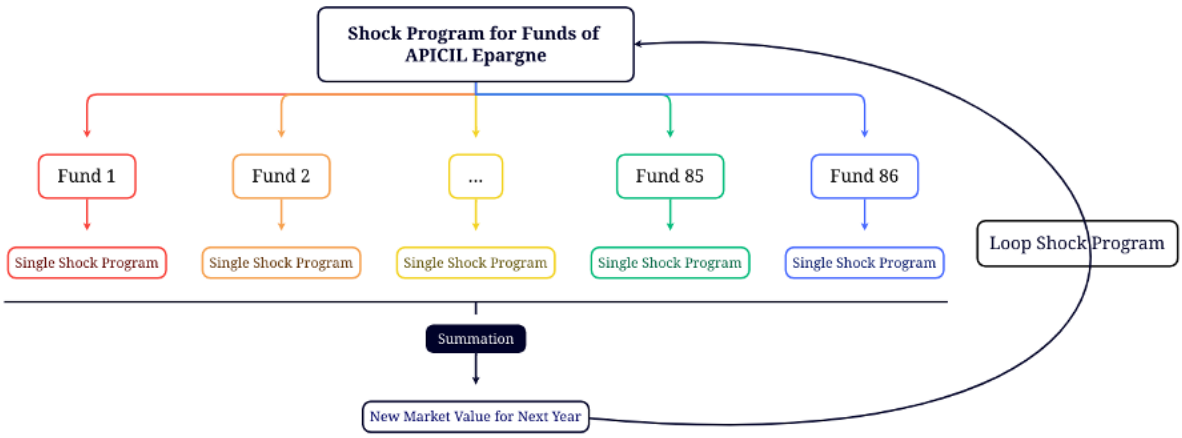

Figure 34: The Structure of the Shock Program for the Funds of APICIL Epargne

The description above delineates the most straightforward and fundamental approach under the guidance of the ACPR climate stress scenarios. Unfortunately, the practical application of this solution is often precluded by data insufficiency. Specifically, approximately 30% of the funds lack detailed fund data, and an additional 20% of the remaining funds do not possess accurate details as of December 31, 2022. This shortfall renders the approach almost infeasible. Nonetheless, articulating this method is crucial, as it provides a foundational resolution for enacting fund shocks under ACPR climate stress scenarios.

An alternative solution: To circumvent the data challenges, the ACPR has furnished us with a concordance between NACE and GICS codes, thus facilitating an alternative methodology. The Global Industry Classification Standard (GICS), developed collaboratively by Morgan Stanley Capital International (MSCI) and Standard & Poor's (S&P) in 1999, categorizes economic activities into 11 major sectors, such as Financial, Health Care, Information Technology, among others. Owing to its widespread adoption, it has become the standard across numerous financial institutions. Particularly in the financial sector, most fund companies' reports conform to the GICS economic sector classification, making the related data accessible via most fund companies' official websites. Utilizing the ubiquity of GICS and the NACE-to-GICS concordance provided by ACPR, we have been able to create a comprehensive dataset encompassing the economic activity sectors and regional distributions for the 86 funds held by APICIL Epargne.

Nevertheless, while GICS data is more readily available (with about 10% of the funds lacking data, for which we compensate by calculating the average from other funds to supplement the data for these 10%), challenges persist in the application of alternative of solution. Hereinafter, our research will delve into these issues and their prospective resolutions.

- **Problem One and Its Solution**

When detailed holdings data for funds are obtained, it allows for a clear understanding of the funds' geographic distribution and the economic sectors involved. In such condition, a cogent logical relationship exists between regions and economic sectors. For instance, using the method described in section 3.4.1.2, the program can precisely extract Fund 1's stock holdings in the French region ("FR") and then categorize them according to the 55 economic activity sectors provided by ACPR. Thus, a logical dependence is established between the geographic and economic sectors as shown in the Figure 35.

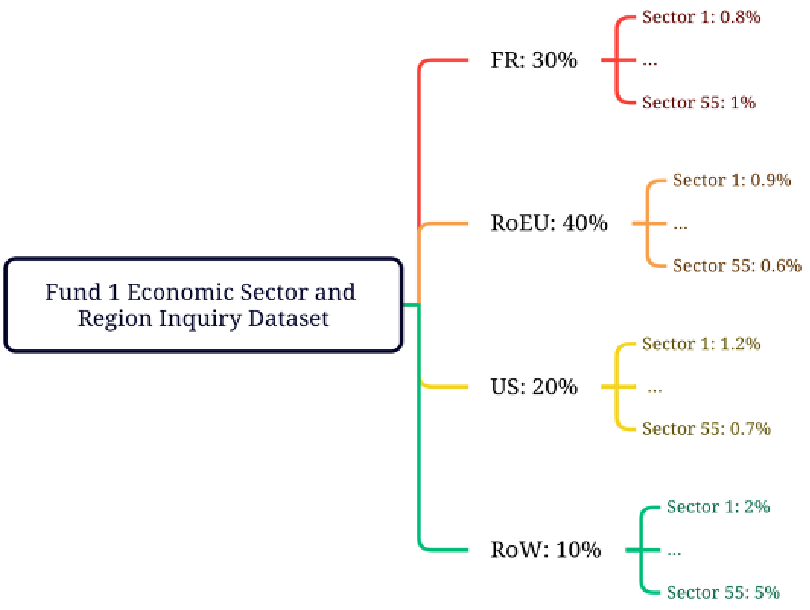

Figure 35: The Structure of the Fund's Economic Sector and Region Dataset with NACE Standard

However, there is no logical dependence between geography and sector of economic activity if the distribution of funds is queried through the reports of the fund companies. More precisely, if we inquire about a fund's Region and Economic Sector distributions through the fund company's report, we can only obtain respectively the Region distribution and the Economic Sector distribution of this fund as shown in Figure 36, not the Economic Sector distribution under a certain Region.

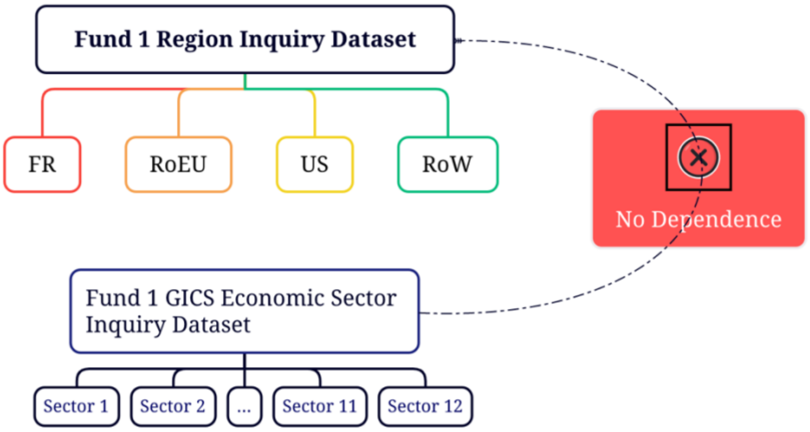

Figure 36: The Structure of the Fund's Economic Sector and Region Dataset with GICS Standard

Consequently, when electing to undertake shock analysis based on the GICS classification standard, we need to make the following assumption: **(A1) The distribution of economic activity sectors across various regions for the 86 funds managed by APICIL Epargne exhibits uniformity and homogeneity.**

- **Problem Two and Its Solution**

According to the economic sector classification of the ACPR, 55 distinct economic sectors is given. However, when referencing the GICS economic activity standard classification, there are only 12 primary sector divisions. This discrepancy inevitably results in a 'one-to-many' mapping conundrum. For instance, the "Telecommunications" sector in GICS correlates to four distinct sectors according to ACPR's concordance: Telecommunications, Advertising and Market Research, Publishing Activities, and Motion Picture, Video & Television Programme Production. It is important to notice that ACPR's climate stress test scenarios are given on its 55-sector delineation. It implies incorporating additional procedural steps to ensure the continuity and accuracy of the test shocks.

During the execution of stress tests, our objective is to identify and mitigate potential risks. **(A2) Thus, a feasible strategy is choosing the 'worst-case' scenario to ensure comprehensive risk coverage.** Taking the "Telecommunications" sector as an illustrative example shown in Figure 37, the program will compare the shocks for the four corresponding sectors within the ACPR climate stress test and select the most adverse scenario. Subsequently, this most adverse shock will be applied to Fund 1's "Telecommunications" holdings, thus ensuring the precision and thoroughness of the stress test.

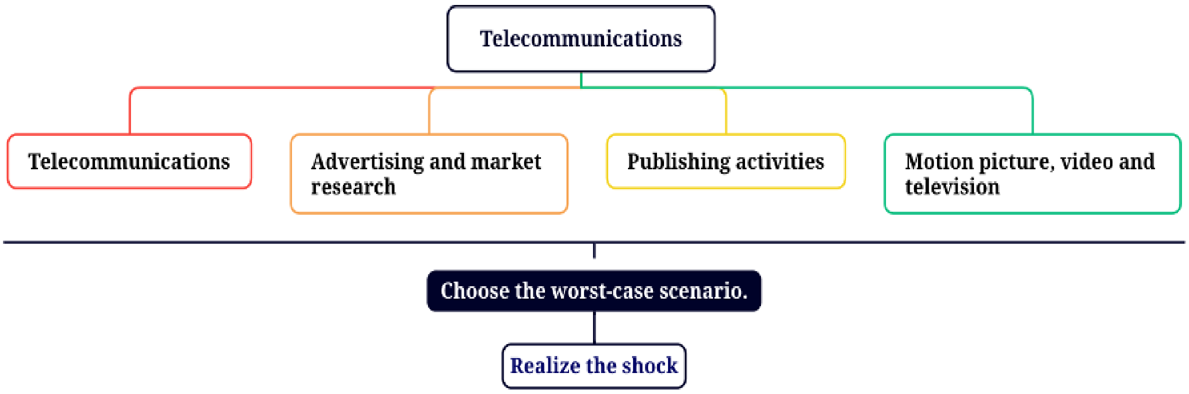

Figure 37: The Worst-case Scenario Selection Mechanism

After establishing two important assumptions A1 and A2 to solve the problems, an equity shock program based on GICS classification standards can then be developed. This protocol equally relies on three pivotal datasets that are needed:

(i) A foundational dataset encompassing the basic information (including fund code and market value) on all funds held by APICIL Epargne in the year 2022

(ii) A detailed exposition of the ACPR climate scenarios (VA Index)

(iii) A dataset including geographical distribution and economic sector distribution according to the GICS standards for all funds

To systematically process this information, the program starts with Fund 1 and proceed sequentially through to Fund 86. Each fund undergoes a systematic computational sequence as follows:

1. The program assimilates the market value data of the Fund for the year 2022;

2. Utilizing the Fund's geographic distribution data, the program allocates market values by Region;
3. The program further redistributes the value in each region according to the Economic Sectors as delineated by the GICS standard;
4. Drawing from ACPR climate scenario data, the program extracts shock parameters that align with designated regions and Economic Sectors. In consideration of the potential 'one-to-many' mapping between GICS standards and ACPR's 55 categories, the program specifically opts for the 'most adverse' shock as the benchmark;
5. Applying the derived shock parameters, the program estimates the impacted value of each Economic Sector within regions and aggregates the results;
6. The program synthesizes the shocked values across all regions to project the Fund's market value for the ensuing year;
7. This predictive approach is replaced, estimating the market value for the Fund from the year 2023 through to 2050.

Recall that this process as showned in Figure 38 is tailored for an individual Fund. To thoroughly estimate the market value for all APICIL Epargne Funds, this procedure necessitates 86 iterations.

By using our adapted computational method proposed based on GICS categorization, we have been able to successfully simulate the market value trajectory for the 86 funds held by APICIL Epargne under the ACPR climate scenarios, as can be seen in Figure 39.

