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Public Debt and Climate-Related Natural Disasters in South Europe

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Public Debt and Climate-Related Natural Disasters in South Europe

By

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This is dedicated to the memories of my father Efstratios Podimatis and my older brother Panagiotis Kavros.

Executive Summary

This Master Thesis scope is to explore the relationship between public debt and climate related natural disasters in South Europe. The following outline describes the main parts and key findings of this research.

Chapter 1 introduces the central theme of the thesis, which examines the fiscal implications of climate change on Southern European countries, specifically Greece, Italy, Spain, and Portugal. It provides an overview of the significance of studying the intersection of climate change and fiscal policy, laying the groundwork for the subsequent chapters. The chapter highlights the necessity of integrating climate resilience into economic planning to mitigate long-term fiscal risks.

In Chapter 2, the literature review explores existing research on the economic impacts of climate change, fiscal policy frameworks, and debt sustainability. It synthesizes findings from numerous studies to establish a comprehensive understanding of how climate-induced natural disasters influence public debt and economic stability. Key theories and models around the most crucial factors of a Debt Loop are discussed, providing a theoretical foundation for the analysis conducted in later chapters.

Chapter 3 outlines the methodological approach used to analyze the fiscal impacts of climate change. It includes details about the data sources, analytical models, scenario analysis techniques and the necessary assumption that were employed to project future economic and fiscal outcomes for the countries of South Europe. The methodology section ensures the robustness and reliability of the study's findings by adhering to rigorous research standards.

Chapter 4 presents the direct and indirect fiscal consequences of climate-related natural disasters through elaborate graphs and summary tables. All scenarios and climatic combinations are demonstrated with best and worst outcome for each country's projections. More specifically, it discusses how increased frequency and severity of such events lead to higher public expenditures on disaster response, recovery, and adaptation measures. The chapter also examines the strain on public finances due to reduced economic growth and increased borrowing costs, creating a vicious cycle of debt accumulation.

Within Chapter 5, it is provided a detailed comparative analysis of Greece, Italy, Spain, and Portugal, highlighting their unique vulnerabilities and fiscal challenges in the face of climate change. Moreover, a discussion about the current fiscal framework revision and an aggregated comparison of Germany and the South Europe are included before proceeding to policy recommendations

Finally in Chapter 6, the thesis concludes with policy proposals to enhance fiscal resilience and sustainability in Southern European countries. It emphasizes the need for tailored fiscal rules that account for climate risks, reassessment of the current framework to avoid inequality phenomena, increased investment in climate adaptation and mitigation, and the establishment of fiscal buffers. The recommendations aim to balance economic growth with proactive climate action but also repairing nature in order to ensure long-term fiscal stability and reduced impacts of climate change.

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List of Abbreviations

Word	Meaning
COACCH	CO-designing the Assessment of Climate Change
ECB	European Central Bank
EPIC	Environmental Policy Integrated Climate
GHG	Greenhouse Gas
IAC	Integrated Assessment Consortium
IAM	Integrated Assessment Model
IIASA	International Institute for Applied Systems Analysis
IMF	International Monetary Fund
LPMjL	Lund-Potsdam-Jena managed Land
NGFS	Network for Greening the Financial System
NOAA	National Oceanic and Atmospheric Administration
OECD	Organization for Economic Co-operation and Development
RCP	Representative Concentration Pathway
SSP	Shared Socioeconomic Pathways

1. Climate damages and South Europe debt vulnerability

1.1 Introduction

Climate Change has made its presence ever clearer in recent times. We have already experienced the effects of climate change through severe weather events, including forest fires, hurricanes, droughts, heat waves, floods, and storms. These extreme weather events have struck the economies all over the globe, including Europe (European Environmental Agency, 2023). As the Nobel Prize winning climate economist William D. Nordhaus (2018) observed in his Prize lecture: "*Climate change threatens, in the most extreme scenarios, to return us economically whence we came*. "Climate change therefore stands as one of the most important challenges that the world must face.

Hundreds of the world's leading climate scientists expect global temperatures to rise to at least 2.5C above preindustrial levels this century, which will likely lead to catastrophic consequences for humanity, with famines, conflicts and mass migration, driven by heatwaves, wildfires, floods and storms of an intensity and frequency far beyond those that have already struck (Carrington, 2024).

In addition to the direct damage of climate change to livelihoods and individual economic activity, natural disasters can significantly impact the government finances in several ways (Agarwala, Burke, Doherty-Bigara, Klusak, & Mohaddes, 2024). Economic slowdowns following disasters can lead to decreased tax revenue due to reduced economic activity, including lower imports and exports. Although external assistance may help offset some of these losses, it is unlikely to fully cover the shortfall. Additionally, government-owned enterprises may suffer losses due to disasters, further straining government finances (Benson & Clay, 2004). Government revenue will be affected by structural change which includes the medium- and long-term impacts through climate adaptation and necessary mitigation measures (Feyen, Utz, Huertas, Bogdan, & Moon, 2020). These events often require extra funds or the reshuffling of existing budgets to cover the costs of repairing public infrastructure and aiding affected individuals. This can result in delays or cancellations of planned projects, budgetary cuts to public services, and postponements of salary increases and hiring. Projects in progress may also face delays, leading to higher overall costs. Furthermore, the aftermath of a disaster constrains administrative resources even further.

Over the past decade, climate change has also significantly affected financial markets, leading to a rise in financial stability ((Giuzio, et al., 2019), (Pagnottoni, Spelta, Flori, & Fabio Pammolli, 2022). For this reason, central banks have created and established the Network for Greening the Financial System (NGFS) in order to map and risk lying ahead. Nevertheless, climate risk is often mispriced, mismanaged, or ignored altogether by financial markets, regulators, and policy makers. An explanation for this is the fact the current models fail to extract precise results and capture the magnitude of risks for the financial institutions and the national economies (Speer, 2023) (Trust, Joshi, Lenton, & Oliver, 2023). It is evident that a more comprehensive and systematic examination is needed to reconsider how disasters are understood, and their impacts assessed within economic analysis frameworks (Benson & Clay, 2004).

1.2 Climate Damages

Natural disasters stemming from climate change have emerged as events that detrimentally impact both financial markets and real-world economies (Mallucci, 2022). In their research, Panwar and Sen have presented the following graph which accumulates the damages both in physical and financial aspect (Panwar & Sen, 2019). In Figure 1-1, depicts the number of catastrophic events occurring between 1980 and 2015 on the left axis, while the right axis shows the absolute number of people affected (in Millions) and the economic damages incurred (in $ billions). The lines are illustrating an evident inclining trend in the number of catastrophic events but also on the economic damages as new peaks are noted every approximately 10 years. This is just one of the many examples that depict the acceleration of climate damage and with it the rise of extreme economic losses from these types of events.

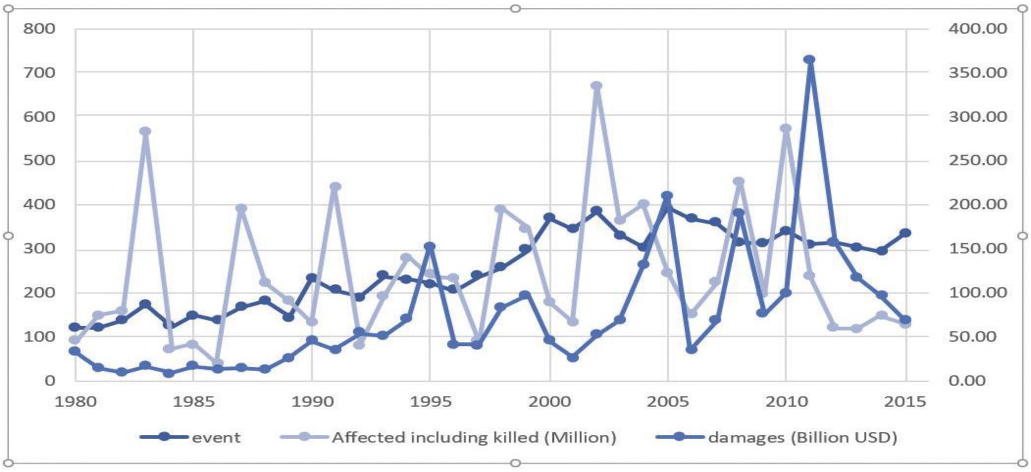

Figure 1-1:Trends in Damages from Natural Disasters Worldwide, 1980–2015 (Panwar & Sen, 2019)

Recent data from the U.S. National Oceanic and Atmospheric Administration (NOAA) shows an increasing trend on the damages and events that took place during 2023 and in general over the last decade (since 2011).

To be more specific, 2023 was the fourth consecutive year with damage events costing more than $18 billion in the US. This number reached 28 (events) this year, which is a new record for the US. The rising trend can be seen more clearly in

Figure 1-2. As with every year in the 2020s, 2023 was marked by a high frequency, significant cost, and wide variety of extreme events that impacted people's lives and livelihoods. In 2023 (indicated by the red line), the U.S. experienced eighteen or more separate billion-dollar disaster events for the fourth consecutive year (2020-2023), establishing a consistent and concerning trend. Historically, the annual average from 1980 to 2023 (black line) was eight events (adjusted for inflation), whereas the average for the most recent five years (2019-2023) has surged to approximately twenty events.

Presenting natural disasters data from the US is crucial for illustrating the global impacts of climate change due to its massive geographic entity and the diverse range of events it experiences, such as hurricanes, wildfires, floods, and droughts. In addition, the responses and policies implemented in the US can serve as examples for other countries, while the visibility and influence of the US in global politics and media help raise international awareness and encourage coordinated action against climate change.

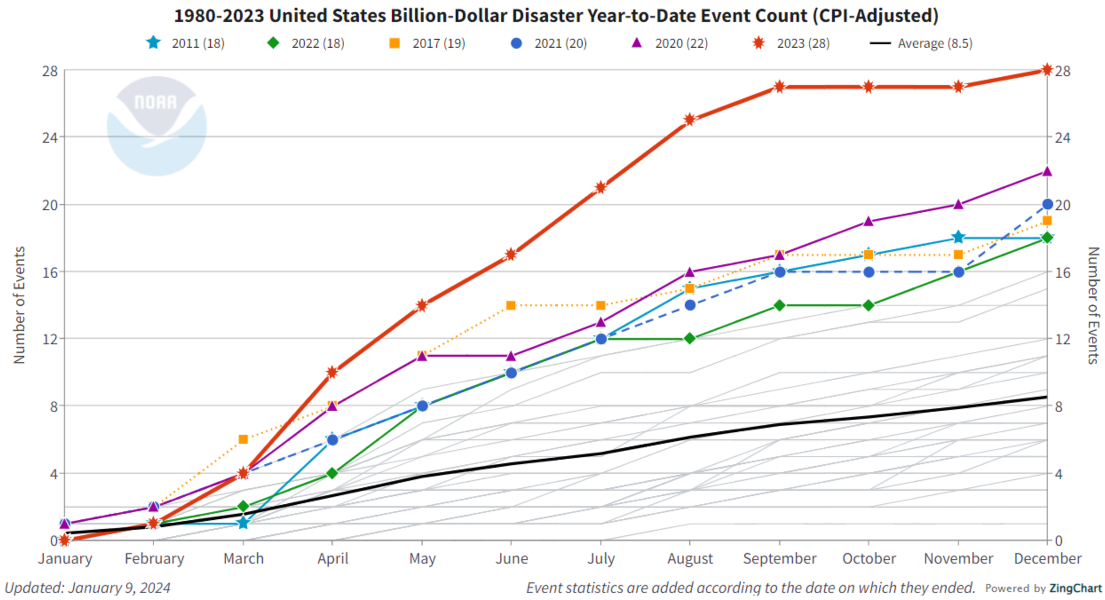

Figure 1-2:US Billion-dollar Disaster events in US (Smith, 2024)

Moreover, in order to put some perspective to the actual quantitative economic losses, the NOAA reports that the total cost of U.S. billion-dollar disasters over the last 5 years (2019-2023) is $603.1 billion, with a 5-year annual cost average of $120.6 billion, the latter of which is more than double the 44-year inflation-adjusted annual average cost. The U.S. billion-dollar disaster damage costs over the last 10-years (2014-2023) were also historically large: at least $1.2 trillion from 173 separate billion-dollar events (Smith, 2024).

In the European Union, natural disasters in 2023 did cost a total of €27 Billion. which is a new record high for the EU (Munich RE, 2024). For the years of the decade of the 2020's, this account already reaches 0,15% of the GDP of the countries of the European Union (EU27). In Figure 1-3 , according to data from the EM-DAT institute, this number is higher in comparison to the previous decades, although it still accounts for only a small portion of EU's GDP.

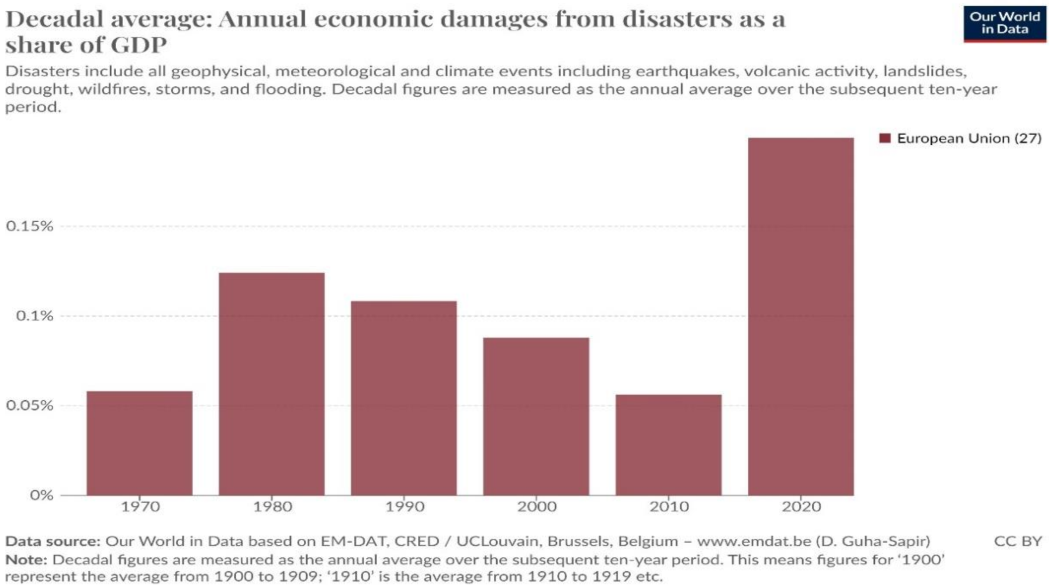

Figure 1-3: Annual Economic Damages from disasters as a share of GDP of the EU-27 (Ritchie & Rosado, 2024)

It is important to clarify that the contribution of geophysical related disasters is limited as they are not connected to ongoing climate change. Figure 1-4 presents data on total economic damages from the disasters (as a percent of GDP) for the countries of Southern Europe

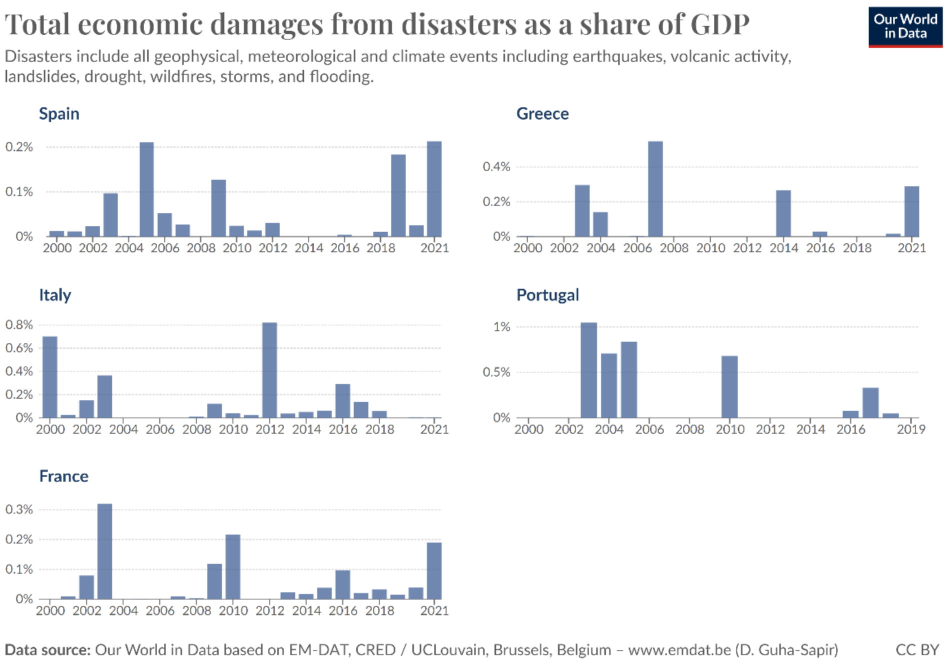

Figure 1-4: Total Economic Damages from disasters as a share of GDP (Ritchie & Rosado, 2024)

Four out of five countries of South Europe have experienced years where damages have reached at least 0,4% of their GDP. The only country according to the data that has not exceeded the threshold of 0,4% is Spain which was impacted by more frequent extreme weather events but less significant from an economic perspective. On the other hand, it is noticeable that Portugal losses are the highest as percentage of GDP, while Italy comes second in the economic losses percentages.

It is important to highlight that the above figures do not include the record-breaking years of 2022, and 2023, when rising damages exhausted the EU's Solidarity and Emergency Aid Reserve. Furthermore, extreme weather events are increasing both in frequency and intensity leading to deep fiscal damages. To be more specific, the July 2021 floods in the Benelux area and Germany are estimated to have cost € 44 billion and the August 2023 floods in Slovenia resulted in damages equivalent up to 16% of the national GDP (European Environment Change, 2024). In 2023, large-scale wildfires, heatwaves and floods have impacted Greece, Italy and Spain. The 2023 wildfires in Greece were attributed a total cost of € 1,66 billion and the floods added on the final account another € 2 billion in damages (Koutantou & Maltezou, 2023). According to Scope Ratings report (Figure 1-5) about the future projections of wildfire damage in Greece, risks will increase with more frequent and damaging outbreaks (Scope Ratings, 2023).

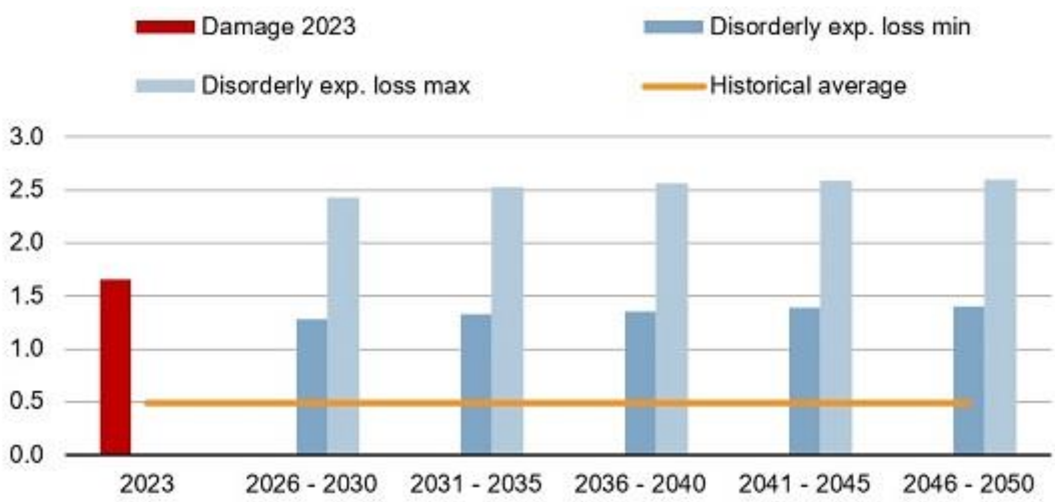

Figure 1-5: Projected yearly wildfire damage (in € billions) in Greece using expected loss method (Scope Ratings, 2023).

As climates change is now considered to be a major risk to public finances, insurers and financial markets in general, it is projected that it will only increase in the future and along with it the inflicted damages. Between 1980 and 2022, climate-related extremes resulted in an estimated € 650 billion in damages (at 2022 prices) in the EU. Hydrological hazards, primarily floods, contributed to nearly 43% of the total, while meteorological hazards, including storms, lightning, hail, and mass movements, accounted for approximately 29%. Climatological hazards, such as heat waves, constituted around 20% of the losses, with the remaining approximately 8% attributed to droughts, forest fires, and cold waves combined. Notable costly events during this period include the 2021 flooding in Germany and Belgium (€ 44 billion), the 2022 compound drought and heat events across the continent (€ 40 billion), the 2002 flood in central Europe (€ 34 billion), the 1999 storm Lothar in Western Europe (€ 17 billion), the 2003 drought and heatwave across the EU (€ 17 billion), and the 2000 flood in France and Italy (€ 14 billion), all adjusted to 2022 prices (European Environmental Agency, 2023).

Even though only 5% of events are responsible for 59% of the cumulative inflicted damage during 1980-2022, the average annual losses, adjusted to constant 2022 prices, were approximately € 10.4 billion in the period of 1981-1990, € 12.2 billion in 1991-2000, € 14.7 billion in 2001-2010, and € 15.9 billion in 2011-2020. Notably, the years 2021 and 2022 recorded the highest annual values for the entire time series, amounting to € 59.4 billion and € 52.3 billion, respectively, followed closely by 2002, 1999, and 1990. Moreover, statistical analysis of a 30-year moving average reveals a consistent increase in economic losses over the years (European Environmental Agency, 2023). The above-mentioned costs can be even higher considering the underreporting of direct economic costs in relevant databases. Furthermore, there are many implications which are connected to indirect economic impacts that can affect the growth of a country (Botzen, Deschenes, & Sanders, 2019).

Focusing on Europe and more specifically on Southern Europe, the Mediterranean region has faced significant challenges due to reduced rainfall, rising temperatures, wildfires and the ongoing effects of climate change. These trends are predicted to exacerbate in the future. Key consequences include less water for drinking and agriculture, lower crop yields, heightened risks of droughts, loss of biodiversity, more frequent forest fires and heatwaves. Although improving irrigation methods in farming can help, it will not fully offset the increased strain on water resources caused by climate change (European Comission, n.d.). Additionally, the hydropower industry will face difficulties due to reduced water availability and higher energy demands, while the summer tourism season may become less attractive. Climate change and socio-economic factors also threaten the essential flow of water needed to sustain aquatic ecosystems (European Comission, n.d.).

Some of the main indirect effects can be attributed to the economic losses of different industries which are directly hit by natural disasters and therefore climate change. Tourism is one of the most thriving industries in South Europe. According to recent reports, its contribution to the GDP of the European Union is close to € 1,2 Trillion (World Travel & Tourism Council , 2023). This impact is translated to almost 20% of the economic output of Greece, 12% for Spain and 9% for Italy (Stüve, 2023). While Tourism is back to pre-pandemic levels, climate change is threatening its future growth and subsequently the economic output and revenues of the countries of the South (Thierie, 2024).

In their empirical research, Antonakakis et al. (2014) have demonstrated that a country can experience both tourism-led and tourism-driven growth and this phenomenon is more pronounced for Cyprus, Greece, Portugal and Spain, which are the European countries that have witnessed the greatest economic downturn since 2009. Tourism-led economic growth (TLEG) suggests that the expansion of the tourism sector directly stimulates broader economic development by increasing foreign exchange earnings, attracting investments, creating employment, and achieving economies of scale. On the other hand, economic-driven tourism growth (EDTG) suggests that overall economic growth and effective policies are the primary catalysts for tourism expansion, as they improve infrastructure, governance, and disposable income, which in turn attract more tourists. The relationship between these dynamics can vary over time and be influenced by significant economic events, highlighting the need for context-specific policy approaches. While TLEG emphasizes direct promotion of tourism, EDTG focuses on holistic economic development to support the tourism sector indirectly. Future climate challenges will apply pressure in both TLEG and EDTG economies and possibly minimize their positive economic effect.