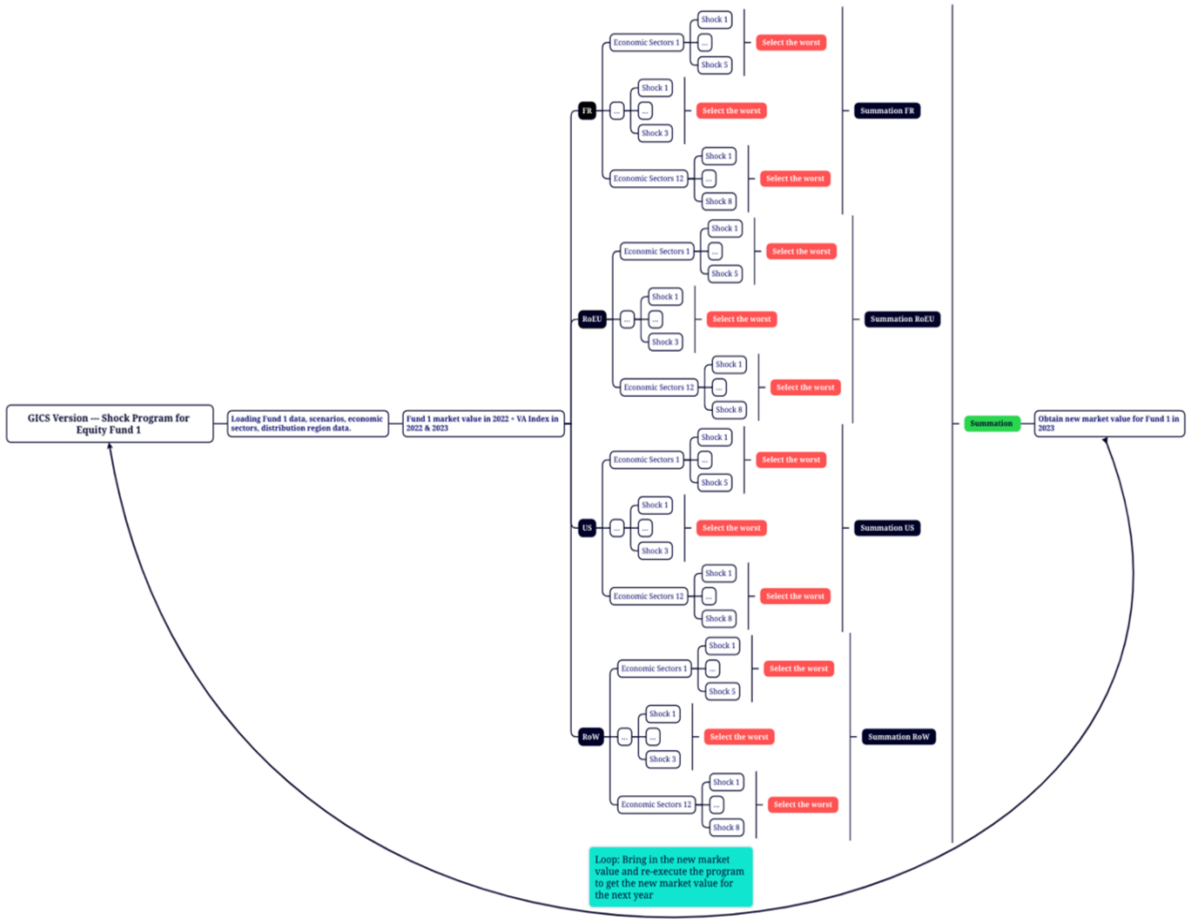

Figure 38: The Structure of Shock Program for Equity Fund 1 by GICS Standard

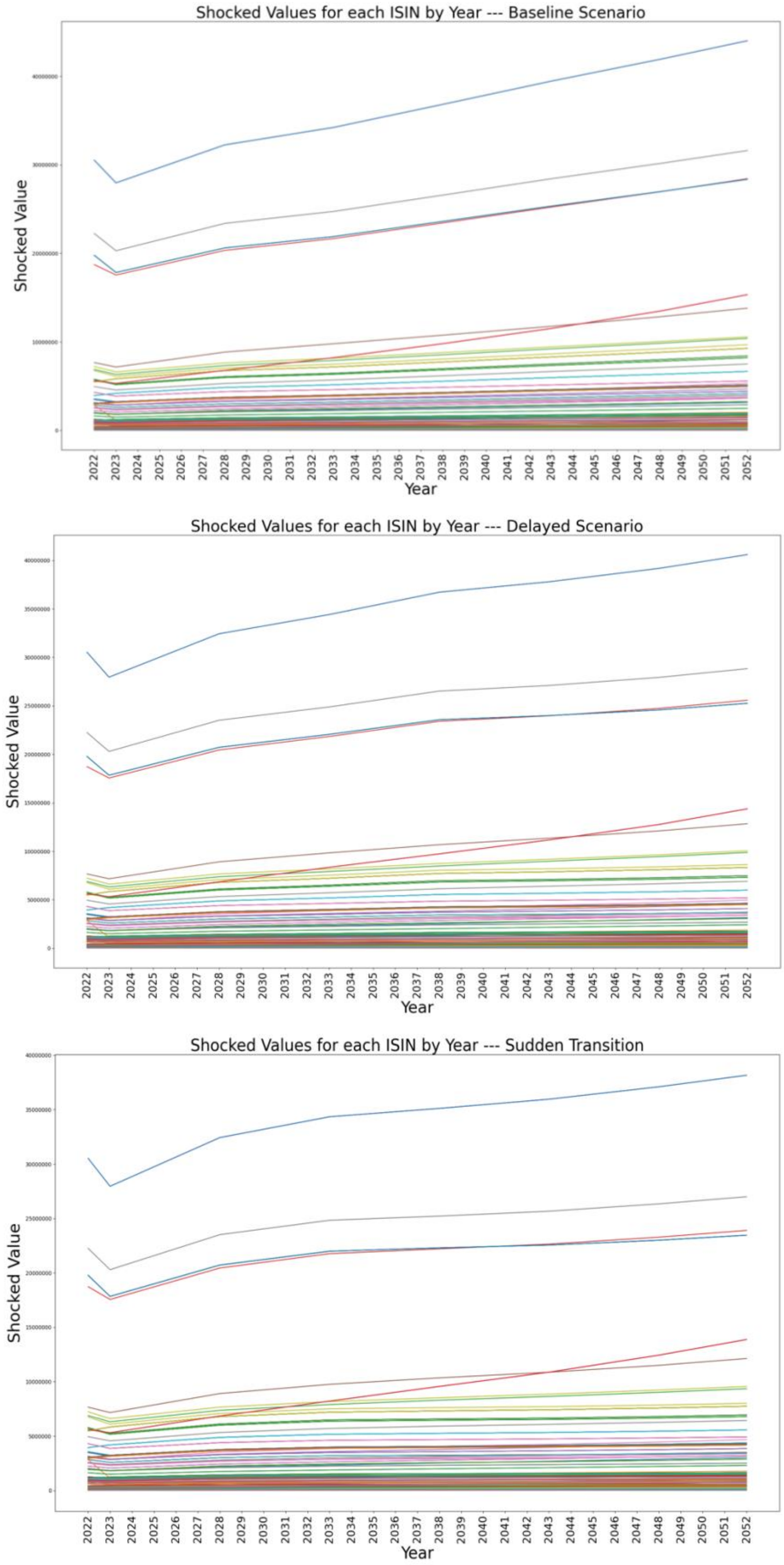

Figure 39: The Changes of Market Value of Equity funds after Shock

3.4.2 Calibration of Risk Free Rate

Considering the climate stress test scenarios published by the ACPR, it has been observed that data pertaining to risk-free interest rates is provided only at five-year intervals starting from the year 2020, culminating in the year 2050. This temporal granularity in the data manifestly falls short of the requisites for conducting precise stress tests. Of paramount concern is the significant volatility in risk-free rates across Europe from 2020 to 2022, necessitating the utilization of the most current data for pertinent calibration.

To address these issues, we propose the following solutions:

- Calibration of the risk-free interest rates in the ACPR climate stress test scenarios using the data published by the European Insurance and Occupational Pensions Authority (EIOPA) for the year 2022.
- Employing the standard forward rate formula to interpolate data for the intervening years within the five-year interval framework.
- Implementing the Smith-Wilson method[34] to extrapolate risk-free interest rates from a 1- to 20-year term out to a 120-year term, thereby satisfying the long-term computational demands of our model.

3.4.2.1 Using the panning method for calibration.

Between 2020 and 2022, the European Central Bank (ECB) was confronted with a complex economic environment, compelling a profound reevaluation and adjustment of its monetary policy. Two pivotal factors—persistent inflationary growth and the robust recovery of the European economy—necessitated for the ECB to reassess and incrementally elevate its key interest rates. Specifically, in 2020, under the widespread impact of the COVID-19 pandemic, the European economy plummeted into a historic bottom. To mitigate this unprecedented economic downturn, the ECB decisively implemented an accommodative monetary policy, which led to the decadal risk-free rate reported by the European Insurance and Occupational Pensions Authority (EIOPA) at the end of 2020 reaching a historic lowest point of 0.0%.

However, as vaccines were widely distributed and administered in 2021, signs of economic recovery in Europe began to emerge. Data indicated a positive GDP growth rate of 4.2% for the Eurozone in 2021. Nonetheless, a confluence of economic factors, such as rising production costs, a surge in raw material prices, and labor market strains, collectively drove inflation rates up to 2.5% by year-end.

By 2022, inflationary pressures intensified, compelling the ECB to implement a series of contractionary policies to maintain economic stability. Notably, by the end of 2022, the ten-year

[34] https://www.eiopa.europa.eu/system/files/2022-12/eiopa-bos-2022-547-new-rfr-technical-documentation.pdf

risk-free rate published by EIOPA had risen from 0.1% in 2020 to 3.1% in 2022—a significant shift.

This marked change in interest rates indicated that the ACPR's projections made in 2020, based on the economic conditions at the time, had diverged from the actual circumstances of 2022. It is pertinent to note that the risk-free rate projection curve used by the ACPR for climate stress test in 2020 had not been updated at the time of this study. Moreover, despite the publication of the corresponding dataset, the underlying predictive model has not been made public by the ACPR. Given this, with the significant rise in risk-free rates in 2022, a corresponding adjustment appears particularly imperative. Under this circumstance, the application of the parallel shift method for revision is considered and appears as a rational and pragmatic choice for the following reasons:

- Clarity and Simplicity: The parallel shift is a straightforward technique, which consists of establishing a fixed interest rate differential to be uniformly applied to every point on the projection curve. This method not only avoids complicated adjustments to the original model but also obviates the need for re-estimation, significantly simplifying the adjustment process.
- Continuity Maintenance: The use of the parallel shift to adjust the interest rate curve is in effect an adjustment to the overall level of interest rates while keeping the interest rate differentials of the original maturity period unchanged. This approach preserves the continuity of market expectations for the future and reflects the relative value of assets of different maturity periods in the new economic environment.
- Avoidance of Model Error: Attempting to make profound modifications or re-estimating the original model may introduce new model errors. By contrast, as a more conservative approach to adjustment, the parallel shift method effectively circumvents this risk.

In summary, given the changes in the European economic environment from 2020 to 2022 and the current deviation in the ACPR's forecast curve, employing the parallel shift method to adjust the risk-free rate forecast curve seems to be a sensible and pragmatic approach. The result is shown in Figure 40.

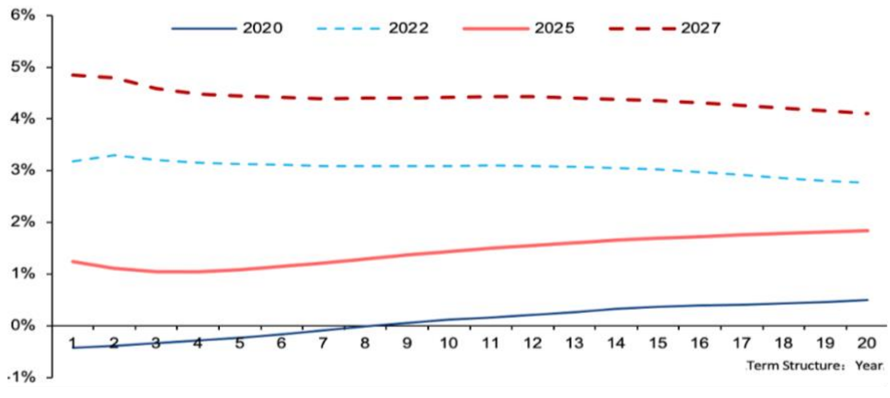

Figure 40: The Term Structure of Interest Rates Adjusted by the Panning Method

3.4.2.2 Filling in Intermediate Years using the Forward Rate

The forward rate is used to indicate the expected interest rate at a specific time in the future. It could be derived from the yields on two zero-coupon bonds of different maturities. It represents the interest rate locked in today for a specific period in the future, rather than the interest rate purchased and held to maturity. In simple terms, the forward rate could be thought of as the expected short-term interest rate for a certain period in the future. The calculation standard formula is as follows:

$$f(t,t+1) = \left(\frac{(1+y(t+1))^{(t+1)}}{(1+y(t))^{t}}\right) - 1$$

where f (t, t+1) represents the forward rate from time t to time t+1， and y (t) is the zero-coupon rates at time t.

Based on the nature of the forward rate formula, if the interest rate term curve data for the first year has been known, the interest rate term structure for the next four years can be derived, as illustrated in Figure 41.

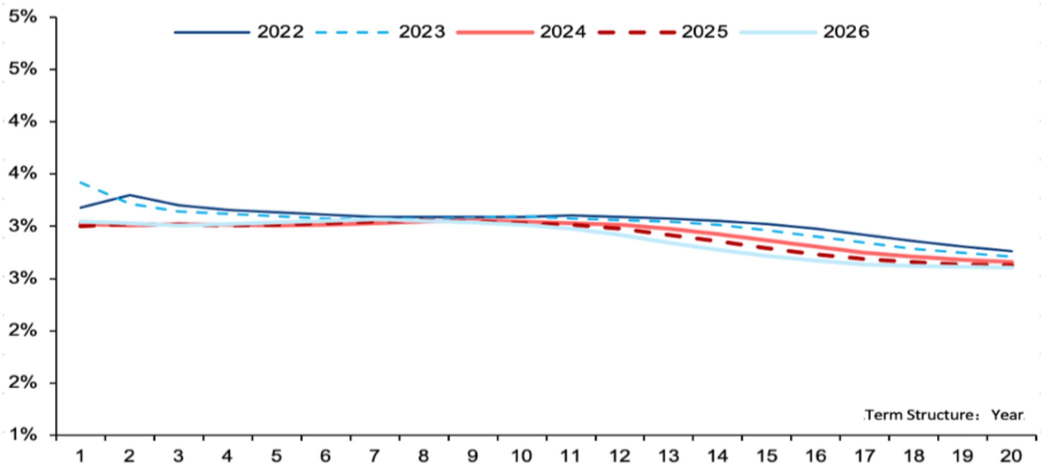

Figure 41: The Interest Rates after Using the Forward Rate Formula

3.4.2.3 Using the Smith-Wilson Method to Extend the Interest Rate Term Structure

The Smith-Wilson method is extensively used for extrapolating the term structure of interest rates, especially in the context of Solvency II regulations in Europe. It is a mathematical technique employed by the European Insurance and Occupational Pensions Authority (EIOPA) for the extrapolation of risk-free interest rates.

The core of the Smith-Wilson method is to estimate future interest rates by using a weighted sum of exponential functions, ensuring a smooth transition from the last liquid point (LLP) where market data is available to the ultimate forward rate (UFR) at which the term structure converges in the long-term.

The calculation standard formula in the Smith-Wilson method is as follows:

$$P(t) = A(t) + B(t)$$

where:

P(t) is the price of a zero-coupon bond at time t

A(t) is the arbitrage-free price of a zero-coupon bond at time t based on market data,

B(t) is the adjustment to ensure the term structure converges to the UFR in the long-term.

The adjustment B(t) is given by:

$$B(t) = \sum_{i=1}^{n} \omega_i \cdot e^{-\alpha \cdot (t+u_i)} \cdot \left(1 - e^{-\alpha \cdot (t-u_i)}\right)$$

where:

n is the number of market data points

ω_i *are the Wilson functions' weights which are determined so that the estimated term structure fits the market data*

α *is a mean reversion speed parameter*

u_i *are the times to maturity of the market data points.*

This method allows for a well-behaved and arbitrage-free extrapolation of the yield curve beyond the point where market data is available, and it ensures the long-term convergence to a pre-specified UFR, which is crucial for the accurate valuation of long-term liabilities.

Following the Smith-Wilson Method, we can extend the interest rate term structure to 120 years as shown in Figure 42 :

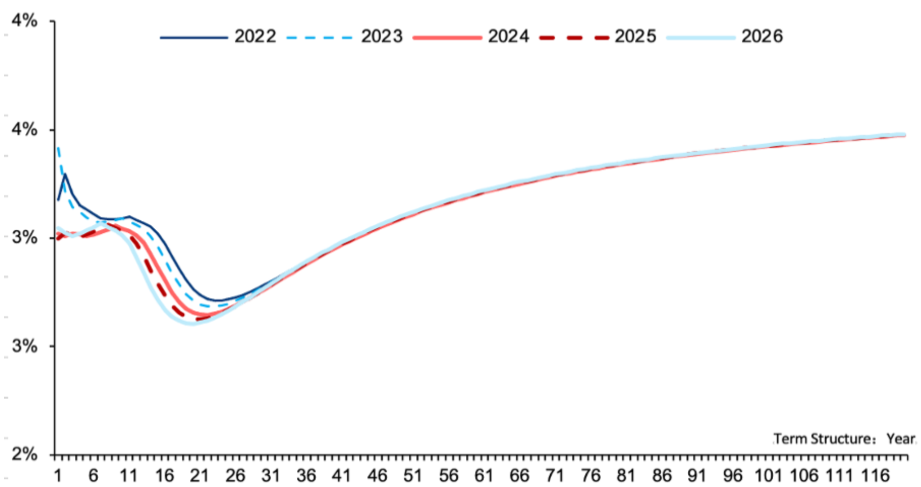

Figure 42: The Term Structure of Interest Rates after Expansion using the Smith-Wilson Method

3.4.3 Calibration of Inflation Rate

In the context of inflation rates, as previously mentioned, according to the climate stress test scenarios published by the ACPR, the data concerning inflation rates is provided only in five-year intervals starting from 2020, until 2050. This temporal resolution of data is evidently insufficient for conducting precise stress test. More critically, from the onset of 2020 through to 2022, the inflation rate in Europe experienced significant volatility. In 2020, France's inflation rate remained at a lower level, with an average annual rate of merely 0.48%. This period coincided with the global pandemic outbreak, where economic activities were severely impacted, slowing both consumption and production. In 2021, as the pandemic situation gradually ameliorated and recovery of economic activities, the inflation rate in France began to ascend, reaching an annual rate of 1.64%, reflecting the tension between demand and supply during the economic recovery phase. By 2022, the inflationary rate notably intensified, particularly influenced by factors such as the surge in international energy prices, supply chain disruptions, the cycle of interest rate increases by the US Federal Reserve, and the uncertainties brought about by the Russo-Ukrainian conflict, culminating in an annual inflation rate of 5.3%. In the middle of the year, the rate momentarily approached 6%, signaling the ongoing accumulation of price pressures across various sectors. Hence, there is an urgent need to employ the most up-to-date data for the requisite recalibrations.

When making the calibration of risk-free rates, the calibration could be effectively addressed through translation method. The translation method relies on a critical assumption: the structural changes in risk-free rates are relatively smooth, and the extent of variation maintains a certain continuity and consistency in the short term. This assumption allows for the translation method to adapt to fluctuations in risk-free rates via straightforward linear adjustments, without the necessity for complex reshaping of the entire rate curve. Moreover, by preserving the fundamental shape of the curve, the translation method avoids potential estimation errors and structural distortions that could arise from model reconstruction.

However, when focusing on inflation rates, this presumption of stability no longer holds true. Especially as previously described, the behavior of inflation rates has demonstrated distinctly nonlinear characteristics and abrupt changes. The application of the translation method is incapable of capturing these dynamic shifts accurately, as it offers only a uniform mode of adjustment, disregarding the nonlinear structures and potential discrete points. Therefore, it is evident that a more refined analytical approach is required for adjusting inflation rates. The primary aim of using models at this section is to maintain data within a reasonable range, capturing dynamic changes and time dependencies, rather than deciphering ACPR ‘s original model.

For precise financial stress test, the continuity and accuracy of time-series data are important. To enhance the utility of the time-series data in this study, average interpolation has been employed to fill in the data points at five-year intervals between 2020 and 2050, to produce a more granular set of annual data.

Incorporating the European Central Bank's (ECB) macroeconomic analyses and projections, the ECB report anticipates a decline in the inflation rate to 2.9% in 2023, with an adjustment to 2.1% in 2024, and a reversion to the 2% inflation target by 2025. Based on these forecasts, we have meticulously updated the data points within the model to ensure they reflect not only the actual observed data but also integrate the central bank's inflationary objectives. Data beyond 2025 remains as initially provided by ACPR, considering 2020-2025 as a period of short-term fluctuation.

This updating process underscores two pivotal approaches in our model construction: firstly, the timeliness of data, which is imperative in capturing rapid shifts in economic conditions, thus ensuring that the inputs to the model are both immediate and accurate. Secondly, the alignment of strategy, implying that the adjustments in the model's forecasts are in sync with policymakers' expectations. After adjustments, we have a total of 33 data points that can be used for modeling as shown in Figure 43.

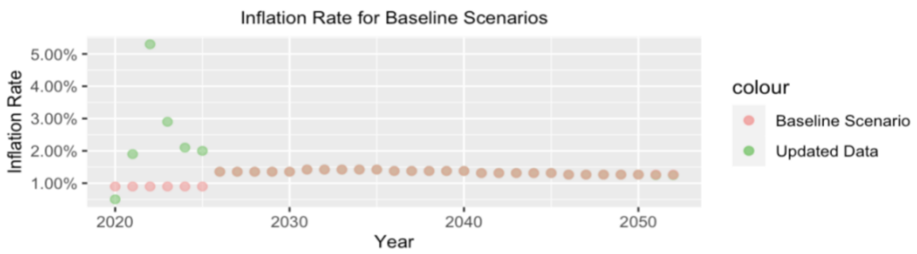

Figure 43: The Inflation Rate after Updating Data for Baseline Scenarios

3.4.3.1 Modeling with Time Series for Inflation Rate

In this section, we start to experiment with analytical modeling for the inflation rate via time series. We suggest to use the most common time series model, the ARMA model, for modeling. This is because ARMA models can effectively capture the autocorrelation and volatility characteristics of time series data.

Before modeling the inflation rate via ARMA time series, it is important to ensure that the data is stationary. For this reason, we used the “Forecast” library in R to determine if the inflation rate data needed to be differenced to achieve stationary status. By applying the “ndiffs()” function to our time series data for the inflation rate, we obtained a result with a 0 order of differencing. This means that the time series is already stationary and no further differencing is required. Therefore, we can proceed directly to the modeling stage of the ARMA model.

Recall that ARMA (Autoregressive Moving Average) model is a popular and widely used time series forecasting model. It is used to model in a linear way time series data that is stationary.

The ARMA model consists of two components:

- Autoregression (AR) component: This component models the linear relationship between the current observation and a specified number of lagged observations (p), known as the order of autoregression. The standard formula for the AR(p) component can be expressed as:

$$Y_t = \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \cdots + \phi_p Y_{t-p} + \epsilon_t \quad (with\ \phi_p \neq 0\ )$$

  where Y_t is the current observation, ϕ_1 to ϕ_p are the parameters to be estimated, and ε_t is. the error term.

- Moving Average (MA) component: This component models the linear relationship between the current observation and a specified number of lagged forecast errors (q), known as the order of moving average. The calculation standard formula for the MA component of order q can be expressed as:

$$Y_t = \epsilon_t + \theta_1 \epsilon_{t-1} + \theta_2 \epsilon_{t-2} + \cdots + \theta_q \epsilon_{t-q} \quad (with\ \phi_q \neq 0\ )$$

  where θ_1 to θ_q are the parameters to be estimated, and ε_t is the error term.

The ARMA model is typically denoted as ARMA (p, q), where p and q represent the orders of autoregression and moving average. The ARMA model could be used to forecast future values of a time series based on its past values and the relationships among them. An ARMA (p, q), model can be written as:

$$\phi(B)(1 - B)Y_t = \theta(B)\epsilon_t$$

where B is the backshift operator, ϕ(B) and θ(B) are polynomials in B of degree p and q, respectively.

The ARMA modeling and prediction process encompasses four key steps:

1. Choose the model order: The order of the ARMA model includes two parameters: p and q, which represent the autoregressive orders and moving average orders, respectively. The values of these parameters are estimated using the autocorrelation function (ACF) and partial autocorrelation function (PACF).

2. Estimate the model parameters: Use maximum likelihood estimation or least squares estimation to estimate the parameters of the ARMA model. This involves fitting the model to the training data and finding the parameter values that minimize the error.

3. Model diagnosis: Diagnose the model to check whether it meets statistical assumptions. This typically involves checking the autocorrelation of the residuals and whether their skewness and kurtosis match a normal distribution.

4. Model prediction: Use the trained model to predict future values of the time series. This involves using existing data to predict future data and could be evaluated using cross-validation methods.

After checking from the ACF and PACF plots as shown in Figure 44 and 45 and computing with the "arima()" function in R, we can set P to be 2, q to be of order 1. Based on the given ARMA model results, the model can be expressed as an ARMA (2,1) model with the following mathematical expression:

$$X_t = 1.4529X_{t-1} - 0.6123X_{t-2} - 1.0000\epsilon_{t-1} + \epsilon_t + 0.0147$$

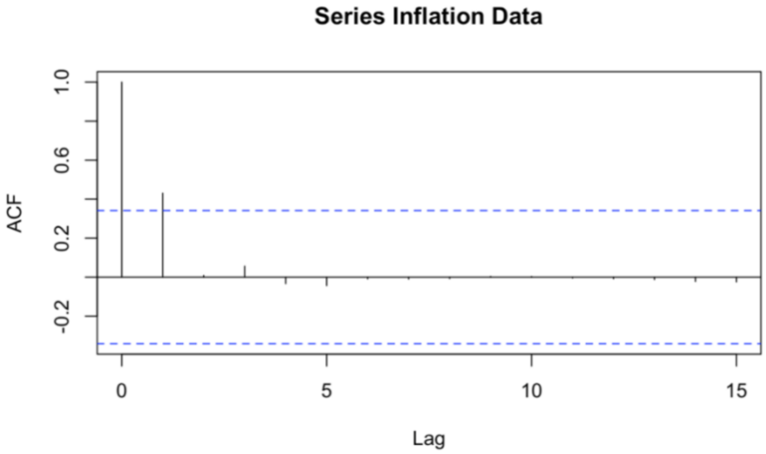

Figure 44: The Autocorrelation Function Plot for the Inflation

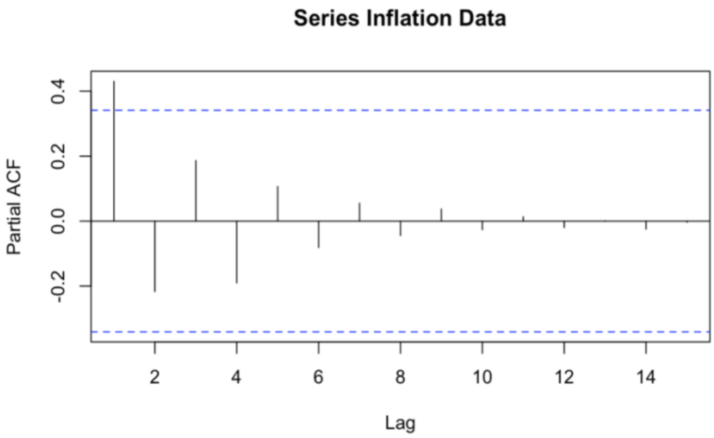

Figure 45: The Partial Autocorrelation Function plot for the Inflation

Here, x_t represents the value of the time series at time t, ε_t represents the white noise error of the time series at time t, the AR (1) coefficient is estimated as 1.4529, the AR (2) coefficient is estimated as −0.6123, the MA (1) coefficient is estimated as −1.0000, and the intercept i is estimated as 0.0147.

In the statistical assessment of the stationarity of the inflation time series residuals, three distinct methods have been employed: the Augmented Dickey-Fuller (ADF) test, the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test, and the Phillips-Perron (PP) unit root test to obtain comprehensive and reliable outcomes. The results are shown in Table 14:

Test Name	Statistic Value	P-value
ADF	-7.4985	0.01
KPSS	0.57513	0.0249
PP	-34.794	0.01

Table 14: The Statistical Assessment by Different Methods

Initially, the ADF test yielded a statistic of -7.4985 with a corresponding p-value of 0.01. This result decisively indicates that at the 99% confidence level, the non-stationary null hypothesis can be rejected, suggesting the stationarity of the residual series. The ADF test examines the presence of a unit root in the data through an autoregressive model, where the presence of a unit root typically denotes the non-stationarity of the time series.

Subsequently, the KPSS test presented a statistic of 0.57513 and a p-value of 0.0249. The KPSS test, another form of stationarity test, initiates from the constant trend of the residuals. The outcome of this test indicates that at the 95% confidence level, the null hypothesis of stationarity can not be rejected, but it can be rejected at the 97.5% level, which may suggest some degree of non-stationarity.

Finally, the PP unit root test offered a statistic of -34.794 with a p-value of 0.01. Like the ADF test, the PP test's conclusion also supports the stationarity of the residual series, rejecting the non-stationary null hypothesis at the 99% confidence level.

Synthesizing the results of these three tests, the residual series exhibits stationarity, lending credibility to our time series model. Following this, the model proceeds with forecasting using our established ARMA model, with the results presented as follows:

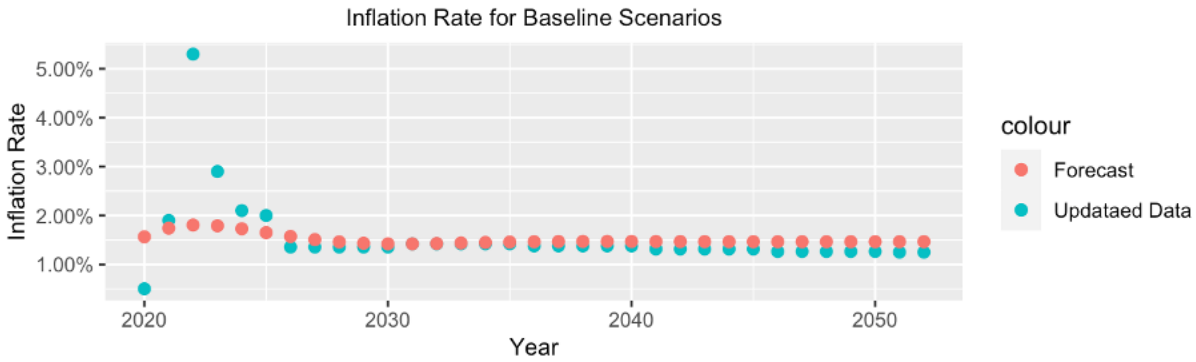

Figure 46: The Comparison of Time Series Modeling with Original Data

Although, from the results of the test, the residual series has smoothness, the ARMA (2, 1) model does not capture the trend of 2020-2025 well. The high inflation rate (5.3%) in 2022 potentially leads to a distortion in the modeling of the whole model and thus the time series modeling approach may not suitable for this context of modeling of inflation rates.

3.4.3.2 Modeling with LOESS Model for Inflation Rate

In grappling with the analytical challenges posed by the severe fluctuations in inflation rates from 2020 to 2022, conventional time series models reveal limitations in capturing such non-cyclical, abrupt economic shifts. Against this backdrop, traditional modeling assumptions such as homoscedasticity of residuals and the linear extrapolation of inherent trends within the data may no longer hold. To depict the true dynamics of economic indicators more accurately, especially under conditions of extreme instability, it seems important to transcend the boundaries of these presumptions.

Consequently, as a result, the focus has shifted to the application of smoothing models, an approach gaining increased prominence in economic time series analysis. Specifically, the Locally Estimated Scatterplot Smoothing (LOESS) method stands out for its nonparametric characteristics and sensitivity to the natural structure of data. The LOESS method, in contrast to traditional global fitting approaches, confers higher weight to local areas of the data, enabling it to capture local variations more precisely and thus offering a clear advantage when dealing with unconventional volatilities.