Furthermore, when countries aim to reduce fiscal deficits and address budget shortfalls, it can inadvertently impact tourism activity. For example, limited funding and infrastructure may deter tourists. All this evidence is directly pointing to the extended but mostly lagging effect that a sudden disaster as a consequence of climate change can fundamentally change the economic projections of growth, revenues and public debt. The natural question that arises from the foregoing discussion is how these weather-related catastrophes translate into economic costs.

1.3 Southern Europe's Debt Crisis

According to the International Monetary Fund, if growth is reduced, fiscal sustainability issues are likely to be exacerbated with further adverse consequences for both the public debt and the capital accumulation (Kumar & Woo, 2010). Stagnating growth is the result of more than 15 years of economic turbulence in the Eurozone area. The Great Financial Crisis, the Covid-19 Pandemic and the most recent energy/inflation crisis have all contributed to this outcome.

The current situation regarding the Southern European countries and their debt is the following according to Eurostat data, presented in Figure 1-6.

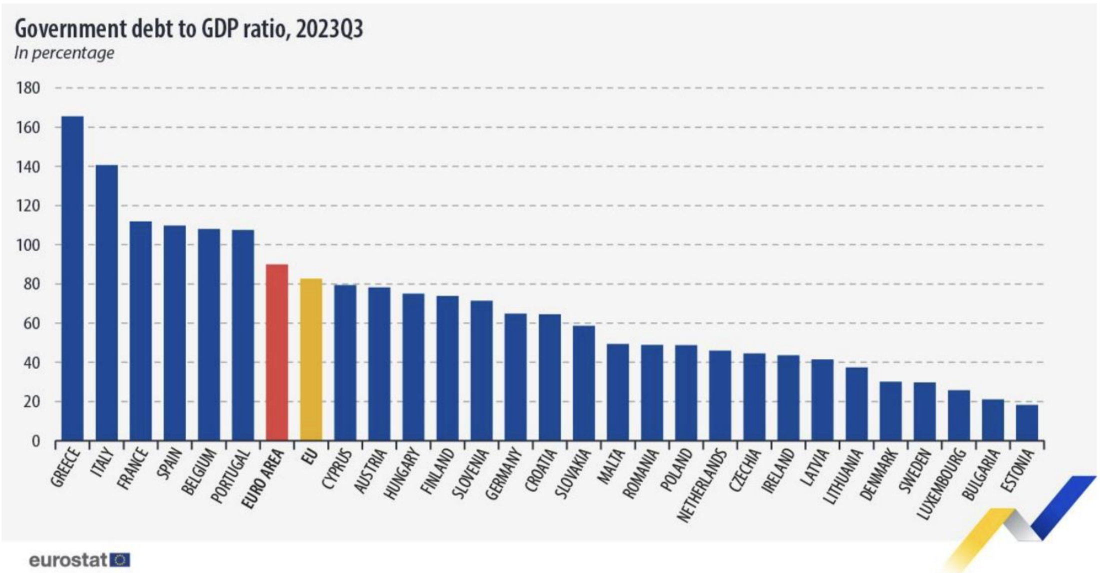

Figure 1-6 : Public Debt to GDP ratio (Eurostat, 2023)

The debt levels in the Southern countries are well above the median of the Eurozone and European Union. As the European's South Debt has increased over the years due to a variety of reasons which will not be the focus of this Master Thesis, it is undeniable that the external shocks of the recurring climate inflicted natural disasters will be adding an extra burden on these already troubled economies.

It is important to highlight that the debt crisis does not completely belong in the past and wrong policy maneuvers and political misjudgments of the situation can easily change the course of the national economies of the South. First, public finances are in a worse state than at the peak of the previous sovereign debt crisis. For instance, Greece's Debt/GDP ratio which stood at 127% in 2009 has ballooned to 211% in 2020. The pandemic and the inflation aftermath combined with other exogenous shocks such as the conflict in Ukraine, have put a strain in governments leading to bigger expenditures than revenue. In addition, in early 2022 after years of stability in the interest rates of Euro, the ECB has started a series of increases which as a result has increased the borrowing costs for every country in the Eurozone. The vulnerability of the bonds of Southern-European states to fire-sales from investors who sense the turmoil in the market makes the situation worse from time to time due to the fiscal constraints that the countries of the South are facing. The recent turbulence in financial markets highlights the ongoing challenge identified by economists Ignazio Angeloni and Daniel Gros as the "centrifugal forces" between core and peripheral countries within the eurozone (Gros & Angeloni, 2021). These tensions pose a continuous threat to the unity of the currency union and stem from an inherent structural flaw that has yet to be effectively addressed (Krecke, 2022`).

Following the rise of inflation, the bond markets showed volatile movements during the rise of the interest rates from ECB with great speculation going forward. Figure 1-7 presents the spreads of 10-Year government bonds of Portugal, Italy, Greece and Spain vs the traditionally best performing country in Eurozone, Germany.

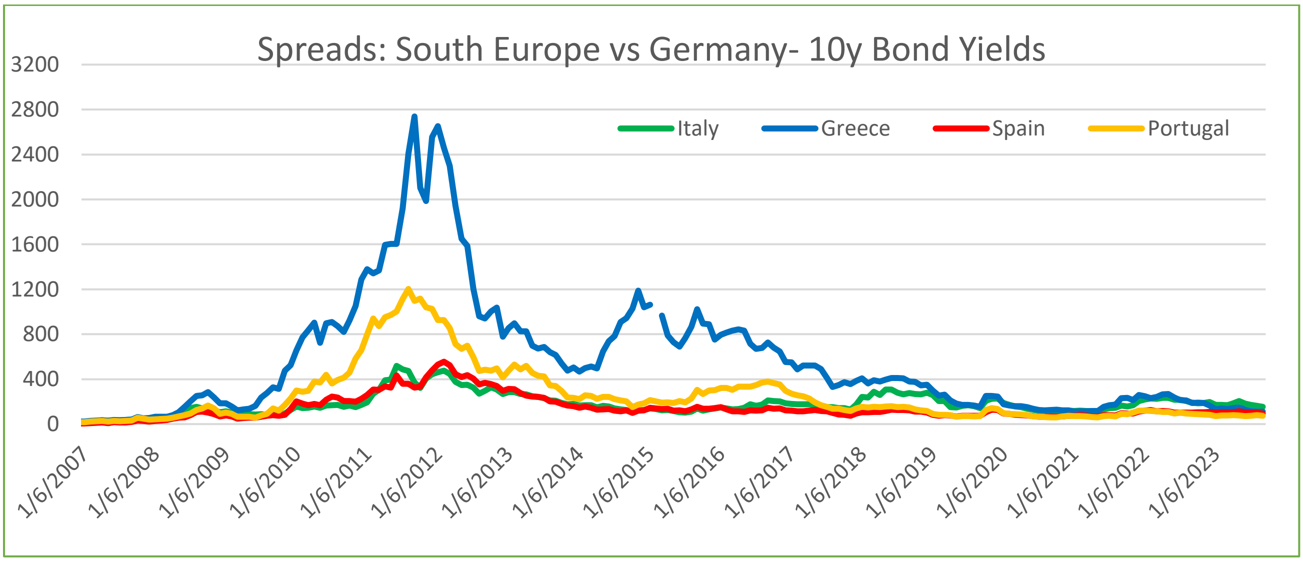

Figure 1-7: Spreads: South Europe vs Germany 10 Year Bond Yields (Federal Reserce Bank of St. Luis, 2024)

Neglecting the turbulent decade of 2009-2019, it is noticeable that the countries of the South have closed the gap between them and Eurozone's leading economy Germany. The Pandemic has pushed and urged for action from the ECB and led to the Pandemic Emergency Purchase Program (PEPP) which boosted the yields of Southern-

European states to almost identical levels with each other, increased their competitiveness and calmed investors in the markets (European Central Bank, 2024). Nevertheless, this emergency program cannot be sustained as other external shocks came up like the continuing war between Russia and Ukraine which led to rising energy and food prices and accelerating inflation in the EU.

Towards the end of 2023 the EU has finally agreed on the new set of Fiscal Rules after lengthy discussions. According to recent ABN-AMRO reports (2024), the EU will maintain the old benchmarks but allowing for a less restrictive path to reach them. This adjustment could still demand significant fiscal efforts, especially for heavily indebted countries, potentially leading to recession and social tensions if implemented hastily. Adherence to these rules is incentivized by the possibility of ECB support through asset purchases, available only to compliant countries. Failure to meet these rules may result in higher bond yields. Overall, the combination of new fiscal rules and EU/ECB conditionalities is expected to encourage countries to improve public finances, potentially leading to long-term spread tightening as risk premia decrease (Schuiling & Renoult, 2024). The strike back from the South regarding its continuous fiscal recovery has been verified by the constant credit rating improvement of Greece, Portugal, Spain, and Italy which are experiencing debt reduction and economic recovery, improving their borrowing ratings and debt ratios (Bienvenu, 2023).

Even though projections and positive news are pushing the Southern European governments towards a normality in their fiscal situations, there are still steps (if not leaps) to be made in the right direction before it will be viable to speak of a total recovery of the financial situation in Southern Europe. IMF's recent statement in April (2024) mentioned that regarding Italy's fiscal situation, while expansionary fiscal policies have supported the recovery, they have also contributed to keeping deficits and debt elevated.

To address this, faster fiscal adjustment is needed while maintaining a sizable primary surplus to reverse the debt trend. This adjustment is crucial for reducing financing risks and ensuring debt sustainability. Additionally, structural reforms aimed at boosting productivity and growth are necessary to support long-term fiscal stability (IMF, 2024). Moreover, IMF projections in the recently published World Economic Outlook (2024), show that Spain's public debt and fiscal deficits will remain at the same high levels until the end of the decade despite the fact that Spanish GDP will grow significantly. Last but not least, Greece may be among the leaders in growth and public debt reduction, especially because it is experiencing a grace period until 2032 when further measures may be needed to keep the deb sustainable as the country is now favored by very low interest rates due to the fact that 86% of its debt is held by official institutions such as IMF, ECB, Central Banks and ESM (Wijffelaars, 2018). It is important to note that despite structural reforms that are taking place in the troubled economies of the South, external shocks (including those due to global warming) can impact fiscal plans.

Risk premiums on sovereign bonds are individual for each Eurozone country and one of the factors that can derail their debt repayment and financing needs schedule. Risk premium is the excessive return that investors are compensated when investing in Bonds that differ from the standard risk-free rate. In contrast to a systemic risk like inflation or the ongoing energy crisis, the premium individual risk entails the uncertainty for a country to be creditworthy. This risk can be heavily affected by the external shocks related to a climate inflicted natural disaster. In consequence the continuous rise of premium can cause a feedback loop of constant credit downgrades and even higher bond return yields which eventually will hinder the country's entrance to the international money markets (Amstad, Remolona, & Shek, 2016).

According to Raddatz et al. (2009) the impact of diverse types of disasters does not correlate with the level of external debt. This conclusion holds true even when distinguishing between several types of climatic disasters such as droughts, extreme temperatures, floods, and windstorms. There is no clear differential response observed among countries with varying levels of indebtedness for any type of climatic or non-climatic disaster (Raddatz, 2009). The combination of increasing debt, decreased revenues (due to the damages) and at the same time falling rates of debt sustainability can be shown to be problematic for the economic outlook of a country. This debt dynamics model will be explained in detail in the second chapter of this thesis.

1.4 The Countries of Southern Europe

This thesis focuses on the four South European countries (Italy, Spain, Greece and Portugal) for specific reasons. These economies share similarities in the economic structure, environmental challenges and fiscal vulnerability (due to elevated public-Debt/GDP ratios).