In this transition, our aim is not only for statistically significant in our models but also for a profound understanding of the true trajectories of economic phenomena. Therefore, the adoption of the LOESS method, when confronting inflation—a key indicator in macroeconomic analysis—becomes a logical imperative.

LOESS (Locally Weighted Scatterplot Smoothing) is a non-parametric smoothing method used to estimate the relationship between two variables in a scatterplot. This method fits a locally weighted regression line to the scatterplot, making the fitted line optimal around each point. The advantage of LOESS is that it captures non-linear relationships between variables and does not make any assumptions about the data, making it useful for small datasets or when the true relationship between variables is unknown.

Recall that LOESS is based on a locally weighted regression model with the following standard formula:

$$y_i = \beta_0(x_i) + \epsilon_i$$

where y_i is the observed value of the response variable, x_i is the observed value of the explanatory variable, $\beta_0(x_i)$ is the regression function at x_i, and ϵ_i is the error term. LOESS estimates the regression function at x_i by weighting the nearby data points for each point (x_i, y_i) using a smoothing parameter $0 < \alpha < 1$. Specifically, LOESS calculates a weighted least squares regression line for each point (x_i, y_i), where each point (x_i, y_i) in the sample is assigned a weight w_{ij}, given by:

$$w_{ij} = \begin{cases} \left(1 - |x_i - x_j|^3/h^3\right)^3 & \text{if } |x_i - x_j| < h \\ 0 & \text{otherwise} \end{cases}$$

where h is a smoothing parameter that controls the degree of local weighting. When estimating the regression function for each point (x_i, y_i), LOESS uses the nearby weighted data points to estimate the regression function $\beta_0(x_i)$ and returns the fitted curve.

It is important to note that the optimal value of span depends on the specific dataset and research question. Generally, smaller span values could better capture the details and nonlinear features in the data but may lead to overfitting. Larger span values could better capture the overall trend in the data but may ignore details and nonlinear features. Therefore, selecting an appropriate span value is crucial for obtaining an accurate fit. When span is set between 0 and 1, LOESS uses a certain proportion of data points around the target point to fit the smoothing curve. For example, when span is set to 0.5, LOESS uses the nearest half of the data points to the target point to fit the smoothing curve.

The smoothness parameter, span, represents a trade-off between achieving smoothness in the model and maintaining accuracy in the data representation. After a trade-off, it is reasonable to set the parameter span to 0.3. This is because it has a smaller residual than the other Span parameters and it can describe the curve trend of the original data better as shown in Figure 47.

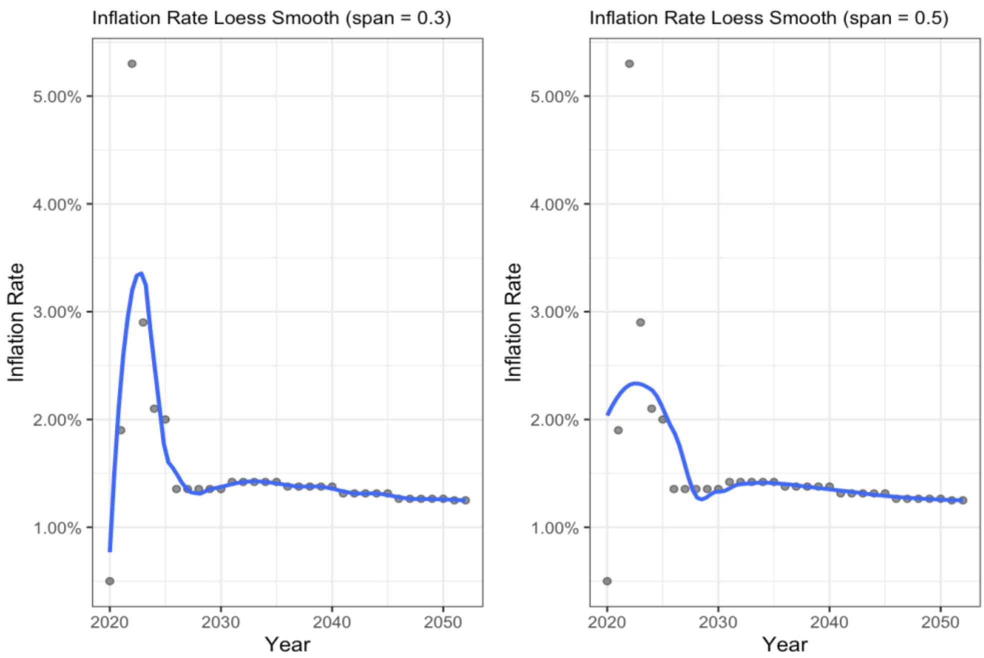

Figure 47: The Comparison of Span = 0.3 and Span = 0.5

Finally, we will compare the forecast results of LOESS (span=0.3) with ARMA (2,1) to determine the modeling choice for the Inflation Rate. Generally, we can compare the advantages and disadvantages of different models through statistical analysis, which includes methods such as residual analysis, calculating the coefficient of determination (R^2), and AIC/BIC criteria. Considering that the LOESS model is a non-parametric model and cannot directly calculate the coefficient of determination and AIC/BIC criteria, we use residual analysis methods that calculate the Mean Absolute Error (MAE) and Mean Squared Error (MSE) to compare the models. The calculated results of MAE and MSE for LOESS (span=0.3) and ARMA (2,1) are shown in Table 15.

Upon comprehensive evaluation:

- For MAE, the LOESS method exhibits smaller errors in most cases, particularly in terms of average error, whereas the ARMA method displays larger errors in both the best and worst scenarios.
- For MSE, the LOESS method also performs better in most situations, especially in terms of average error and the error in the worst-case scenarios, which are smaller than those of the ARMA method.

	Model	**Min**	**1st Quartile**	**Median**	**Mean**	**3rd Quartile**	**Max**
MAE	LOESS	9.610e-07	7.830e-06	7.353e-05	1.322e-03	1.979e-04	2.110e-02
	ARMA	5.990e-06	9.087e-04	1.521e-03	3.003e-03	2.001e-03	3.496e-02
MSE	LOESS	0.000e+00	1.000e-10	5.400e-09	1.583e-05	3.910e-08	4.450e-04
	ARMA	0.000e+00	8.257e-07	2.314e-06	4.671e-05	4.005e-06	1.222e-03

Table 15: The Comparison of LOESS and ARMA Modeling Residuals

Overall, the LOESS method appears to provide more stable and accurate forecasts in this specific case. Therefore, we have chosen the LOESS (span=0.3) model for modeling the Inflation Rate as illustrated in Figure 48.

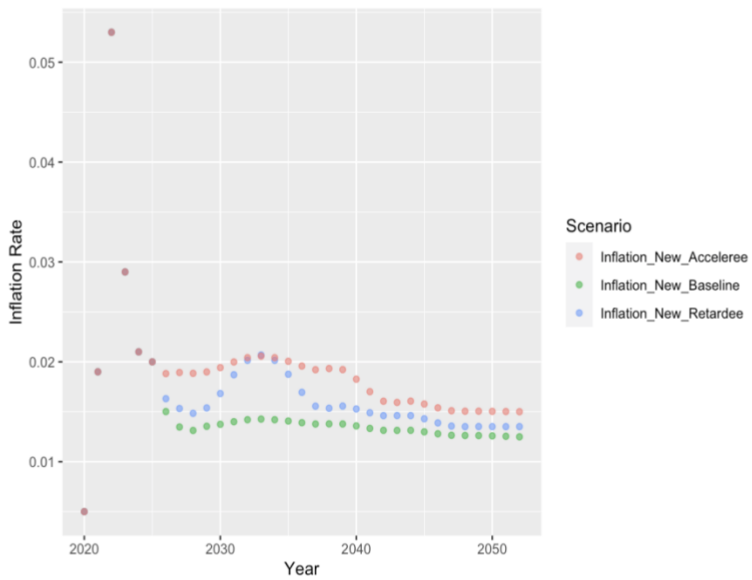

Figure 48: The Inflation Rate Generated by LOESS Model

Chapter 4: Comparison and Analysis of ACPR 2019 Climate Stress Test Results

After updating the input files of Addactis Modeling and launching Addactis Modeling for the Solvency II-based simulation work, we obtained simulation calculations results for ORSA Central scenario, Baseline scenario, Delayed Transition scenario and Sudden Transition scenario. It is necessary to point out that the ORSA Central scenario represents the regular ORSA stress test scenario for APICIL Epargne. In the following, we will compare and analyze the balance sheets of ORSA Central Scenario and Baseline scenario, then, the balance sheets of Baseline scenario, Delayed Transition scenario and Sudden Transition scenario. Since the Solvency II-based balance sheet involves a variety of items, we will select the important parts for graphing, comparing, and analyzing.

4.1 Comparing and Analyzing ORSA and Baseline's Results

4.1.1 Hypothesis Comparison

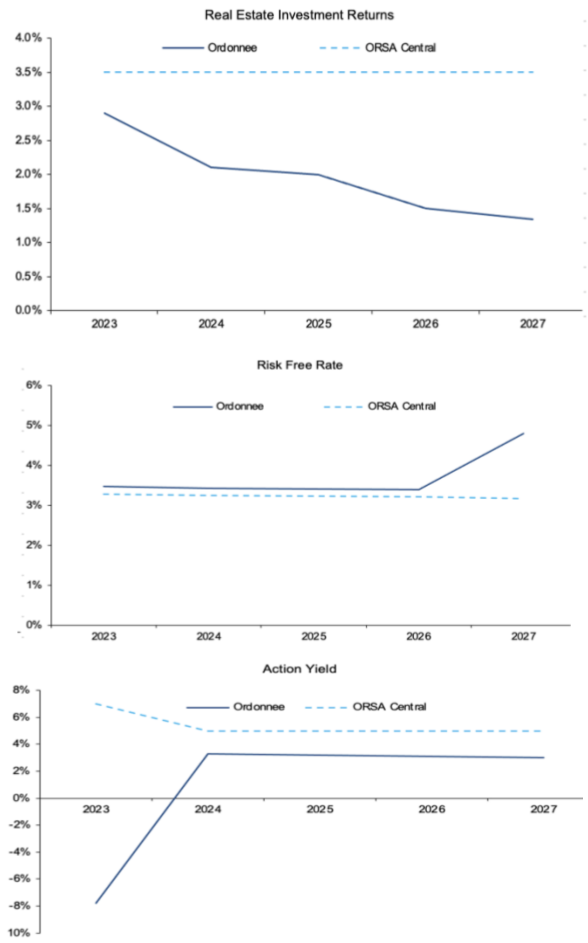

Figure 49: The Comparison of Real Estate Investment Returns, Fund Yields and RFR

From the comparison of real estate investment returns, fund yields and RFR as shown in Figure 49, we observe that within the Baseline scenario from 2022 to 2027, the real estate investment returns and equity yields have demonstrated a consistent trend, averaging 2% and 1% respectively. These values stand notably lower compared to the ORSA Central values, which average 3.5% and 5.4% respectively for the same period. Conversely, the Baseline scenario's risk-free rate, averaging 3.7% over these five years, has consistently exceeded that of ORSA Central, which averages 3.23%. Particularly noteworthy is the rapid rise observed in the Baseline's risk-free rate during 2027.

4.1.2 Asset Side Comparison

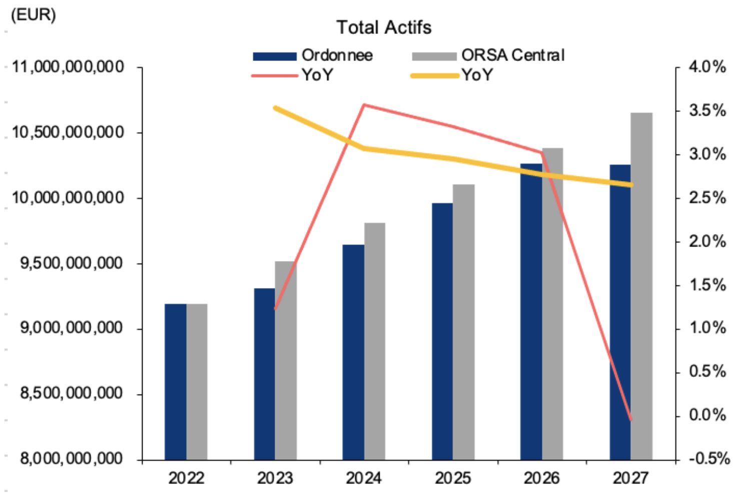

Figure 50: The Comparison of Total Assets

In the investment part, the Baseline scenario exhibits a significantly higher risk-free rate compared to ORSA Central, particularly notable in 2027 when Baseline's risk-free rate surges to 4.8%, starkly contrasted against ORSA Central's 3.17%. This discrepancy contributes to lower inflation relative to ORSA Central, coupled with a diminished equity yield in comparison. Consequently, the market value of the company's investment underperforms that of ORSA Central within the climate stress test Baseline scenario. By the end of 2027, under the Ordonne scenario, the company's total assets are valued at €10.26 billion, in contrast to ORSA Central's total assets, which stand at €10.66 billion at the same period, as shown in Figure 50. The Baseline scenario and ORSA Central's UC investments have a five-year average investment return of 7.91 % and 6.71 %, respectively, while their EURO five-year average investment returns are - 3.83 % and - 0.85 %, respectively.

4.1.3 Liability Side Comparison

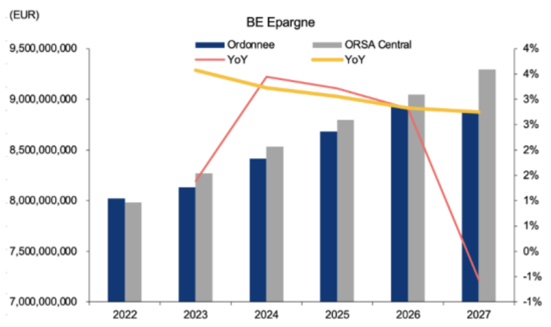

Figure 51: The Comparison of Best Estimate

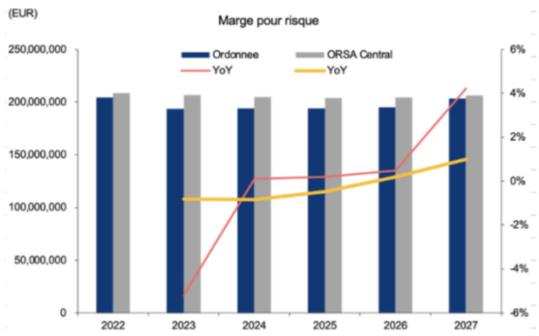

Figure 52: The Comparison of Risk Margin

Best Estimate: Influential factors include projections of future liabilities, variations in discount rates, and changes in policy numbers. A key distinction between the Baseline and ORSA Central scenarios lies in their differing risk-free rates. The Baseline scenario's higher risk-free rate influences an increase in the discount rate. Consequently, as of year-end 2027, the Best Estimate stands at €8.88 billion for Baseline, contrasting with €9.30 billion for ORSA Central, as shown in Figure 51.

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Risk Margin: As of year-end 2027, the value for Baseline is €203 million, slightly lower than ORSA Central's €206 million, as shown in Figure 52. This margin is primarily shaped by the risk-free rate and the projected SCR. The elevated risk-free rate in the Baseline scenario contributes to a comparatively lower Risk Margin than that of ORSA Central.

4.1.4 SCR Market Comparison

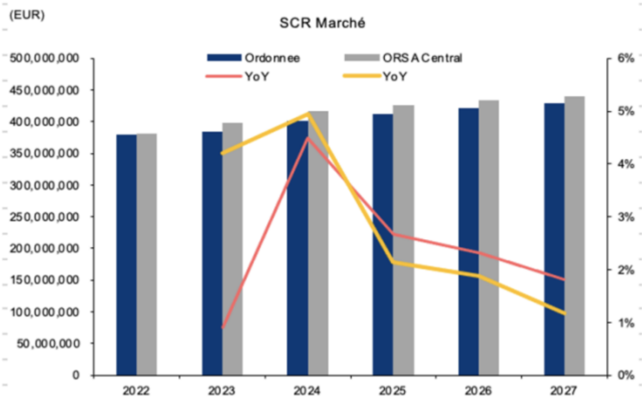

Figure 53: The Comparison of SCR Market

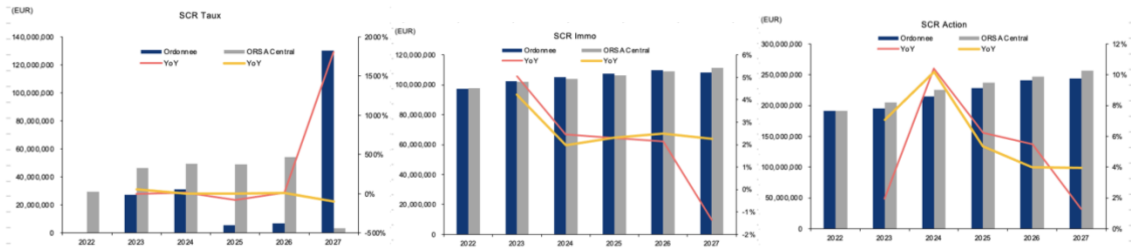

Figure 54: The Comparisons of SCR Interest, SCR Property and SCR Equity

SCR Taux: As of year-end 2027, Baseline's SCR Taux is € 130 million, while ORSA Central's SCR Taux is 3.4 million, as shown in Figure 54. This is mainly due to the higher risk-free interest rate at Baseline compared to ORSA Central.

SCR Action & SCR Immo: At year-end 2027, Baseline's SCR Immo and SCR Action are €108.2 million and €244.3 million, respectively, compared to ORSA Central's SCR Immobilier and SCR Action are €111.4 million and €256.9 million, respectively, as shown in Figure 54. For SCR Immobilier and SCR Action, the Baseline scenario shows lower values compared to ORSA Central. This difference primarily stems from reduced yields and market risk exposures in Baseline's real estate and equity investments. The less favorable returns in these areas, relative to ORSA Central, consequently lead to a lower SCR for both property and equity investments.

SCR Marché: Combining the effects of SCR Taux, SCR Action, SCR Immobilier, SCR Spread and SCR Change, the SCR Marché at year-end 2027 for Baseline and ORSA Central would be € 428 million and € 439 million, respectively, as shown in Figure 53.

4.1.5 SCR Life Comparison

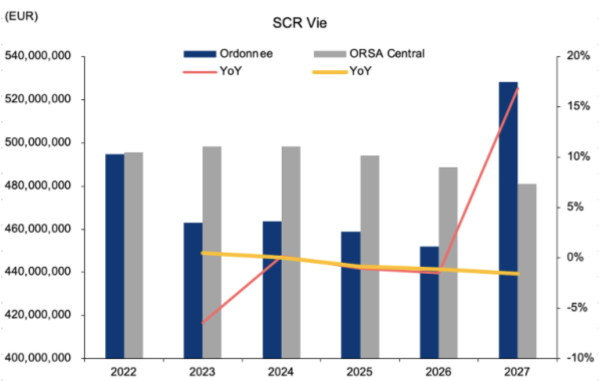

Figure 55: The Comparison of SCR Life

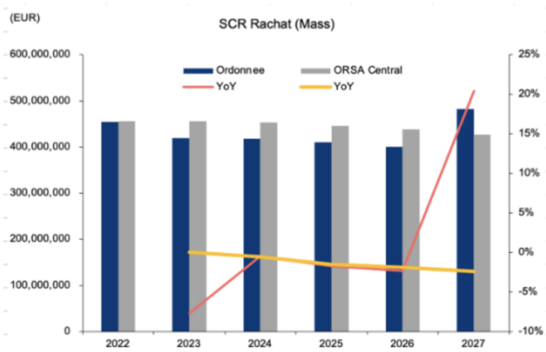

Figure 56: The Comparison of SCR Lapse

SCR Vie: As of year-end 2027, Baseline and ORSA Central have SCR Vie of € 528 million and € 481 million, respectively, as shown in Figure 55. The SCR Vie is mainly composed of SCR Mortalité, SCR Longévité, SCR Rachat and SCR Frais, etc. The above SCR assumptions for SCR Vie are not adjusted. However, the SCR Rachat for Baseline and ORSA Central are significantly different, with values of € 482.7 million and € 427.5 million, respectively, as shown in Figure 56. The main reason for this is the lower return on investment brings about changes in dynamic lapse rate. In this context the Rachat Rate would be significantly increased for Baseline scenario, leading to a significant increase in the SCR Rachat. As a result, Baseline's SCR Vie is significantly higher than ORSA Central's SCR Vie.

4.1.6 SCR Total, Own funds & S2 Ratio Comparison

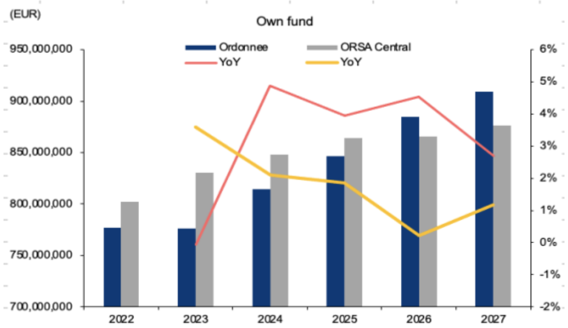

Figure 57: The Comparison of Own Fund

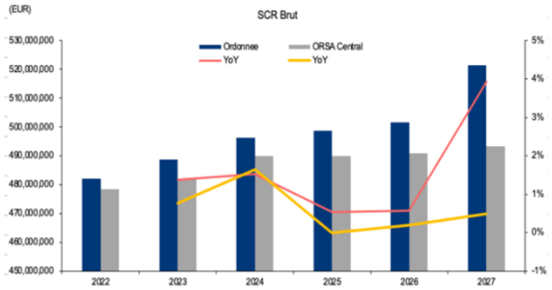

Figure 58: The Comparison of SCR

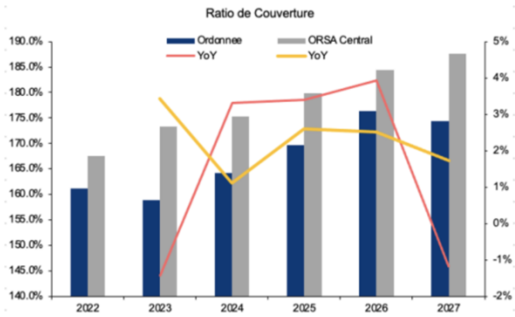

Figure 59: The Comparison of Solvency Ratio

SCR Total: For a savings insurance company, the total SCR of the company is mainly driven by SCR Vie and SCR Marché. The total SCR of Baseline and ORSA Central as of year-end 2027 is €521 million and €493 million, respectively, as shown in Figure 58. The primary reason for that Baseline's total SCR is higher than ORSA Central's total SCR is because the SCR Rachat is higher in Baseline's SCR Vie.

Own Funds: Baseline and ORSA Central were €908.8 and €925.1 million, respectively, with the difference mainly influenced by the risk-free rate, as shown in Figure 57.

Solvency Ratios: At year-end 2027 the solvency ratios for Baseline and ORSA Central are 174%

and 188% respectively, the solvency ratio under climate stress that is approximately 14 percentage points lower than the Company's expectations, as shown in Figure 59. Thus, it can be concluded that even in the scenario of Baseline, which has the lowest transition risk, the impact of climate risk on the company is much greater than the company had originally expected.

4.2 Comparing and Analyzing the Baseline, Delayed Transition, Sudden Transition 's Results

4.2.1 Hypothesis Comparison

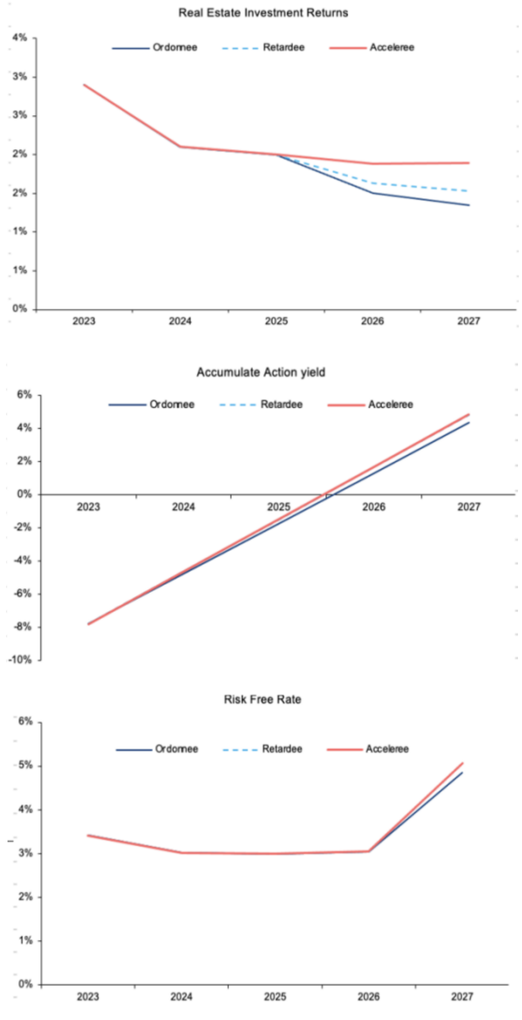

Figure 60: The Comparison of Real Estate Investment Returns, Fund Yields and RFR

In the scenarios of Delayed Transition and Sudden Transition, the Compound Annual Growth Rate (CAGR) for equity investments was recorded at 1.19% in both cases. This rate surpasses the Baseline scenario's equity investment return, which stands at 1.07%, as shown in Figure 60. Furthermore, the 5-year average return on real estate investments in the Delayed and Sudden Transition scenarios are 2.03% and 2.16% respectively, both higher than the Baseline’s 5-year average of 1.97%, as shown in Figure 60.

However, it is important to note that both Delayed Transition and Sudden Transition scenarios exhibit higher risk-free rate, with 5-year average rates of 3.508% and 3.507% respectively, compared to Baseline's average of 3.464%, as shown in Figure 60. This elevated risk-free rate in the Delayed and Sudden Transition scenarios could adversely affect the valuation of bonds in which investments are held.

4.2.2 Asset Side Comparison

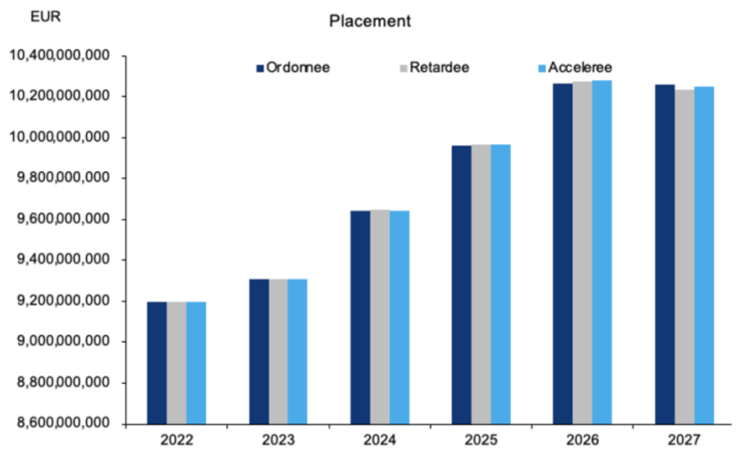

Figure 61: The Comparison of Total Assets

In the investment part, the company's investment strategy is characterized by a significant emphasis on bonds, which constitute 78% of the investment portfolio. This investment distribution, in conjunction with the lower risk-free rate observed in the Baseline scenario, results in a notable valuation outcome. As of 2027, the Baseline's investment assets are valued at €10.26 billion. This valuation is marginally higher than those in the Delayed Transition and Sudden Transition scenarios, where the corresponding asset values stand at €10.23 billion and €10.25 billion, respectively, as shown in Figure 61. The five-year compounded average investment returns for UC investments and EURO investments of these three scenarios are maintained at the level of 8% and - 4%, respectively.

4.2.3 Liability Side Comparison

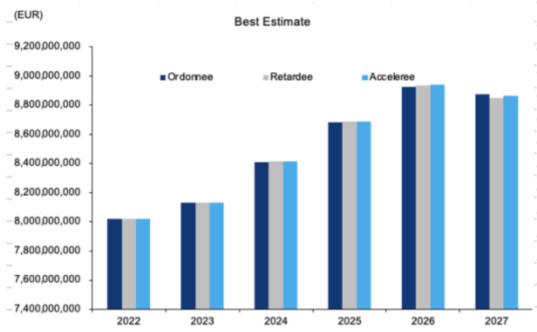

Figure 62: The Comparison of Best Estimate

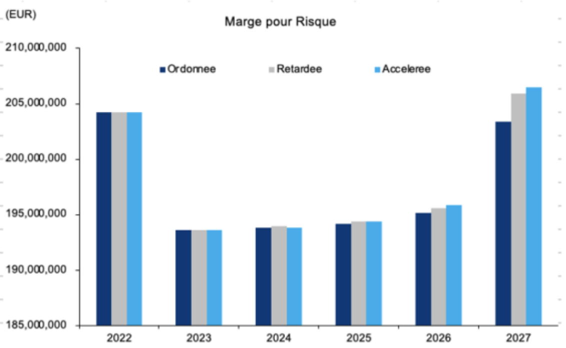

Figure 63: The Comparison of Risk Margin

Best Estimate: A principal difference among the three scenarios – Baseline, Delayed Transition, and Sudden Transition – lies in their respective risk-free rates. With Delayed Transition and Sudden Transition exhibiting higher risk-free rates than Baseline, this leads to an elevation in discount rates. Consequently, in this context, the Best Estimates for Delayed Transition and Sudden Transition are projected at €8.85 billion and €8.86 billion respectively as of 2027, marginally lower than Baseline's €8.87 billion, as shown in Figure 62.