1. Climate Vulnerability

The graph in Figure 1-8 provided by the Copernicus Climate Change Service, shows a clear trend of increasing summer temperatures in recent decades, with significant anomalies appearing particularly from the 2000s onward.

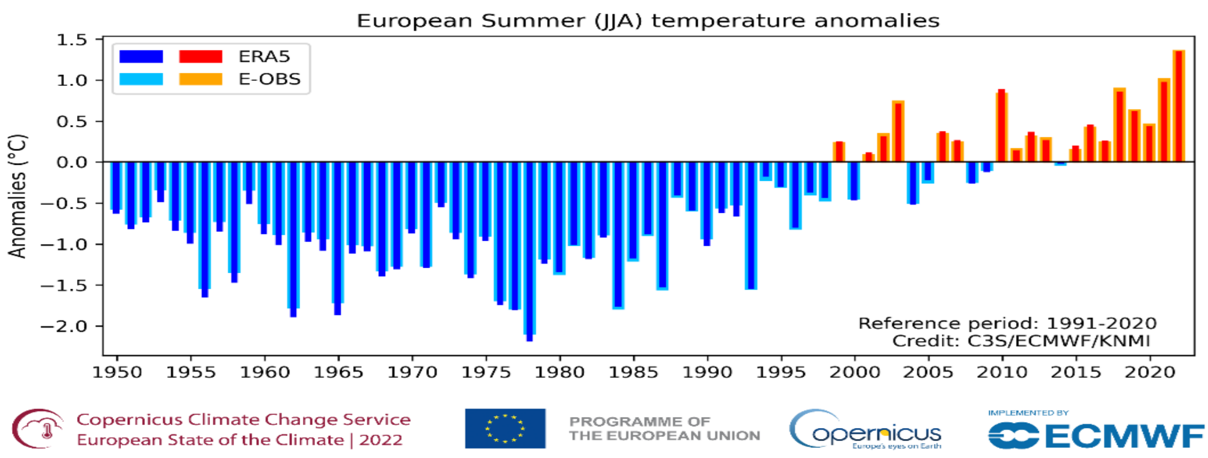

Figure 1-8: European Summer Anomalies (Copernicus-European Comission , 2023)

Those temperature anomalies can lead to droughts and wildfires increase. Droughts have an impact on the National GDP of the countries through sectors such as agriculture and drinking water usage which will also affect both tourism and living conditions in general. Another indication is Southern Europe's wildfire season which used to typically run from July to September, but now data shows that it is getting longer and more intense. Climate change is leading to longer and more extreme heat waves, which dry out vegetation, enabling fires to spread quickly.

According to the European Forest Fire Information System (EFFIS) database, as of August 26, the total burned area in the four main European countries of the Mediterranean basin (Spain, France, Italy and Greece) was already the average of previous years. With the fire season not yet over, almost 330,000 hectares of forest have already gone up in smoke in the region, compared with an annual average of 190,000 hectares from 2006 to 2022 (Fleck, 2023).

Greece accounts for around half of the surface area burned by wildfires in Southern Europe to date: almost 160,000 hectares, or four times the annual average recorded in the country from 2006 to 2022. "This summer's the worst in history, since the beginning of meteorological data collection," the Greek Minister for Climate Crisis and Civil Protection told a press conference at the end of August (Elissaiou, 2023).

2. Strong economic dependence on Climate Sensitive Sectors

Agriculture, which is important to all the South European economies is accounting for roughly between 2% and 4% of each country's GDP. The lines in Figure 1-9 showcase a declining trend for 2000-2022. This common point in all four counties exhibits another reason for exploring the debt sustainability under the climate damage pressure.

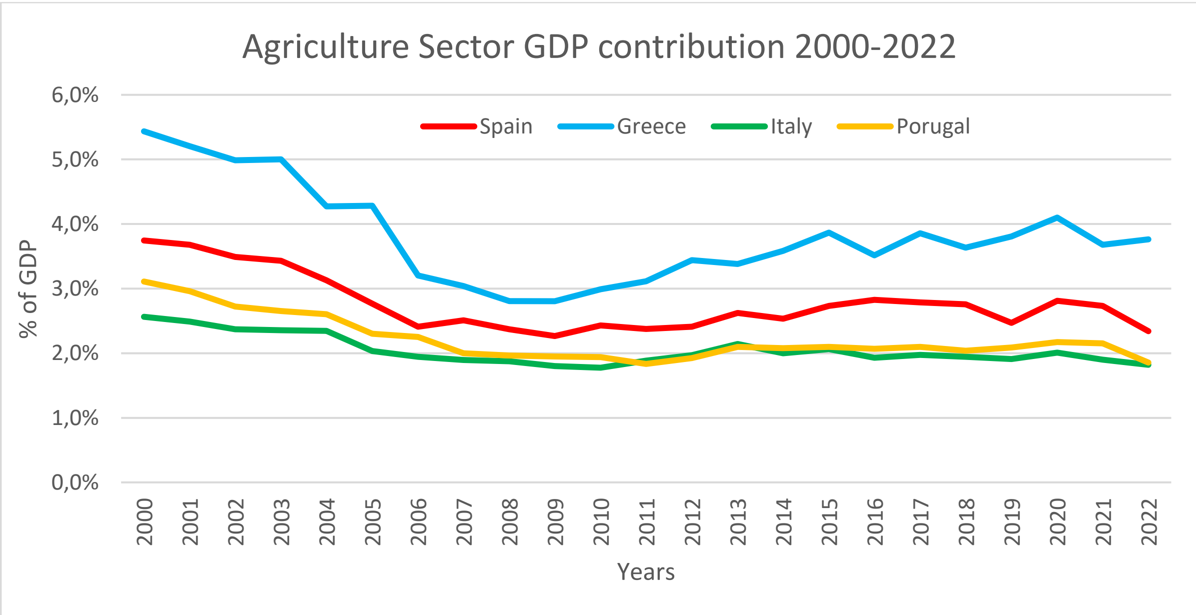

Figure 1-9: Agriculture GDP contribution in 2000-2022 (World Bank, 2024)

An additional example is the Tourism sector which currently thrives in South Europe, that can be severely impacted both by extreme weather events and by long-term climate change. Extreme events such as heatwaves, floods, and wildfires can disrupt travel plans, damage infrastructure, and pose safety risks, leading to immediate declines in tourist arrivals and revenues. Additionally, rising temperatures and changing climate patterns can alter the attractiveness of destinations, shifting tourist preferences away from traditional hotspots towards cooler regions or seasons.

Energy is another sector that is heavily impacted by climate change in the context of increased temperatures or weather events can lower the consumption of heating but at the same time increase the demand for cooling systems.

3. Structural Economic Issues

A common characteristic of Southern European economies is the high unemployment rates which are above the average rate of EU (Eurostat, 2024). Unemployment is a pervasive issue in Greece, Italy, Portugal, and Spain, representing a significant common characteristic that exacerbates their economic vulnerabilities. These countries have historically experienced high levels of unemployment, particularly in the aftermath of the 2008 financial crisis and the subsequent Eurozone debt crisis.

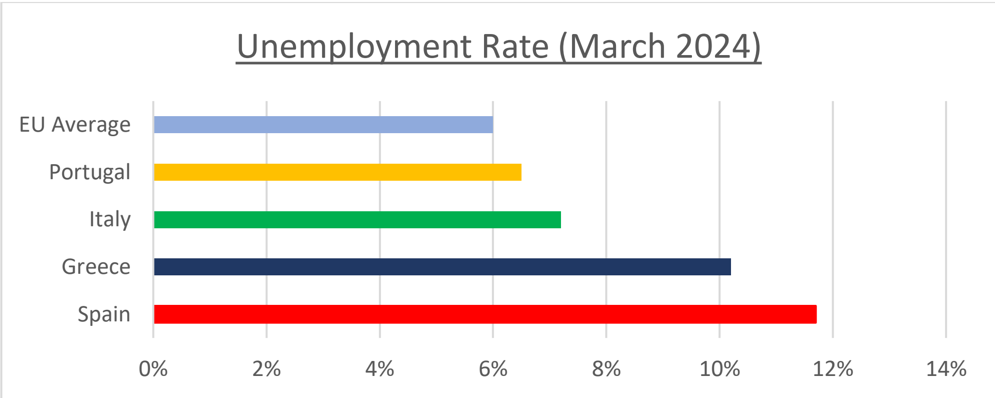

Figure 1-10: Unemployment rate in March 2024 (Eurostat, 2024)

Low productivity remains a critical issue within Greece, Italy, Portugal, and Spain, countries characterized by economic vulnerabilities and inefficiencies (Eurostat, 2024). This issue is compounded by the adverse effects of climate change, which exacerbates existing productivity challenges. For instance, increased temperatures, unpredictable weather patterns, and frequent extreme weather events disrupt agricultural yields, energy production, and labor productivity. As these Southern European nations rely heavily on agriculture and tourism, sectors particularly susceptible to climate variations, their economic output faces further strain. Addressing productivity in the context of climate resilience becomes essential to mitigate these risks and foster sustainable economic growth.

Investment gaps, particularly in infrastructure resilience, pose significant risks to the economies of Greece, Italy, Portugal, and Spain (Zachariadis, 2018). Severely hit by the economic downturn of the financial crisis, South European countries with GDP growth averaging only 0.44 % between 2009 and 2015 and GFCF declining by an averageof -8.35 % per annum (Zachariadis, 2018). Fiscal consolidation had a negative impact on public investment spending, while weak economic recovery further slowed down infrastructure investment. This underinvestment leaves them vulnerable to the impacts of climate change, such as flooding, heatwaves, and other natural disasters. Strategic investment in resilient infrastructure is crucial to ensure long-term economic stability and safeguard against the growing threats posed by climate change.

4. Policy And Governance

Greece, Portugal, Spain and Italy are all members of the European Union, which mandates a framework of common policies, including those related to climate change and fiscal rules. EU membership mandates adherence to the European Green Deal, which aims to make the EU climate-neutral by 2050. These countries are also bound by the Stability and Growth Pact which was revised in 2023 and enforces fiscal discipline. The alignment with EU policies ensures a coordinated approach to addressing climate change and economic governance, providing a structured pathway for implementing necessary reforms and resilience measures.

Financial support from the EU plays a crucial role in aiding member states affected by natural disasters. Greece, Italy, Portugal, and Spain have all benefited from substantial EU assistance following extreme weather events. More specifically, the solidarity fund was emptied in 2023 as the € 1.2 billion budget has been granted to countries in need and more specifically, Greece and Italy were among the countries claiming significant amounts of recovery due to catastrophic floods (Reuters, 2023). This support includes grants from the EU Solidarity Fund, which helps cover the costs of recovery and rebuilding efforts. Such financial mechanisms are vital for these countries, as they provide immediate relief and enable long-term recovery planning, thereby mitigating the economic impact of climate-induced disasters.

Being members of the Eurozone, these countries adhere to the monetary policies set by the European Central Bank (ECB). The ECB's policies aim to maintain price stability and support economic growth across the Eurozone. This common monetary policy framework contributes to economic stability and provides a safety net during financial crises. ECB policies ensure access to financial instruments and support mechanisms that can alleviate the economic pressures induced by climate change. The coordinated monetary policy approach within the Eurozone fosters a more resilient economic environment capable of addressing both short-term shocks and long-term structural challenges.

Because of the reasons above and complemented by the fact that the existing literature focused on the Southern Eurozone countries is limited regarding the subject of Debt sustainability and Climate risks, the author chose to focus on Greece, Italy, Spain and Portugal. Despite the similarities mentioned, it is important to underscore that the countries are different in population size and density, economic output and preparedness for climate change. Nevertheless, that does not make the comparison and research less reasonable but instead adds more perspective on the critical analysis of the following results.