Risk Margin: In these scenarios, the influence of the future SCR is more significant than that of the risk-free rates. This results in the Risk Margins for Delayed Transition and Sudden Transition being higher, at €205.9 million and €206.5 million respectively as of 2027, compared to Ordonne's Risk Margin of €203.4 million, as shown in Figure 63.

4.2.4 SCR Market Comparison

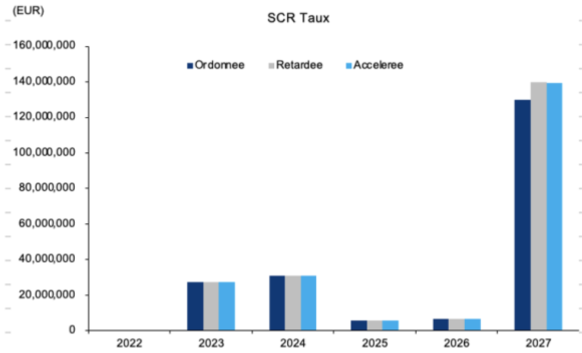

Figure 64: The Comparison of SCR Interest

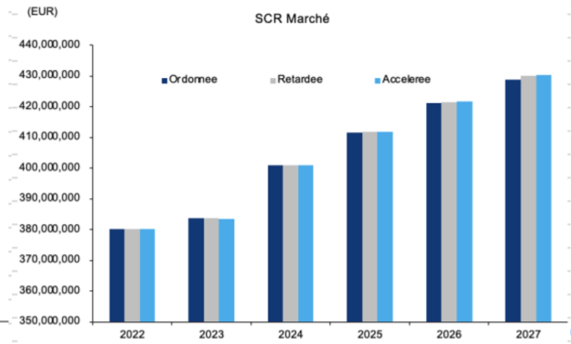

Figure 65: The Comparison of SCR Market

SCR Marché: In the scenarios of Delayed Transition and Sudden Transition, the risk-free rate is observed to be higher than that of the Baseline. This higher risk-free rate leads to an increased SCR Taux in both Delayed Transition and Sudden Transition, amounting to €140.0 million and €139.5 million respectively as of 2027. In contrast, Baseline's SCR Taux is lower, recorded at €130.0 million in the same year, as shown in Figure 64. This disparity in the risk-free rates and

SCR Taux is a primary factor contributing to the differences in SCR Marché values among these scenarios. Consequently, the SCR Marché for Delayed Transition and Sudden Transition is higher, standing at €430.0 million and €430.3 million respectively as of 2027, compared to Baseline’s SCR Market value of €428.7 million, as shown in Figure 65.

4.2.5 SCR Life Comparison

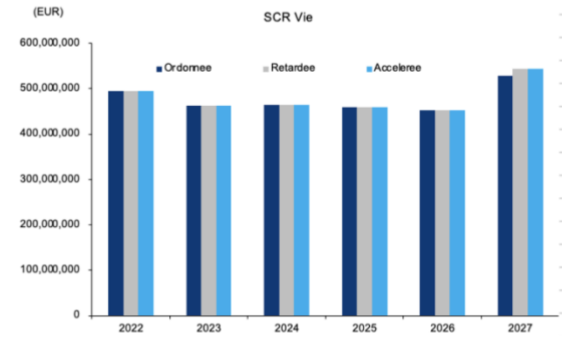

Figure 66: The Comparison of SCR Life

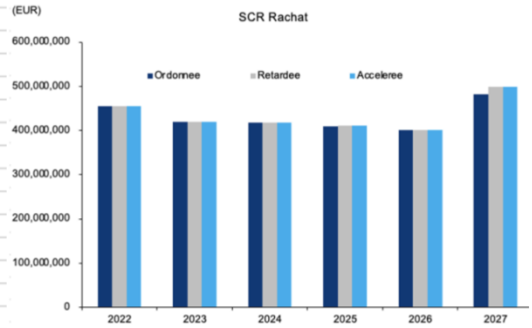

Figure 67: The Comparison of SCR Lapse

SCR Vie: In the scenarios of Delayed Transition and Sudden Transition, the higher risk-free rate, in comparison to Baseline, results in an increased expected return on assets. This elevation in return expectations subsequently leads to an increase in the dynamic lapse rate. As a direct consequence, the SCR Rachat for Delayed Transition and Sudden Transition is calculated to be €499.2 million and €499.8 million respectively as of 2027, exceeding Baseline’s SCR Rachat of €482.7 million for the same period, as shown in Figure 67. This significant difference in the dynamic lapse rates and expected returns is the primary factor behind the higher SCR Vie for Delayed Transition and Sudden Transition, which stand at €543.7 million and €544.7 million respectively as of 2027, in comparison to Baseline's SCR Vie of €528.3 million, as shown in Figure 66.

4.2.6 SCR Total, Own Funds and S2 Ratio Comparison

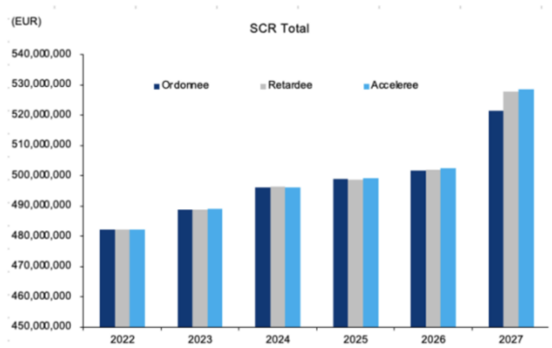

Figure 68: The Comparison of SCR

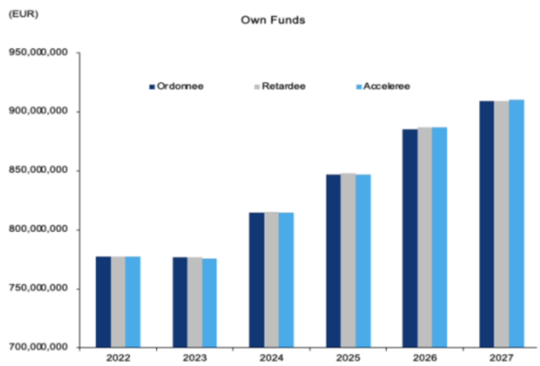

Figure 69: The Comparison of Own Funds

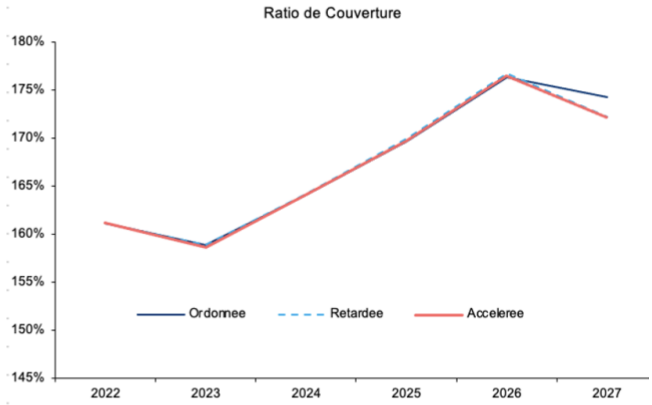

Figure 70: The Comparison of Solvency Ratio

SCR Total: In the scenarios of Delayed Transition and Sudden Transition, both SCR Vie and SCR Marché are higher than in the Baseline scenario. Consequently, the SCR Total for Delayed Transition and Sudden Transition as of 2027 are projected at €528 million and €529 million respectively, surpassing Baseline's SCR Total of €521 million, as shown in Figure 68.

Own Funds: As of 2027, the own funds of Baseline, Delayed Transition and Sudden Transition are €908.8, €909.0, and €910.1 respectively with the difference mainly influenced by the risk-free rate, as shown in Figure 69.

Solvency Ratios: At year-end 2027 the solvency ratios for Baseline, Delayed Transition and Sudden Transition are 174%, 172% and 172% respectively, as shown in Figure 70. During the 2022-2027 period, the Baseline scenario performs best. The fundamental reason is that it has lower RFR compared to the Delayed Transition and Sudden Transition's RFRs.

4.3 Summary of the Analysis

The comparison in 4.1 and 4.2 leads us to the following three important conclusions and the links between the conclusions and their insight source are shown in Table 16:

- **Focus on the Volatility of the Risk-free Rate:** The impact of the risk-free rate is ubiquitous, presenting a dual nature. Firstly, it is intricately linked to numerous calculation formulas on the balance sheet under the Solvency II framework, highlighting its fundamental role in financial assessments. Secondly, as insurers have a natural tendency to invest a large amount of assets in bonds, movements in the risk-free rate will have a more impact on the performance of their portfolios.
- **UC Investments Perform Better:** Under the three climate scenarios, the five-year compounded average investment returns for UC investments and Euro investments are maintained at 8% and - 4%, respectively, from 2022 to 2027. This indicates that UC investments perform better under climate stress scenarios, more precisely in conditions of higher risk-free rates triggered by climate pressure. Since the arbitrage rates are set to be

small and fixed in the stress tests, the increase in the value of the UC investments is clearly not derived from the transmission of EURO but is rather driven by the increase in the market value of the assets. The UC investments and the EURO investments, although both of their bonds' market values are negatively impacted by the high interest rates, the growth potential of UC investments is realized through the appreciation of equity funds and other non-fixed-income assets, thus increasing the overall value of the UC investments. As a result, investment products with greater diversification of asset allocation and growth potential show a comparative advantage in facing the pressures of climate stress.

- **Higher Financial Volatility in Climate Stress Scenarios:** By comparing ORSA Central with the three climate stress test scenarios, it is noticeable that the volatilities of those values, from the assets to the liabilities, and then to solvency, are higher in the climate stress scenarios than the volatilities of the relevant values of the company's regular ORSA stress test. This phenomenon reflects the complex impact of climate change on the financial stability of insurers and highlights the urgency of adjusting at the strategic level. Therefore, insurers must maintain an intensive monitoring on climate risk to ensure financial stability and sustainability.
- **Emphasis on Climate Transition Risks:** Insurance companies must place substantial emphasis on climate transition risks. Even under the Baseline scenario, considered to have the lowest transition risk, the solvency ratio is markedly 14-percentage point lower than the solvency ratio in the company's regular ORSA stress test.
- **Necessity of Monitoring the Long-term Climate Risk:** Although from the solvency ratios, Delayed Transition and Sudden Transition have only a 2-percentage point reduction in solvency compared to the Baseline scenario. It is imperative to consider that this analysis spans only a five-year period from 2022 to 2027 and these results can indeed be considered significant. With the extension and progression of the analysis period, the Delayed Transition and Sudden Transition scenarios are likely to exhibit increasingly concerning solvency issues. Notably, the Delayed Transition and Sudden Transition are regarded as highly probable in the foreseeable future than Baseline scenario.

Conclusions	Insight Source
Focus on the Volatility of the Risk-free Rate	Sec.4.1.2; Sec.4.1.3; Sec.4.1.5; Sec.4.2.2; Sec.4.2.3; Sec.4.2.5
UC Investments Perform Better	Sec.4.1.2; Sec.4.2.2
Higher Financial Volatility in Climate Stress Scenarios	Sec.4.1.2; Sec.4.1.3; Sec.4.1.4; Sec.4.1.5; Sec.4.1.6;
Emphasis on Climate Transition Risks	Sec.4.1.6
Necessity of Monitoring the Long-term Climate Risk	Sec.4.2.6

Table 16: The Links between Conclusions and Insight Source

Chapter 5: Limitations, New Trends, Improvements and Future Work

5.1 Limitations of the Thesis

Although this study helped progress in analyzing the impacts of climate transition risk on a life insurance company, it must be acknowledged that there are inevitable limitations in the research process. Future research might require continued research and optimization in terms of data transparency, model assumptions, methodological innovations, and applications to construct a more robust and adaptive climate risk assessment framework to better respond to the challenges posed by climate change.

- **Limitations on Investment Assumptions:** For the climate scenario shocks to the 86 funds managed by APICIL Epargne, we chose an alternative solution to resolve data deficiencies. To do so, we assumed that the distribution of economic activity sectors across various regions of the funds exhibits uniformity and homogeneity. However, this is a strong assumption, which may not accurately reflect the differences in the distribution of economic activities between regions, thus might lead to biased results in our assessment of the impacts of climate change on the funds. Moreover, in addressing the issue of bond maturities, we assumed that the company would continue to purchase new bonds with the same characteristics such as coupon rate and maturity. However, climate change and its wider impacts on the economy could lead to changes in bond markets, making such reinvestment more difficult to achieve. Hence, the risks associated with bond reinvestment were not thoroughly considered in this stress test. These constraints underscore the pressing need for closer scrutiny of the reinvestment mechanism and the enhancement of data transparency, ensuring that the assessment results provide a more realistic view of the potential impacts of climate risks on investment portfolios.

- **Limitations on Liability Assumptions:** Within the scope of this study's climate stress tests, while the ACPR supplied abundant data relating to market risks, such as inflation rates and risk-free rates, these parameters are essential assumptions for the asset side. Important parameters on the liability side, such as lapse rates and arbitrage rates, were not provided with direct data support and adjustment methods. Estimating accurately lapse rates and arbitrage rates is a complex task influenced by various factors such as policy changes, economic environment, and policyholders’ risk appetite. Due to the lack of extensive data and methodological support based on different climate scenarios, we have not been able to make specific adjustments to such key parameters on the liability side. This limitation reveals an important direction for future work: models need to be constructed such that they include a wider range of climate-related economic and behavioral parameters, thus giving us the ability to assess climate risk more comprehensively.

- **Limitations on the Test Results:** In this study, the Addactis actuarial platform was employed to execute climate stress tests. Nevertheless, one of the intrinsic constraints of the Addactis platform is its inability to conduct climate stress tests beyond a five-year horizon at a single execution. Therefore, the analyses in this thesis only show the results for 2022-2027 based on ACPR's climate stress test scenarios. Meanwhile, the ACPR guidelines allow for adjustments to strategic assumptions after the first five-year climate stress test, including investment share, risk management strategy, reinsurance share, and business distribution, etc. However, due to the limitations of the platform's functionality and the fact that these strategy adjustments require long-term experience and complex calculations, we have not been able to show the results of a strategy-adjusted long-term climate stress test in this study. This limitation suggests that future research needs to employ more powerful simulation tools and a more systematic approach to strategy adjustments to provide a more comprehensive and long-term assessment of climate risk for insurers.

5.2 2023 ACPR Climate Stress Test Introduction

In July 2023, the ACPR released its latest set of climate stress test scenarios. These newly released data exhibit several significant and noteworthy differences compared to the data published by ACPR in 2019. These differences, as well as the still-existing limitations, are elaborated on below:

5.2.1 Changes in Climate Scenarios

The most substantial alteration observed in the ACPR's 2023 climate scenarios is in the assumption of the "Baseline" scenario. The 2023 version of this scenario constructs a hypothetical situation in which the economy faces neither physical nor transition risks, leading to no new climate policies being implemented (excluding the carbon taxes already in effect in 2023). This decision by ACPR aims to more clearly delineate the costs faced by insurance companies under transition risks through comparative analysis.

Moreover, in the new scenarios of ACPR 2023, "Below 2°C" largely corresponds to the "Baseline" scenario of ACPR 2019, and the updated "Delayed policy transition" is essentially aligned with its namesake from the previous edition. Notably, the "Sudden policy transition" scenario is absent in the new ACPR 2023 scenarios. ACPR has not elaborated on the specific reasons for this omission, but it could be surmised that this might be due to the low probability of policy formulation or implementation of the "Sudden policy transition" (which hypothesizes a sudden increase in carbon tax in 2025). The Comparison of ACPR 2019 and ACPR 2023 scenarios is shown in Table 17.

	ACPR 2019 - Long Term Only	**ACPR 2023 - Long Term**	**Comments**
Description of the Scenario	Baseline scenario: The baseline scenario refers to an orderly transition. It assumes that an optimal carbon price is introduced immediately at the start of the climate stress tests. This price increases by about $10 per ton of CO^2 per year until the end of 2050. Because the carbon price is introduced earlier and increases steadily over time, the actual physical and transition risks remain low, and the 2°C climate target can be achieved by 2100.	Baseline: This is a fictitious scenario in which the economy is exposed neither to physical risk nor to transition risk, and which therefore does not give rise to any climate policy (excluding carbon taxes already implemented in 2023).	1.The 2023 exercise takes as its reference the projected evolution of the NIESR Baseline scenario. Using this scenario as the Baseline scenario could better describe the costs of insurers facing transition risk.
	Negative scenario 1: Delayed policy transition scenario. This scenario implies a delay in policy action and mainly describes a situation where a carbon tax is introduced late. According to the NGFS narrative, it is assumed that the 2030 GHG reduction target is not met, and that carbon capture and storage technology is not mature. To be consistent with the goal of reaching carbon neutrality by 2050, the government decides to revise the carbon price.	Below 2°C ： Mostly the same Baseline scenario as ACPR 2019, with data and assumptions updated accordingly.	
	Negative scenario 2: The second negative scenario describes a sudden, earlier-than-expected transition situation that is made worse by the immaturity of technological innovations. It combines an early increase in the carbon price with a productivity shock. In this scenario, the carbon price adjusts unexpectedly and is assumed to reach $184 per ton of CO^2 in 2030, consistent with the carbon trajectory set for a disorderly transition in the NGFS reference scenario. At the same time, it is assumed that low-carbon energy production technologies are less mature than expected in 2025, and the required investment translates into lower productivity gains compared to the baseline scenario.	Delayed policy transition： Mostly the same Delayed policy transition scenario as ACPR 2019, with data and assumptions updated accordingly.	2.Considering national commitments at COP26, recent technological advances in the field of renewable energy, and improvements in physical risk modeling.

Table 17: The Comparison of ACPR 2019 and ACPR 2023 Scenarios

With the addition of the new scenarios in ACPR 2023, a comparison with the IPCC and NGFS climate scenarios is shown below:

IPCC Scenarios	**NGFS Scenarios**	**ACPR Scenarios (2020)**	**ACPR Scenarios (2023 Long Term)**
Very low (SSP1-1.9)	Net Zero 2050		Baseline scenario (no physical risk, no transition risk)
	Below 2°C	Baseline scenario	Below 2°C
	Delayed transition	Delayed policy transition	Delayed policy transition
	Divergent Net Zero	Sudden policy transition	

Table 18: IPCC, NGFS and ACPR Scenarios Related Relationships

***Note**: The correspondences between the different scenarios are not identical or could be said to be only roughly the same. The organizations have modified them accordingly to their own understanding.*

5.2.2 Adding Short-Term Climate Stress Test 2022-2027

In the 2023 climate stress test released by ACPR, a new component has been introduced, focusing on the short-term climate stress test covering the period from 2022 to 2027. The objective of this test is to identify and assess physical risk factors that could potentially impact financial institutions within a shorter timeframe. The specific outline of this added element is as follows:

- Baseline: The short-term scenario is based on a sequence of urgent physical disasters occurring in sequential order of time. First, severe physical disasters (drought/heat wave and localized flooding) occur between 2023 and early 2025, resulting in losses that are primarily the liability of insurance companies. In the second phase, from 2025 to 2027, market shocks begin in the second quarter of 2025.
- Alternative: The short-term scenario is based on a sequence of urgent physical disasters occurring in sequential order of time. First, severe physical disasters (drought/heat wave and localized flooding) occur between 2023 and early 2025, resulting in losses that are primarily the liability of insurance companies. In the second phase, from 2025 to 2027, market shocks begin in the second quarter of 2025.[35]

In comparing the long-term climate stress test of 2019 by ACPR with the newly added short-term climate stress test in 2023, the latter offers a more distinct advantage in measuring physical risks. In the 2019 version, the physical risk is assumed to be relatively high. Its physical risk scenarios are assumed to be consistent with the risks in the IPCC RCP 8.5 scenarios (2023 version is RCP

[35] https://acpr.banque-france.fr/en/communique-de-presse/acpr-launched-its-second-climate-stress-test-covering-insurance-sector-today

4.5). This is not reasonable, because effective climate governance will increase transition risk but decrease physical risk. Therefore, the potential physical risk behind any of the transition scenarios should not be estimated using the highest physical risk scenario.

In contrast, the 2023 ACPR climate stress test framework, by incorporating both short-term and long-term perspectives, successfully differentiates and clarifies physical and transition risks. This approach not only strengthens the logical coherence of the long-term stress test scenarios but also offers a clearer and more precise lens for analyzing and interpreting physical risks and their potential impacts. Through this dual-perspective approach, ACPR 2023 can capture and assess the complex risks posed by climate change across different time scales more comprehensively, thereby enhancing the overall depth and breadth of the climate stress test. The Summary of the ACPR 2023 Short-Term Climate Stress Test is shown in Table 19.

Scenario	Description of the Scenario	Time Horizon	Comparison Analysis
ACPR 2023 - Short Term	Baseline: The short-term scenario is based on a sequence of urgent physical disasters occurring in sequential order of time. First, severe physical disasters (drought/heat wave and localized flooding) occur between 2023 and early 2025, resulting in losses that are primarily the liability of insurance companies. In the second phase, from 2025 to 2027, market shocks begin in the second quarter of 2025.	2022-2027	1. Baseline and Alternative occur in the same context, with Alternative's assumptions being worse. 2. ACPR 2023 added the short-term climate stress test designed to better measure physical risk. 3. Physical risk is assumed to be quite high in ACPR 2019. This is somewhat confusing. However, ACPR 2023 separates physical risk from transition risk by using short term and long term which allows for clearer scenario logic for long term stress test.
	Alternative: The short-term scenario is based on a sequence of urgent physical disasters occurring in sequential order of time. First, severe physical disasters (drought/heat wave and localized flooding) occur between 2023 and early 2025, resulting in losses that are primarily the liability of insurance companies. In the second phase, from 2025 to 2027, market shocks begin in the second quarter of 2025.	2022-2027	

Table 19: The Summary of the ACPR 2023 Short-Term Climate Stress Test

Overall, the 2023 edition of the climate stress test released by ACPR epitomizes the French financial and insurance regulatory body's sustained focus and deepening concern regarding climate change issues. This move signifies not just an important signal to insurance companies but also a call to action. It necessitates that insurance companies intensify their focus on climate issues within crucial domains such as risk management, investment strategies, and strategic planning, while continuously innovating and updating at both theoretical research and technical implementation levels. As climate-related risks evolve, the insurance sector must adapt its business models and strategies to ensure effective and sustained management of these risks in an increasingly complex climate change landscape.

5.2.3 Changes at the Implementation Level

Most of the research in this thesis is based on the ACPR 2019 version of the Climate Stress Test scenarios. However, to help APICIL Epargne implement the latest version of ACPR's Climate Stress Test in 2023, we have made the following operational updates based on the ACPR 2023 Climate Stress Test Guidance:

- For Inflation Rate, we have directly adopted the ACPR 2023 Climate Stress Test scenarios without the need for calibration work.
- For the Risk-Free Rate, we also directly used the ACPR 2023 climate stress test scenario without the need for calibration work.
- For the VA Index, ACPR reduces and consolidates the 55 NACE economic activity sectors in 2019 to 22 NACE economic activity ranges (instead of sectors) in 2023, based on the consistency of their evolutionary paths. For the design of the Equity Fund Shock Program, the logic can still be "an alternative solution" as described in Section 3.4.1.3. It will not be repeated here.

Due to time constraints, the author was not able to input the ACPR 2023 Climate Stress Test scenarios into the Addactis modeling system to simulate the solvency calculations before leaving the company. However, after the author updated the Equity Shock program and prepared the Addactis modeling system input files according to the latest data, colleagues in the Risk Management Department of the APICIL Group have successfully executed the ACPR 2023 Climate Stress Test according to the latest data.

5.2.4 Limitations on ACPR Climate Stress Test

Although, from a comprehensive perspective, the climate stress tests conducted by the ACPR exhibit a high level of data granularity and operability in assessing the risks posed by climate change to the insurance industry, setting a new benchmark for regulatory frameworks, they also reveal some non-negligible limitations during the implementation process. Given their significance, the climate stress test framework of the ACPR and its limitations merit further attention and continuous research from both the industry and academic to ensure a more complete and accurate assessment and management of climate transition risks. The following are the limitations within the ACPR climate stress test framework that warrant attention.

- **Lack of Scenario Research on the Liability Side:** While the ACPR's climate stress test framework has taken detailed consideration of asset-side risks, there is a relative deficiency in the multi-scenario analysis of key parameters on the liability side, such as mortality rates and lapse rates. Under the backdrop of climate change, variations in important assumptions on the liability side could significantly affect the liabilities of insurance companies. Hence, neglecting the potential changes in these parameters under different climate scenarios might result in underestimation or misunderstanding of the actual impacts of climate change on the financial stability of insurance companies.

- **Leniency in the Regulation of Strategic Assumption Adjustments:** The ACPR allows insurance companies to adjust their strategic assumptions such as investment strategy, after the initial five-year climate stress test based on scenario assumptions. Although this offers a degree of flexibility, the lack of stringent regulations on these adjustment methods could lead to regulatory arbitrage, particularly in investment strategy. For instance, to improve the results of their climate stress tests, insurance companies might be inclined to concentrate more investments in sustainable areas. Such a strategy is not only an unrealistic investment approach but might also foster regulatory evasion behaviors. From a market supply and demand perspective, if all insurance companies adopt similar strategies, it could lead to artificial inflation of market values for sustainable investments, thereby undermining the original assumption basis.

- **Timeliness with Data Updates:** The frequency of data updates in the ACPR's climate stress tests is insufficient, with only two updates from 2020 to 2023, failing to reflect the rapid changes in international situations and macroeconomic factors, such as the changes due to the Russian-Ukrainian conflict. If the data provided by the ACPR cannot capture the latest dynamics of the macroeconomy and market conditions promptly, then the expected utility and accuracy of the climate scenario analysis conducted by insurance companies based on these data could be significantly compromised, affecting the effectiveness of the stress tests and, consequently, the rationality of decision-making.

5.3 The Shortcomings and Enhancements of Actuarial Modeling

In this study, the Addactis Modeling software for conducting climate stress tests has been employed. However, due to the software's design constraints, our research was limited to conducting the ORSA simulations in five-year intervals. During our comprehensive climate stress test process, we regrettably found that due to time constraints and certain limitations of the Addactis Modeling software, we were unable to complete the entire test cycle. We attempted to experiment with some alternative methods but encountered stability issues with Addactis Modeling when performing solvency calculations.

Given this context, in addressing the long-term climate stress tests set by ACPR, we suggest that actuarial software providers like Addactis Modeling should consider implementing the following key functional updates in their systems:

- **Extending the Solvency Calculation Period:** expanding the solvency calculation time frame to 30 years is recommended. This would allow for a more comprehensive assessment of the long-term impacts of climate change on the insurance industry.
- **Customizable Asset Shock Parameters:** Introduce features that allow users to customize asset shock parameters. This would enable precise simulations of shocks to assets such as interest rates, stocks, and real estate, tailored to specific regional and industry needs.
- **Adding Strategic Assumption Input Channels:** Develop new input channels for future business plans, risk management strategies, and other key strategic assumptions. This enhancement would clarify and streamline strategic management, increasing the model's flexibility and adaptability.

These improvements would significantly enhance the stability and reliability of the model, thereby more effectively supporting insurance companies in their decision-making processes in response to the challenges posed by climate change.