1.5 Physical Risks

The need for adaptation and policies to increase resilience against climate change is critical for Southern European countries. These nations face a significant dilemma: while they require substantial public investment to enhance climate resilience and economic stability, they are simultaneously constrained by the fiscal rules of the Eurozone. These rules limit their fiscal policy space, making it challenging to allocate the necessary funds for crucial adaptation measures.

In the case of climate change and the physical kinds of risks that it brings along, only estimations and projections can be made. Credit rating agencies are in the process of adding physical risk that derives from climate change and quantify the implications in the model. The physical risk is connected with the actual risk that countries face of being hit with extreme weather events that will inflict major damage on their economies and infrastructure. Physical impacts of climate change generate significant revenue and expenditure pressures and add uncertainty to fiscal management. Climate-related risks can affect public sector balance sheets in many ways including via economic growth, commodity prices, public health emergencies that can raise the risk of epidemics and economic damages on state-owned enterprises (Feyen, Utz, Huertas, Bogdan, & Moon, 2020).

At the time being, credit rating agencies are not disclosing how ESG (Environmental, Social, Governance) risk is materializing in the magnitude of adjustments to the actual credit rating of countries. What ESG translates to, is standards based on which a company is graded in order to help socially conscious investors to assess potential investments. Environmental criteria consider how a company performs in environmental aspects such as greenhouse emissions. Social criteria examine how it manages relationships with employees, suppliers, customers, and the communities where it operates. Governance deals with a company's leadership, executive pay, audits, internal controls, and shareholder rights. Subsequently, despite the descriptions of the standards, the non-disclosure practices create even more ambiguousness since the risk is usually reported in a qualitative and descriptive manner of a disclosed change in the country's creditworthiness (Breitenstein, Ciummo, & Walch, 2022)

The phenomenon of global warming introduces two main challenges: gradual, sector-specific shifts in productivity and the potential for more severe sudden impacts (International Monetary Fund, 2008). Nations such as Greece, Italy and Spain that rely on tourism for extended revenue, fishing rights, for instance, as well as those witnessing declines in agricultural output, could suffer notable decreases in income. Additionally, governments may face strains on public expenditure due to damaged public infrastructure, a slowdown of economic growth, lower public revenues and higher spending on healthcare and social security. The extent and nature of these fiscal effects will differ from country to country but are expected to be particularly severe in areas where overall vulnerability to climate change is highest (International Monetary Fund, 2008). Carbon-heavy assets and fossil fuel reserves might become outdated and left unused, leading to potential financial losses for firms. This shift could happen gradually or suddenly, depending on a range of factors like policies, technological advancements, and consumer choices. In a worst-case scenario, the realization of stranded carbon-heavy assets happens suddenly and is worsened by insufficient investment in low-carbon, climate-resistant assets and technologies. The way this shift occurs will significantly impact financial institutions and markets and in consequence nations that are dependent on the markets to secure their credit line and financial needs (Feyen, Utz, Huertas, Bogdan, & Moon, 2020).

Money markets and financial systems all over the world are linked with managing and allocating the necessary resources after first analyzing the available information. Comprehending and measuring the macroeconomic implications of natural disasters holds significant importance in enabling policymakers to effectively allocate resources. Specifically, it aids policymakers in determining the appropriate allocation of funds for enhancing pre-disaster resilience through improved infrastructure, as well as in deciding the number of fiscal reserves to maintain for managing post-disaster consequences, depending on the specific risks they confront. The literature on natural disasters' economic impact is quite extensive but it is important to stress the lagged effect of these phenomena. The financial consequences of sudden disasters might not be immediately apparent due to delayed effects. For instance, a detailed study of the 1988 flood in Bangladesh demonstrates that certain repercussions of the disaster took time to manifest. When a disaster's effects are delayed, they may not be accurately reflected in statistical analyses or models that operate at a broad level of aggregation (Benson & Clay, 2004).

The risks include exposure to external economic shocks such as changes in trade and financial markets, fluctuations in exchange rates, and global commodity prices. Macroeconomic risks involve challenges related to economic performance, inflation dynamics, and sovereign creditworthiness. Banking risks encompass issues like exposure to various sectors, loan defaults, and valuation of climate-exposed assets. Public sector risks include concerns about public debt, fiscal positions, and financing needs for climate-related policies. Corporate sector risks involve debt levels, profitability, and viability of climate-exposed business models. Household risks include debt, unemployment, and impacts on assets. Market and liquidity risks pertain to financial asset repricing and volatility. Monetary and financial conditions encompass monetary policy, availability of credit, and green finance. Risk appetite involves market prices, investor sentiment, and demand for green assets (Feyen, Utz, Huertas, Bogdan, & Moon, 2020).

Existing literature focuses on the short-term effects of the disasters while the long-term effects in growth are usually neglected. Bayoumi et al. (2021) have found that higher disaster preparedness is associated with better growth performance following a natural disaster, while in addition lower debt is associated with higher investment and output growth following a disaster. These indications underscore the importance of both preparedness and fiscal space to mitigate the possible repercussions of the catastrophe. In addition, Bayoumi et al. (2021) conclude that debt thresholds and constraints should take into consideration the fiscal implications of a catastrophic weather event on growth and therefore fiscal rules should be more lenient towards more susceptible and vulnerable countries.

Nevertheless, current studies remain inconclusive regarding the effects of natural disasters on growth as some existing studies report positive, negative and no effects both on short- and long-term horizons (Panwar & Sen, 2019). This uncertainty regarding the financial repercussions of climate change is battled with Integrated Assessment models (IAMs) which serve as primary instruments for gauging these costs.

1.6 Research Questions

The countries of Southern Europe face a dilemma. On the one hand, they are burdened by high public debts (relative to GDP), which they will have to bring down to 60% of GDP, the level that is in accordance with the fiscal policy rules of the Eurozone. As a result, the fiscal policy space of the Southern-European government is and will remain severely constrained. On the other hand, the economies of Southern Europe are facing and will continue to face disproportionally larger damages caused by climate change (compared to Northern Europe). This high and rising climate damage will negatively impact the fiscal health of these countries and contribute to a further tightening of the fiscal policy space.

A solution to this dilemma could lie in public policies aimed at climate adaptation in order to strengthen resilience of society and economy to extreme weather events. But this will require increased public spending. The strict fiscal policy rules of the Eurozone are unlikely to permit the increase in public spending that is needed for climate adaptation. The countries of Southern Europe find themselves in a "catch-22": climate change and the resulting damages will worsen the fiscal health of these economies, but the prevailing fiscal rules will not permit governments to increase spending that is needed to lower the expected climate damages.

With high public Debt/GDP ratios, these nations struggle to find the resources needed for important infrastructure and climate resilience projects. They are dealing with ongoing economic issues made worse by the global financial crisis and the pandemic, which puts them in a fragile position. Add to that their heavy reliance on sectors like agriculture, tourism, and energy, which are all sensitive to climate change, and the picture becomes even more complicated. This makes it important to understand how climate change impacts their economies and debt. Thus, this research will dive into how the economic costs of climate change will affect the debt levels in these Southern European countries during 2025-2070, aiming to find ways in which they can better manage their public finances and become more resilient to climate challenges. Putting all the above together leads to the following research question of this Master's Thesis:

Research Question: "What is the likely impact of the climate-related natural damages on public debt in European South Economies during 2025-2070?"

The main research question gives rise to the following sub-Questions:

1. How significant are the (projected) future climate damages for the economies of Southern Europe in different adaptation and climate-change scenarios?
2. What will be the impact of climate change on the public-Debt/GDP ratios in Southern Europe during 2025-2070 in different climate-change scenarios?
3. Will the country-wise bond interest rate spreads in Southern Europe (compared to Germany) be affected by future climate change?
4. How is public debt affected by these changes in interest rates country premium?
5. Do the EU fiscal rules offer sufficient fiscal policy space to the economies of Southern Europe in light of the projected impacts of climate change on public debts? If not, how can the EU fiscal rules be changed to enable these economies to invest in climate resilience and climate change adaptation?

Being able to provide answers to these questions will be useful not only directly for the governments of the Southern European countries, but also for the policy makers of the European Union and the citizens of Spain, Italy, Greece and Portugal who would desire stability over reincarnated problems of the past. The target of this master's Thesis is the delivery of realistic suggestions and proposals to the European Union which can change the current course of Debt and the push for more drastic action towards climate change.

1.7 Research Methods

This section briefly describes the methodology that will be used in the thesis. To model the effects of climate change, the author used the results of the Co-designing the Assessment of Climate Change Costs (COACCH) Project. The "COACCH project is an innovative research project that gathers leading experts on climate change sciences from 13 European research institutions which aims to advance knowledge regarding climate change impacts and policy that can be used directly by stakeholder communities" (COACCH, 2022). The COACCH Project publishes the economic valuation of climate action (mitigation and adaptation) in the EU at various scales (spatial grids, regions, countries and economic sectors) over short to longer-term timeframes to support a better-informed policy process in the achievement of intended nationally determined contributions (INDCs) for the EU.

Being able to extract economic damages at a spatial regional level for the counties of the focus group was crucial to the research objective in order to produce an aggregated effect on the national GDP of every country. The damages concerned the horizon of 2025-2070 under different adaptation scenarios (SSPs) and climatic scenarios (RCPs). In climate research, socio-economic and emission scenarios serve to offer realistic depictions of potential future developments across several dimensions, including socio-economic shifts, technological advancements, energy and land use patterns, and emissions of greenhouse gases and air pollutants. These scenarios are utilized to inform climate model simulations and to evaluate potential impacts of climate change as well as mitigation strategies and their associated costs. To enhance comparability between different studies and facilitate clearer communication of model outcomes, it is advantageous to employ a standardized set of scenarios that is widely accepted within the scientific community (Van Vuuren, 2011).

In consequence by combining datasets from the COACCH project and future GDP projections (2025-2070) from the International Institute for Applied Systems Analysis (IIASA), it was possible to design multiple scenarios concerning the future public debt of the Southern European economies. During the process of building the Debt Dynamics model, different assumptions were used in order to complete the model and the missing data. Every dataset was made available through a publicly open source except for the calculations of the author.

After the completion of the quantitative part, a more qualitative assessment follows on the results and conclusions that can be drawn. These final remarks are translated into policy suggestions and proposals for the institutions which are playing a critical role in the debt management of the southern European countries but also for their governments.

1.8 Synopsis

The remainder of this thesis is structured as follows.

Chapter 2 offers a comprehensive narrative detailing the potential resurgence of a debt crisis in South-European countries. Here, the factors of the debt dynamics model are explained and what is the role of each one in the Debt Loop.

In Chapter 3, the methodology that was followed for the entire project, is thoroughly analyzed and explained in a step-by-step format. In addition, the data sources that were utilized for the completion of the debt-dynamics model are presented together with the logical assumptions needed for the extraction of results.

Chapter 4 is dedicated to presenting and elucidating the results from the damage and debt scenarios for the four Southern-European economies in more detail. The differences and highlights of the countries are illustrated providing a complete narrative behind the results.

In Chapter 5, the thesis delves into an informative discussion around the key findings, offering valuable insights and recommendations that can serve as guiding principles for policymakers and advisors alike. Furthermore, a final comparison between Southern Europe and Germany is presented on the context of fiscal governance and climate damages.

The conclusion of the thesis is presented in Chapter 6 and some extra results are demonstrated in Appendix.

2. Avoiding the Debt-Loop

Building on the crucial topics explored in the previous chapter, which delved into the foundational concepts of fiscal policy, public debt, and economic growth, we now turn our focus to the intricate relationship between these elements and the imperative of addressing climate change. As governments worldwide struggle with increasing deficits and escalating public debt, the challenge of balancing immediate economic stability with long-term growth prospects becomes increasingly complex. Simultaneously, the ever-pressing need to combat climate change imposes additional fiscal pressures, demanding substantial investments in green technologies and climate adaptation measures. This chapter examines how these forces interact, analyzing the influence of economic growth and interest rates on debt dynamics and exploring how targeted climate investments can both challenge and enhance debt sustainability. Through a comprehensive analysis of historical trends, theoretical frameworks and empirical evidence, this chapter aims to illustrate the pathways by which economies can achieve sustainable development amidst mounting fiscal and environmental pressure.

As explained in Chapter 1, the current Debt/GDP ratios of the Southern countries of Europe are the highest among the members of the Eurozone. Despite current projections and expectations regarding their financial future, things can derail easier than someone would expect to, due to unforeseen consequences such as public expenditure and decreased revenues from taxes.

2.1 Fiscal deficits and public debt

It is important to clarify how a fiscal deficit occurs and under which circumstances. A government budget deficit occurs when a government's expenditures exceed its revenues in each fiscal period. To finance this deficit, the government borrows money, thereby increasing its public debt. Over time, persistent deficits lead to a growing debt burden. History has demonstrated this with multiple examples including the governments of Greece, Italy, Portugal and Spain (Zulkifli & Yusof, 2024) (Cencini, 2017) . Economic growth for a country in debt is particularly important to secure the viability and sustainability of its debt. Insufficient economic growth exacerbates the debt situation by reducing the government's revenue base, which is primarily derived from taxes (Cao, Gaspar, & Adrian Peralta, 2024). With slower growth, tax revenues stagnate or decline, making it harder for the government to cover its expenditures without resorting to additional borrowing. This creates a vicious cycle where growing debt necessitates more borrowing, which further increases the debt burden.

In order to stop the cycle, governments need to create the right financial environment and be able to create the conditions for steady, reliable and sustainable growth for the country. In the case of Greece and the rest of the Southern European countries, the measures that were taken by the government and associated institutions, targeted into the steep decrease of the public expenses through a fiscal tightening. This reaction created further problems for an already stagnating economy and led to another rescue loan for Greece. The relationship between the economic growth rate and the interest rate on debt is crucial for debt sustainability. If a country's economic growth rate is lower than the interest rate it pays on its debt, the Debt/GDP ratio will likely increase, making the debt burden more challenging to manage (Checherita-Westphal, 2019). Subsequently, if the growth rate exceeds the interest rate, the Debt/GDP ratio can stabilize or even decrease, easing the debt burden.

Explaining the mechanisms above allows now to define the "Debt Loop."

Based on Zenios (2024) research on the subject, the climate sovereign Debt Loop is defined as a self-reinforcing cycle where climate change impacts exacerbate sovereign debt challenges. Climate-related damage increases fiscal burdens, leading to higher borrowing costs as investors demand higher risk premiums. These increased costs, coupled with reduced fiscal space and slowed economic growth from climate disruptions, push Debt/GDP ratios to unsustainable levels. This constrains governments' ability to invest in necessary climate adaptation and mitigation, worsening future climate impacts and perpetuating the cycle. The loop can also cause political and financial instability, further undermining economic performance and fiscal health. Effective management of this loop requires integrating climate resilience with fiscal policies, improving risk assessment, and fostering investments in mitigation and adaptation to ensure long-term economic stability.

2.2 Causes of a 'Debt Loop'

In his recent study, Zenios (2024) highlights several mechanisms that can trigger a "Debt Loop" for the more vulnerable countries.

The first mechanism is the strain on public finance sector. Even in a relatively moderate climatic scenario such as the RCP 2.6 (Van Vuuren, 2011), the pressure on public finance and debt cost is increased. More specifically for countries with limited fiscal space, a climate disaster which constitutes an external shock for the economy can lead to downgrades in their credit rating (Patrycja, Agarwala, Matt, Kraemer, & Mohaddes, 2021). The rise in costs to service debt becomes evident as economic growth contends with adverse climate impacts, leading to Debt/GDP trends that may turn into unsustainable territory.

In the second mechanism, uncertainty rules over the climate risks, as assessment becomes difficult, due to lack of scientific methods with proven results and the (future) uncertainties involved. The complexity of the subject concerns the projections of both climatic and financial scenarios and in consequence, risk assessment and incorporation in a debt sustainability analysis becomes rather difficult. As Michael Bloomberg said "*Climate change may not be correctly priced—and as the costs eventually become clearer, the potential for rapid adjustments could have destabilizing effects on markets* " (Bloomberg, 2017). This mispricing can potentially lead to a housing market crisis with unpredictable consequences for the economy (Gourevitch, et al., 2023). Again, this possibility has many implications as a flood risk disclosure can lead to an abrupt repricing and a crash in the house market which of course can severely impact the economy (Zenios, 2024).

Adding to the point of uncertainty, Gennaioli et al. (2012) model indicated that both investors and intermediaries often neglect certain improbable risks (such as climate-related physical risks) associated with new securities. This neglect leads to an over-issuance of securities perceived as safe but exposed to these overlooked risks. When these risks materialize, it triggers a rapid shift in investor behavior, leading to a flight to safety and a sharp decline in the prices of the newly issued securities and their underlying assets which detonates a chain reaction for the country's economy.

The third mechanism that can pull a country into the "Debt Loop" is the connection between banks and the real economy which deeply affects public finance. Negative impacts on the banking sector diminish lending to the economy and influence public finances, while declining public finances negatively impact the banking system.

Current literature started to focus on the links between sovereign spreads and climate risks. Despite the fact that credit rating agencies are highlighting climate as a potential source of credit risk, so far, no major credit rating downgrade has been attributed to the increasing climate risk (Bolton, et al., 2022). Glass et al. (2015) highlight a rare occurrence where a country's debt is downgraded due to a natural disaster, citing Grenada in 2004 after Hurricane Ivan as an example. However, they emphasize that one of the primary reasons for this rarity is that often the countries most impacted by natural disasters do not possess a sovereign rating at the time of the catastrophe. Glass et al. (2015) conclude that "sovereigns most vulnerable to natural hazards are likely to be small island states with next to no geographical diversification and a narrow economic base". In their research Beirne et al. (2021) have underscored six possible channels through which the climate change is impacting the spreads of government bonds:

1. Impact on natural Capital and resources: Depletion and degradation of natural resources, leading to reduced economic productivity and increased costs.
2. Climate related natural disasters: Frequent and severe natural disasters causing significant economic losses and increasing fiscal burdens.
3. Adaptation and mitigation Expenditure: Excessive costs associated with adapting to and mitigating the effects of climate change, impacting government budgets.
4. Financial Crisis due to stranded assets: Assets becoming obsolete or devalued due to shifts towards a low-carbon economy, leading to financial instability.
5. Reduction in Trade and higher capital flow volatility: Climate change disrupts trade patterns and causes volatility in capital flows, affecting economic stability.
6. Political Instability: Climate-induced stress leading to political unrest and instability, which can increase sovereign risk and affect bond spreads.

Governments are in no position to have an absolute and holistic effect in all of these channels, but they should try avoiding one of the mechanisms that will eventually lead to the "Debt Loop" explained earlier in the chapter. All nations, especially those highly susceptible to climate impacts, must allocate resources towards climate adaptation measures. This includes fortifying buildings and infrastructure against natural disasters, constructing dams and natural barriers to mitigate storm surges, safeguarding vulnerable populations from extreme heat, implementing water conservation measures, adjusting agricultural practices to changing conditions, and managing the relocation of communities from vulnerable coastal areas. Swift investment in adaptation efforts can help prevent the loss of assets and minimize the impact on lives and livelihoods. There is broad agreement that the economic benefits of such investments are substantial, with estimated average returns ranging from 80% to 100% while specific investments, such as storm protections, have been shown to yield returns exceeding 1,000% (Aligishiev, Bellon, & Massetti, 2022).

2.3 Uncertainty

The interaction between climate conditions and macroeconomics is characterized by deep uncertainty. Not only due to the genuine difficulties to accurately predict how the climate change is going to impact the planet, but also because many changes can be avoided or alternated by the choices that humanity and societies are going to make. Tol (2018) compared 23 different studies where there is noted disagreement between natural scientists and economists regarding the seriousness of climate change as estimations differentiate to an extent which doesn't allow which doesn't allow for a consensus on the economic impacts and the urgency of mitigation measures. This discrepancy underscores the challenges in integrating scientific and economic perspectives to formulate coherent and effective climate policies. Estimations of the structural damage or external shocks of climate change and natural disasters are further complicated by the inherent unpredictability of human responses and societal decisions. The interplay between climate phenomena and macroeconomic dynamics underscores the necessity for comprehensive risk assessments and adaptive policy measures. As societies struggle with the complexities of climate change, understanding the multifaceted nature of these decisions is crucial for informed decision-making and effective mitigation strategies.

In response to a request from the Intergovernmental Panel on Climate Change (IPCC), the Integrated Assessment Consortium (IAC) was established. This consortium devised a narrative scenario framework to address the uncertainties inherent in assessing climate change impacts. This framework integrates representative concentration pathways (RCPs) of atmospheric greenhouse gas (GHG) levels with narratives outlining shared socio-economic development pathways (SSPs). By combining these elements, the scenario framework offers a range of potential future scenarios for analysis, even in the absence of precise probability estimates (Zenios, 2022). These narrative scenarios are valuable for the understanding of climate change and its implications on economy.

Another effort with comparable results comes from the Network for Greening the Financial System (NGFS). NGFS is a group of central banks and financial-sector supervisors committed to sharing best practices, contributing to the development of climate– and environment–related risk management in the financial sector and mobilizing mainstream finance to support the transition toward a sustainable economy (NGFS, 2024). The NGFS Climate Scenarios provide a globally coordinated set of pathways for transition, assessments of how climate change will physically impact regions, and economic indicators.

While there have been significant research strides, it is important to use the results carefully, especially when looking at specific details. To address uncertainties, in this thesis, multiple models have been used for each scenario and warming level whenever possible. While important steps have already been taken in this area, most of these proposals are still lacking certain elements that are crucial to fully assess the impact of climate risks on the financial system and the real economy. The rise in both the frequency and intensity of supply shocks caused by extreme weather poses challenges for central banks in predicting output gaps.

2.4 Risk Estimation and Stress Testing

Physical risks and transition risks are the two main types that are dominating the subject of climate change and its impact on the economy. Physical risks refer to the direct and tangible impacts of climate change on assets, operations, and financial performance. These risks are associated with the immediate effects of climate-related events and long-term shifts in climate patterns. On the other hand, transition risks arise from the process of adjusting to a low-carbon economy. This thesis will be focusing solely on the results that derive from the physical risk as transition risks are considered a standalone research topic and will deviate the discussion into another multicomplex direction.

To better explore the possible repercussions of climate change in the banking system and the European economy, he European Central Bank has already conducted a Eurozone-wide Stress Test (European Central Bank, 2021) under the different climatic scenarios that were designed by the NGFS organization as explained in the previous paragraph. The results point towards the advantages of taking proactive measures. The immediate expenses associated with mitigation and transition policies are far outweighed by the future costs of unchecked climate change over the medium to long term. Early implementation of policies aimed at facilitating the shift to a carbon-neutral economy would also yield advantages in terms of investment in and deployment of more efficient technologies. These outcomes underscore the critical and pressing necessity of moving towards a more sustainable economy, not only to fulfill the objectives outlined in the Paris Agreement but also to mitigate the prolonged disruptions to economies, businesses, and livelihoods. In addition, the ECB (2021) states that if policies to transition towards a greener economy are not introduced, physical risks become increasingly higher over time, with the potential that these will become very significant.

Projections regarding the likelihood of default for firms and banks over the next three decades indicate that by 2050, the most significant repercussions would arise in a scenario where no transition towards sustainability occurs. This outcome is primarily attributed to escalating damage caused by natural disasters. The impact would be particularly pronounced for businesses situated in geographically vulnerable regions and for banks holding portfolios heavily concentrated in countries most susceptible to natural hazards. Therefore, initiating an early and gradual change is paramount to alleviating the costs associated with both the shift towards sustainability and the potential future ramifications of natural disasters (European Central Bank, 2021).