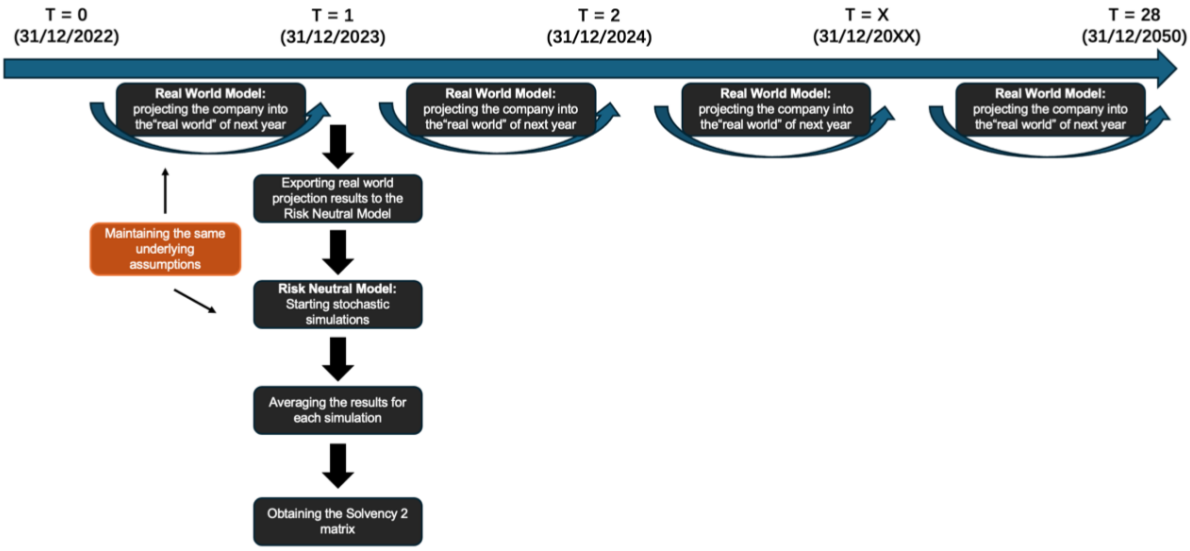

Figure 71: Climate Stress Test Complete Workflow

Next, we provide a more detailed description of the modeling framework that would be suitable for ACPR's climate stress test, combined with figures. As shown in Figure 71, at a general level, the implementation of a climate stress test requires the creation of two separate models, the "Real World" model and the "Risk Neutral" model. It is important to note that the underlying core structure of both models is based on the ALM (Asset-Liability Management) model from insurance companies, and they also need to have the ability to calculate the assumptions based on different economic activity sectors and regions. The main difference between "Real World" and "Risk Neutral" models is that the task of the "Real World" model is to project the state of the company from year N to year N+1 in a deterministic way based on a specific set of assumptions, whereas the task of the "Risk Neutral" model is to generate numerous possible economic scenarios in risk neutral measure [36]using stochastic simulation techniques based on the state of the company in year N+1 and then to evaluate the impact of these scenarios on the financial and solvency status of the company. Note that the assumptions for each year of the "Real World" and "Risk Neutral" models need to be consistent. In the context of the climate stress test, given its characteristic of extensive time horizon, it is necessary to sequentially execute the climate stress test for each year, subsequently progressing to the next year. This procedure is to be iteratively conducted, covering the entire duration of the testing period. By adopting this year-by-year incremental approach, a comprehensive set of climate stress test outcomes could be obtained. The process for a single year of climate stress test is shown in Figure 72:

[36] The risk neutral measure is defined based on the no-arbitrage assumption, which ensures that there are no risk-free arbitrage opportunities in the market. Consequently, there exists a unique probability measure that assigns a positive probability to all potential market events, thereby ensuring the market's completeness and transparency. Under the risk neutral measure, discounted asset prices follow a Markov process, meaning that the future price of an asset depends only on its current state, independent of its past trajectory. In this measure, the theoretical price of a financial asset is equal to the expected present value of its future cash flows, calculated under the assumption that market participants are neutral towards risk.

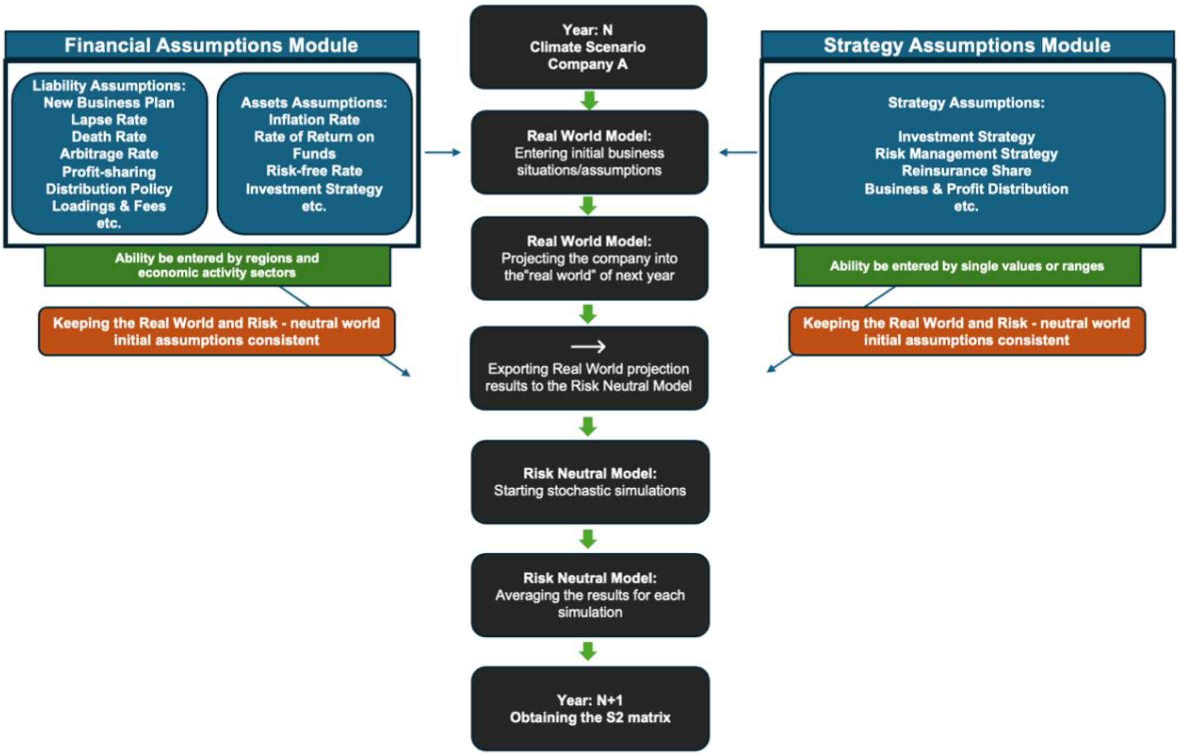

Figure 72: Single Year Climate Stress Test Process

The detailed single year climate stress test execution workflow is described below:

1. **Entering initial business situations/assumptions (Year N, Real World Model).** The business situations mainly include balance sheet, income statement, investment portfolio information, insured portfolio information, etc. The Assumptions Module is divided into the Financial Assumptions Module and the Strategy Assumptions Module. In the Financial Assumptions Module, the assumptions for the assets side include Inflation Rate, Rate of Return on Funds, Risk-free Rate, Investment Strategy, etc. and the assumptions for the liabilities side include New Business Plan, Lapse Rate, Death Rate, Arbitrage Rate, Profit-sharing Distribution Policy, Charges & Fees etc. Note that this module needs to have interfaces to transfer assumptions for different economic activity sectors and regions to the core calculation model. In the Strategy Assumptions Module, the company could input Investment Strategy, Risk Management Strategy, Reinsurance Share, Business & Profit based on the expected macro environment and company situation. These assumptions might currently be individual values. However, in the future, as the computing power is upgraded, these assumptions might be a range of values, i.e., the optimal strategy is achieved by cyclic simulations under certain conditions.

2. **Projecting the company into the "Real World" of next year (Year N+1, Real World Model).** In this phase, based on the assumptions that are entered in the first step, the model projects the company's various corporate financial metrics for the next fiscal year, including, but not

limited to, balance sheet, income statement, investments, and portfolio of insureds.

3. **Exporting Real World projection results to the Risk Neutral Model (Year N+1).** In migrating the Real World projection results to the Risk Neutral Model, it is important to ensure that the initial assumptions are consistent between the two models. This means that the Risk Neutral Model revaluates the performance of the financial metrics in a risk neutral environment without changing the asset-liability structure, and financial and strategy assumptions.

4. **Starting stochastic simulations (Year N+1, Risk Neutral Model).** In this step, the model generates many possible economic scenarios through stochastic simulation techniques, such as Monte Carlo simulation, to adequately simulate the cash flows of the firm's assets and liabilities over the time horizon of the demise of the liability portfolio.

5. **Averaging the results for each simulation (Year N+1, Risk Neutral Model).** The model calculates the average results for each simulation to reduce the chance of a single scenario and to improve the robustness and reliability of the model predictions.

6. **Obtaining the Solvency 2 matrix (Year N+1, Risk Neutral Model).** Eventually, the Solvency 2 matrix is derived based on simulations in the risk neutral world.

Insurance companies or actuarial software providers could build on their existing ALM models to develop climate stress test systems with long-range forecasting capabilities and higher granularity inputs to assess the potential impact of climate change on a company's future financial and solvency status. Because of the long-term nature of climate stress tests, it is nearly impossible to adjust the core strategic assumptions for the following year based on the results of each year's climate stress test. To achieve the balance between time efficiency and assessment accuracy, it is proposed to adopt a five-year cycle climate stress test structure. As illustrated in Figure 73, at the end of each assessment cycle, the insurer should reevaluate and adjust its core strategic assumptions based on the results from the previous cycle. Subsequently, the insurer conducts the climate stress test again for the next five-year cycle. The above descriptions are the modeling frameworks that are suitable for the ACPR climate stress test.

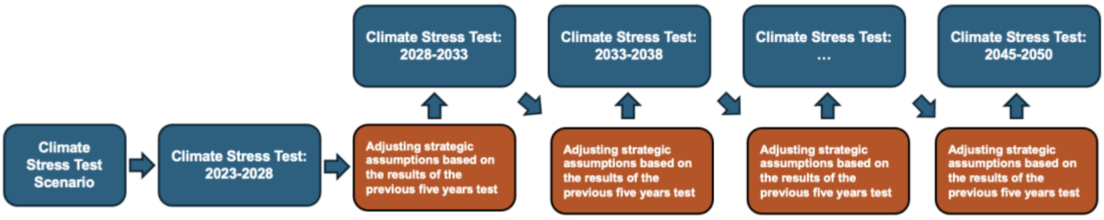

Figure 73: Recommended Climate Stress Test Process

In the implementation of climate stress tests for life insurance companies, simulation-based valuation methods play a crucial role in the construction of a more accurate and robust financial and solvency valuation system. Given the strong interaction between assets and liabilities of life insurance companies and the long periods involved in climate stress tests, we do not recommend any oversimplified valuation methodology. For example, for the calculation of the Best Estimate Liability (BEL), although the European Commission has proposed in Article 60 of "RÈGLEMENT DÉLÉGUÉ (UE) 2015/35"[37] a method of cash flow forecasting based on the premium adjustment mechanism, which assumes that the growth of claims and loadings will be in line with the premium adjustment. However, such a simplified approach might be more appropriate for the estimation of liabilities for non-life insurers, especially under conditions where there is a lack of significant dynamic interaction between assets and liabilities. Clearly, the methodology is not appropriate for life insurance companies. In the context of long period climate stress tests, the application of such a method could lead to significant distortions in assessment results.

5.4 More Comprehensive and Detailed Efforts

Given the wide-ranging impacts and profound effects of climate risk, its management and assessment demand long-term tracking and in-depth research across multiple domains. In exploring climate risk-related issues, it is imperative not only for a single company's risk department to focus, but also for the entire organization to engage collectively and continuously efforts.

Taking the departments involved in this research as an example: In conducting climate risk studies, it involves the company's performance department (responsible for formulating future business plans), the technical department (executing actuarial pricing calculations), and the investment department (determining investment strategies). Each department must collaboratively formulate and adjust the company's long-term strategy based on the initial results of the climate stress test.

Specifically, the performance, technical, and investment departments need to replan the company's business development strategies, actuarial assessment parameters, and investment

[37] RÈGLEMENT DÉLÉGUÉ (UE) 2015/35 DE LA COMMISSION. (2015). *Journal Officiel de l'Union Européenne*.

strategies based on the preliminary results of the climate stress test provided by the risk department. These revised plans are then submitted to the risk management department for further climate risk assessment, ensuring that the strategies meet both internal corporate and regulatory standards. This represents a dynamic balancing process, requiring a deep understanding, recognition, and technical capability within each relevant department to effectively assess and manage climate risks.

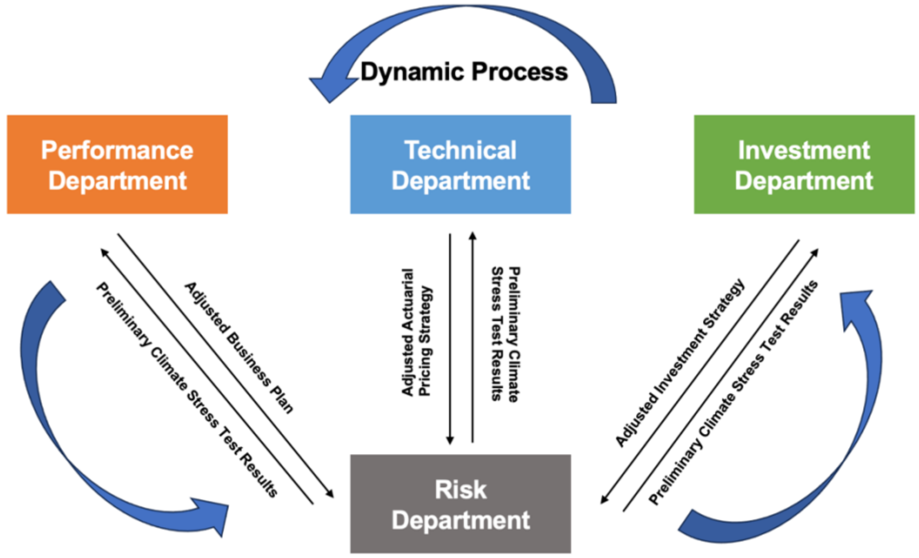

Figure 74: A Dynamic Process needed for An Insurance Company to Manage Cliamte Risk

Conclusion

The primary objective of this study was to thoroughly delineate the execution process of climate stress test and assess the impact of three climate scenarios set by the ACPR on the solvency of a life insurance company.

After an in-depth analysis of the research outcomes of authoritative bodies such as IPCC, NGFS, and ACPR, it was observed that the climate stress scenarios they offer differ significantly in terms of data detail and type. Both the IPCC and NGFS provide regional-level data, yet the former focuses more on measuring ecological impacts, while the latter emphasizes macroeconomic effects. In contrast, ACPR's data exhibits finer granularity and specificity, particularly in the segmentation of economic sectors, aligning perfectly with the current trends in sustainable finance regulations. Hence, considering operability and adaptability, ACPR’s climate scenarios are deemed more appropriate for French insurance companies.

In the preparatory phase of implementing ACPR's climate stress test, considerable and meticulous adjustments are required in areas such as risk-free interest rates, value added index, and inflation rates. The outcomes of the climate stress test reveal that, even under the Baseline Scenario with relatively lower climate transition risks, the solvency ratio of the tested life insurance company decreased from an original 188% to 174% as of 2027, marking a significant 14 percentage point drop compared to the results of the regular ORSA stress test. This underlines the imperative for insurance companies to intensify their focus on climate issues.

Given the long-term nature of climate stress tests, it is suggested that actuarial software providers extend the timeframe for solvency calculations, introduce more flexible asset shock parameters, and develop new input channels for future business plans and risk management strategies, thus enhancing the adaptability and flexibility of the model. Moreover, effective climate risk management requires cross-departmental collaboration, involving performance, technical, and investment departments, to collaboratively adjust strategies based on initial climate stress test results, ensuring efficient assessment and management of climate risks.

The 2023 edition of ACPR’s climate stress test showcases the regulator's escalating attention to climate change issues. This not only signals a strong call to action for insurance companies but also demands continuous innovation and updates in critical areas such as risk management, investment strategy, and strategic planning. Climate problems are a long-term and complex research task. Given numerous limitations and uncertainties that still exist, it requires sustained attention, continued investment and in-depth research by the insurance industry and academia.

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