Complementing the analysis of ECB (2021) on physical risk and its consequences on European economies, the Oliver Wyman (2023) corporation has conducted their own Stress Test for firms and banks. This report and the results from the member survey highlight the considerable progress banks have made in enhancing their stress testing capabilities for climate risk since the ECB's 2022 exercise. Although climate risk stress testing and scenario analysis are still in the learning phase, there is a consensus among regulators, supervisors, and banks that it is the most effective method for understanding how physical risks will evolve and impact bank balance sheets. Establishing a standardized data framework that considers the impact on both banks and their clients is crucial for developing a reliable understanding of climate risk transmission. This framework is expected to be completed within the next few years (Oliver Wyman, 2023).

In summary, the uncertainty and complexity of risk estimation classify it as a highly challenging task even for industry experts. This difficulty arises from the current inadequacies in computational methods, which are still under development, and the limited quality and availability of necessary data.

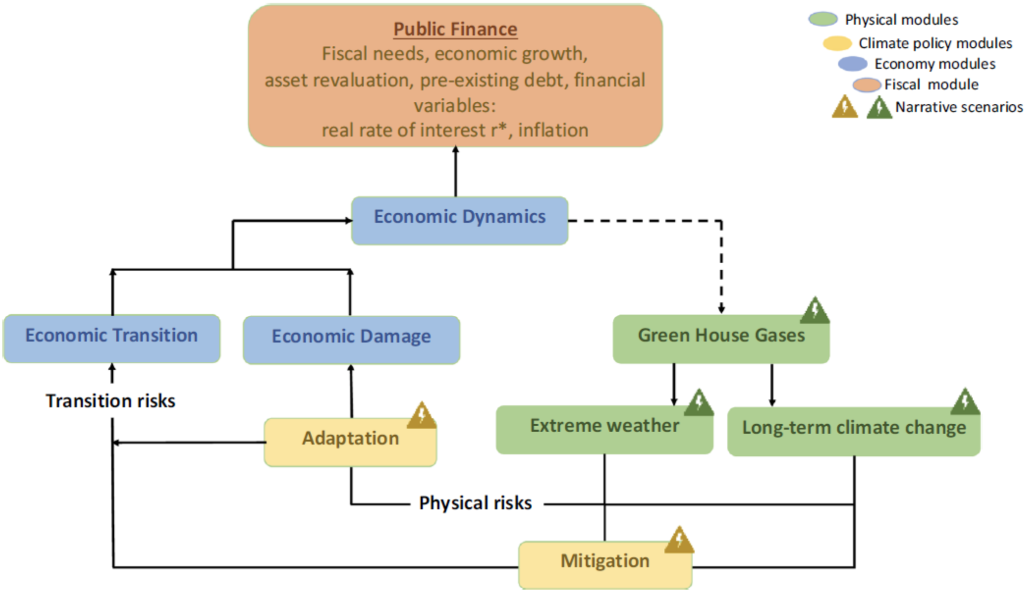

Figure 2-1: Integrating climate risks to sovereign debt sustainability analysis (Zenios, 2022)

Figure 2-1 illustrates the flowchart of dynamics between the different modules and their complex interactions. Public finance underpins economic activities and is crucial for funding adaptation and mitigation strategies. Economic dynamics drive both the economic transition to a low-carbon economy and the economic damages from climate impacts. The loop of actions is closely related to the Debt Loop that was previously described and therefor the

The impact of climate change's physical risks is shaped by climate policies, can also yield positive climate outcomes. The effects of climate change on public finances are attached to the consequences of climate policies on both climate conditions and public finances (Zenios, 2022). Mitigation policies are associated with the extreme weather effects, and they create more transition risk but can put a limit on climate change and therefore reduce the actual physical risk.

2.5 Climate Adaptation

The estimated global public adaptation requirements amount to approximately one-quarter of a percent of the world's GDP annually on average, although this figure may not accurately reflect the challenges faced by individual countries. Literature suggests that the investment needs for climate change adaptation in developing nations could vary significantly, ranging from negligible amounts to $300 billion per year by 2030 and between $50 billion to $500 billion annually by 2050 (Aligishiev, Bellon, & Massetti, 2022). These estimates, when compared to the projected global GDP for their respective years, represent investment needs ranging from minimal to approximately 0.3 percent of the projected global GDP annually in 2030.

By 2050, these investment needs are anticipated to rise across all studies, even after accounting for global economic growth. However, it is important to note that these estimates are subject to high levels of uncertainty due to limited studies and outdated data. The wide range in estimates can be attributed to variations in defining needs and assumptions regarding future development and climate change. The results below are based on the United Nations Environment Program, United Nations Framework Convention on Climate Change, the World Bank and a study led by the Organization for Economic Co-operation and Development in 2009–2011 (Agrawala) under different Integrated Assessment Models.

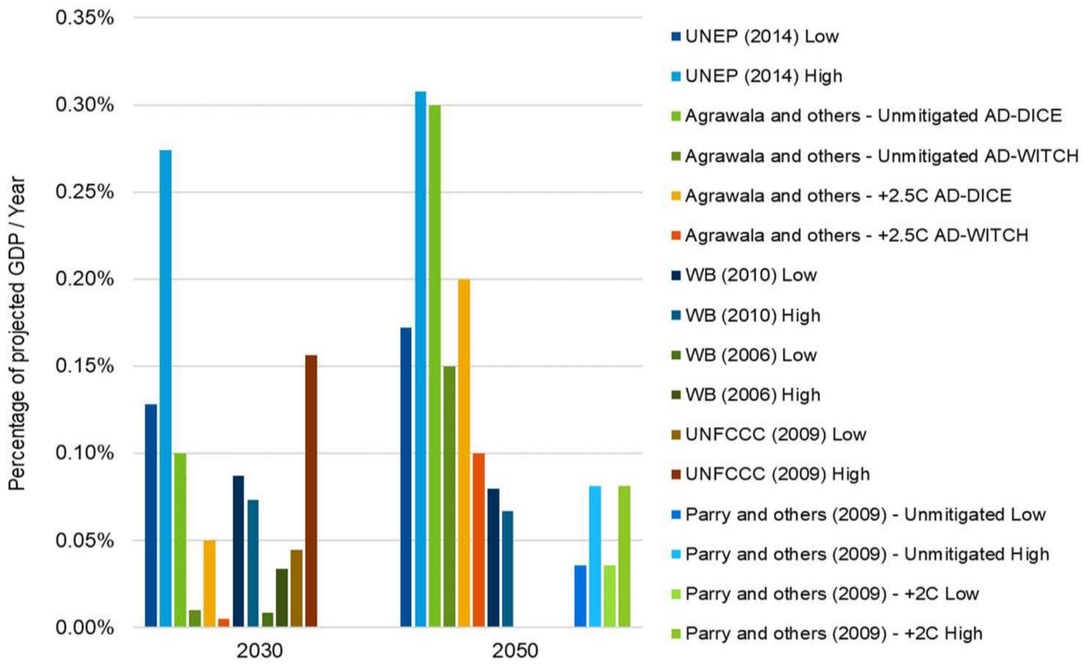

Figure 2-2: Estimates of investment needed in Adaptation measures (Aligishiev, Bellon, & Massetti, 2022).

The countries of South Europe are among the top 40 countries of the world in the ranking of the ND-GAIN Index which "summarizes a country's vulnerability to climate change and other global challenges in combination with its readiness to improve resilience" (University of Notre Dame, 2024). This composite index is based on two main dimensions:

1. **Vulnerability:** This dimension assesses a country's exposure, sensitivity, and capacity to adapt to the negative effects of climate change. It considers sectors such as food, water, health, ecosystem services, human habitat, and infrastructure.
2. **Readiness:** This dimension evaluates a country's ability to leverage investments and convert them into adaptation actions. It considers economic, governance and social readiness factors.

In both dimensions, Greece, Italy, Spain and Portugal are performing satisfactorily as developed countries despite being in an area which is particularly vulnerable to climate change such as the Mediterranean (Intergovernmental Panel on Climate Change, 2022). With time this environmental performance can change specially after a large magnitude climate related disaster such as the floods of 2023 in Greec. As a result, despite their index ranking, the adaptation measures that will be needed in the following years, still remain a challenge for these heavily indebted countries.

In consequence, there are certain questions/resolutions that arise from analyzing the previous facts:

How is Southern European counties can adjust to the imminent climate change when their financial resources are limited, and their fiscal buffer constrained by European Union's rules?

How is the investment gap going to be filled as the issuance of new debt is already expensive enough due to high interest rates and the rise of Debt/GDP ratio is not easily tolerated inside the EU?

2.6 Fiscal Implications

The economic impacts of physical risks from climate change are increasingly evident, primarily emerging through disruptions to both the supply and demand sides of the economy. Acute physical risks, stemming from extreme weather events, can lead to various consequences such as damage and disruption to capital assets, loss of productivity due to extreme conditions, disruptions in trade, and decreases in consumption and investment. Similarly, chronic physical risks resulting from gradual global warming can also adversely affect the economy by reducing productivity due to extreme heat, diverting resources away from productive capital investments towards climate adaptation, and altering investment and consumption patterns.

These impacts are expected to be most pronounced in communities situated in areas highly exposed to climate disasters and those with limited capacity to prepare for and respond to such events. Sectors heavily reliant on natural resources and stable climate conditions, such as agriculture and fishing, are likely to bear the weight of these impacts (Gagliardi, Arevalo, & Pamies, 2022). For Greece, Italy, Spain and Portugal

According to Elkins & Speck (2013), fiscal sustainability refers to a government's ability to service its debt over the business cycle and in the long term. Adaptation expenditures for climate change are relevant to fiscal sustainability because some of these costs will need to be covered by the public sector. However, these expenditures can also reduce the need for future post-disaster spending. Given the uncertainties about the future impacts of climate change, determining the appropriate level of adaptation expenditure is challenging. Investing in improved, more detailed climate change modeling at regional and local levels could provide valuable insights into the cost-effective level of adaptation spending (Ekins & Speck, 2013).

The economic impacts of climate change will be felt through reduced government revenues, particularly in countries heavily dependent on climate-sensitive sectors such as tourism, agriculture, and fisheries. These sectors may face significant productivity losses, which in turn, reduce tax revenues (Jones, Keen, & Strand, 2013). In addition, the slow-moving nature of climate change means that the fiscal impacts will evolve over decades, requiring long-term planning and investment. This includes addressing the intertemporal mismatch between the immediate costs of mitigation and the delayed benefits, which complicates policy design and requires careful consideration of discount rates in economic modeling (Jones, Keen, & Strand, 2013).

Lastly, the uncertainty surrounding the trajectory and impacts of climate change adds another layer of complexity to fiscal planning. Governments need to be prepared for a range of possible outcomes, including severe weather events and other catastrophic impacts, which may necessitate significant emergency spending.

2.7 Insurance Mechanism

Another relevant parameter to add to the discussion, is the lack of insurance that could potentially replenish and repair to a certain extent the amount of damage from the disasters. In the countries of the European South (Greece, France, Spain, Italy, Portugal), only 10,4 % of the total losses due to extreme weather events during 1987-2022 were insured. If we exclude France, the insured percentage of climate damages drops to a mere 4,25% (European Environmental Agency, 2023). These collected data do not include the costs of the devastating floods and wildfires that impacted the economies of Greece, Spain and Italy in the summer of 2023.

Insurance can play a significant role in helping to mitigate the impact of that greater risk, but at the same time insurance coverage may fall due to climate change. The future impact of catastrophes may consequently be greater than similar events in the past, and economic models which fail to account for this mechanism may underestimate the full magnitude of the costs of climate change (Rousová, et al., 2021).

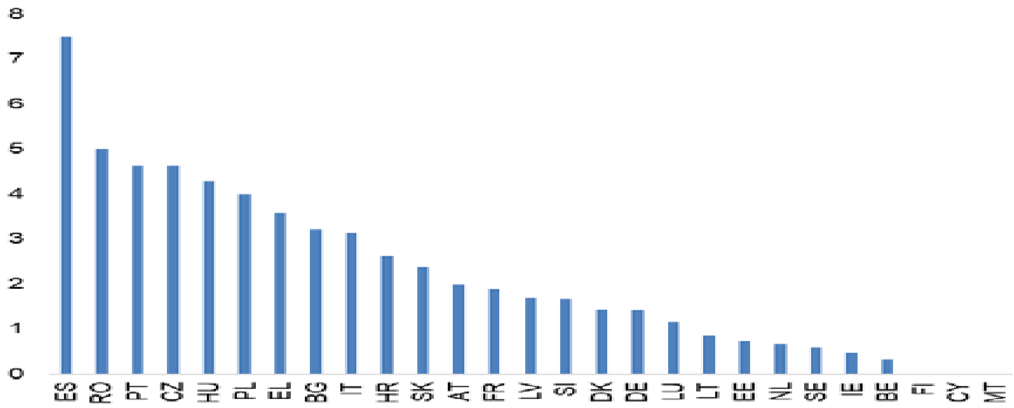

Figure 2-3 :Cumulated Uninsured average economic losses, 1980-2020 events (% of country GDP) (Gagliardi, Arevalo, & Pamies, 2022)

In Figure 2-3 , in terms of countries' economic size, the most exposed countries appear to have been mostly Southern and Eastern European ones. This is the case for Spain (cumulated uninsured economic losses representing 7.5% of GDP over 1980-2020), Romania (5% of GDP), Portugal, Czechia, Hungary (4.5% of GDP), followed by Poland (around 4% of GDP) and a slightly lower impact (ranging from 3% to 3,5% of GDP) for Greece, Bulgaria, and Italy. On the contrary, a more modest exposure tends to be found in countries exhibiting sufficient insurance coverage, despite relatively high occurrences of natural disasters (e.g., Germany, Belgium, and Austria) (Gagliardi, Arevalo, & Pamies, 2022).

Adequate insurance coverage could help to alleviate the effects of physical damage caused by climate change. Although insurance may not prevent the loss of assets, effectively designed climate risk policies serve to enhance the management and alleviation of the economic consequences of disasters. By serving as a safety net and buffer in the aftermath of extreme events, these policies provide essential financial support. Additionally, they play a crucial role in promoting risk awareness among stakeholders (Cebotari & Youssef, 2020).

When considering insurance options beforehand, it is expected that insurance would contribute to debt due to the low likelihood of catastrophic events, which would result in expected payouts remaining below the annual premium payments (Cebotari & Youssef, 2020). However, evaluating the budgetary impact of insurance ex-ante may not be the most appropriate criterion for assessing its benefits. Post-disaster, natural calamities could incur significantly higher costs than anticipated beforehand, impacting not only fiscal or financial aspects but also exerting macroeconomic and social effects. Therefore, despite its costs, insurance remains compelling for sovereigns due to risk aversion towards the potentially catastrophic effects of disasters on the economy. Additionally, the immediate availability of insurance payouts would substantially ease the binding financial constraints that a country is likely to encounter following catastrophic disasters.

The characteristics of extreme weather events, marked by their significant cost and low likelihood of occurrence, typically suggest an insurance-based solution. With the substantial economic damage incurred by these events juxtaposed against their relatively rare incidence (though increasingly common), insurance appears as a logical choice to mitigate such risks, particularly when adaptation measures are either impractical or prohibitively expensive. However, a critical challenge for catastrophes lies in aggregate risk, where a single event can lead to losses for numerous policyholders of the same insurer. This constraint on insurers arises not from individual policyholder characteristics but from the collective (systemic) exposure of all policyholders affected by the event. Consequently, the private sector may face important challenges in issuing insurance for all potentially impacted households or businesses. For instance, in flood insurance, an underwriter's ability to offer new policies in certain areas hinges on the volume and size of policies it has already underwritten. In severe instances, aggregation risk can extend industry-wide, as the combined capital of insurers and reinsurers may prove insufficient to cover the needs of policyholders in regions vulnerable to such risks (Lis & Christiane, 2009).

The countries of South Europe need to take private property under insurance seriously as public insurance contains several challenges both for the government and insurance holders. Initially, an insurance fund could be established at the regional, national, or supranational level. Given the expansive reach of extreme weather events, which often transcend national borders and affect large geographic areas, a supranational insurance fund may be considered the optimal choice (Lis & Christiane, 2009). Such an approach could help alleviate the aggregation issue, particularly for smaller countries that may struggle to cover losses within a national insurance fund when impacted areas span a sizable portion of the country. Additionally, a supranational fund would spread risk across a broader area. However, the benefits of risk-sharing can be limited by correlated shocks, which may undermine the effectiveness of spreading risk. The establishment of a supranational fund presents challenges in terms of financing, as it would necessitate agreement among numerous countries on a unified scheme. Moreover, ensuring the integrity of the fund and preventing fraud becomes more complex with a larger number of participating countries, necessitating stringent verification measures (Rousová, et al., 2021).

2.8 Debt Financing

As the main research objective of this thesis, debt financing is important to all the governments of South European countries. Despite the abundance of research on the long-term economic implications of both climate change and disasters, the body of knowledge remains inconclusive. Moreover, the exploration of the fiscal impacts of climate change is comparatively underdeveloped. However, there is a lack of research examining the influence of climate vulnerability on sovereign debt costs. This gap in knowledge is significant because the cost of government finance not only impacts the public budget and the government's capacity to invest in climate mitigation and adaptation but also limits potential investments in critical areas such as infrastructure, education, and public health (Kling, Lo, Murinde, & Volz, 2018). Additionally, it has implications for private sector investments, potentially leading to a wide range of spillover effects.

Irrespective of the level of government debt, public insurance schemes can introduce moral hazard. For instance, if the anticipation of public funds in the event of flooding encourages disproportionate development in flood-prone areas, this phenomenon represents an adverse consequence of public insurance, reflecting excessive risk-taking behavior enabled by the expectation of government support (European Commission, 2021).

The South European governments have increased financing needs due to the large outstanding public debts. For medium term horizon, the European Commission is assessing the fiscal sustainability of the countries of the South as mild risk. Although the commission is mentioning the fiscal pressures and the challenges that lie ahead for these countries, it almost totally neglects the climate dangers and consequences that pose a significant threat to derail the economies of the South (European Commission, 2024).

To be more specific, Greece, Italy, Spain, and Portugal each face significant medium-term fiscal sustainability risks, despite some progress in reducing their Debt/GDP ratios. Greece's public Debt/GDP ratio is expected to decline from 172.6% in 2022 to 148% by 2025, yet continuous primary surpluses and the impact of recent natural disasters present ongoing challenges (European Commission, 2024). Italy's situation is marked by a projected increase in its Debt/GDP ratio from 148% in 2029 to around 164% in 2034, driven by high public debt and low economic growth (European Commission, 2024). Spain, despite a reduction in its Debt/GDP ratio from 115.9% in 2022 to an estimated 106.5% in 2023, faces persistent high debt levels and fiscal deficits, with gross financing needs slightly exceeding 20% of GDP by 2034 (European Commission, 2024). Portugal's Debt/GDP ratio is expected to decline from 99% in 2023 to 83% by 2034, but the country still faces substantial gross financing needs averaging around 8% of GDP annually, influenced by economic and demographic factors (European Commission, 2024).

Each of these countries confronts unique challenges related to their economic structures, fiscal policies, and external vulnerabilities, highlighting the need for comprehensive strategies to ensure long-term debt sustainability and economic resilience. These strategies need to address the threats posed by climate change to avert a possible initiation of a "Debt Loop" and the consequences that countries of the South Europe have already experienced in 2008-2016.

While Greece benefits from a substantial portion of its debt being held at concessional rates, it remains vulnerable due to high non-performing loans and persistent current account deficits. Italy's high structural primary deficit and adverse interest rate-growth differentials exacerbate its fiscal risks, despite progress in managing bank exposures to sovereign debt. Spain's fiscal deficits and the expiration of temporary revenue-increasing measures contribute to its high-risk assessment, and stress tests indicate a faster increase in debt under alternative scenarios. Portugal's favorable initial budgetary position and structural reforms under the Recovery and Resilience Plan are crucial in mitigating its risks, although it remains vulnerable to economic and financing condition changes and the impact of demographic aging on public finances.

Without getting into even more details about the countries' financial performance and troubles, it is important to highlight that possible implications of repetitive climate related disasters with extreme economic losses accompanied by the gradual and structural damage of climate change can increase the financing needs of the Southern European countries.

2.9 Interest rates and Premiums

A special mention needs to be made about the risk premium imposed on government bond interest rates that Greece, Portugal, Spain and Italy are carrying in comparison to the standard in debt and bond yields which is Germany. Continuing the narrative of this chapter and taking as granted that repetitive disasters will increase the pressure on public finances via the pushing mechanisms that were introduced previously, it is reasonable to assume that the risk premiums will also increase. The risk premium is determined by comparing the interest rate a specific euro area country pays on its debt to the rate paid by a country with a perceived negligible risk of default, such as Germany. For risk-neutral investors, the risk premium reflects the anticipated loss in the real value of the debt. This is typically calculated as the probability of default multiplied by the expected loss in value if a default occurs (Cinzia & Daniel, 2019).

According to the most recent Debt Sustainability Monitor report by the European Commission, the results under different stress tests and scenarios are pointing towards the fact that High-debt Member States are more affected by the 'financial stress' scenario. This scenario increases debt by more than 1 %. of GDP by 2034 in only five countries, namely those with the highest projected debt ratios, which are Greece, Italy, France, Spain and Belgium. This occurs because higher interest rates have a more significant impact on interest payments when applied to large debts. This effect is intensified by the assumption that countries with high debt levels experience larger interest rate shocks (European Commission, 2024). Additionally, the sensitivity of a country to interest rate shocks depends on the maturity of its debt; shorter maturities mean that changes in market rates are more quickly reflected in the implicit interest rate. Moreover, the overall impact is also influenced by changes in gross financing needs which were discussed in the previous paragraph. As investors and ratings agencies increasingly recognize the vulnerability of these economies to climate change, they may expect to extract higher interest rates to cover the additional climate-related risk premium. The combination of falling ratings, rising default probabilities, and increased yield spreads found under higher emissions scenarios can be expected to increase borrowing costs in every country (Agarwala, Burke, Doherty-Bigara, Klusak, & Mohaddes, 2024).

2.10 Investment in Resilience and Adaptation

Investment in climate resilience is not just an environmental necessity but also an economic imperative for Southern European countries. These investments encompass a wide range of measures, such as fortifying infrastructure, developing early warning systems, and enhancing emergency response capabilities. Fortifying infrastructure involves upgrading buildings, roads, bridges, and other critical structures to withstand extreme weather events like floods and wildfires. This not only protects lives and property but also ensures that economic activities can resume quickly after a disaster.

It was highlighted in section 2.5 how the investment gap in adaptation policies plays an important role in future climate damages, it is also important to understand how crucial resilience is for the countries of South Europe. Reconstructing crucial infrastructure can take considerable time while finding the necessary funds to do so, can apply important fiscal pressure to the government's balance.

According to Catalano et al. (2019) baseline scenarios for both gradual global warming and extreme events suggest that without adaptation efforts, climate change will significantly reduce GDP, increase fiscal deficits, and raise debt levels. The study's main conclusion is that taking early, preventive measures to address climate change is far more effective than delaying action and opting for remedial measures later. Delaying action will result in the need for larger and more expensive adjustments in the future.

By increasing spending on mitigation and resilience early on, before gradual changes erode capital stock and extreme events cause further damage, fiscal and economic resilience can be improved, reducing the necessity for future expenditures. While early action is crucial, it alone is not enough to fully manage the extreme events linked to climate change. Countries often stabilize budget revenues, such as by mobilizing tax revenues, only after experiencing the impacts of climate change, rather than saving in advance (Gerling, 20217). Governments are particularly prone to focus on remedial actions if their fiscal policies are already procyclical (Catalano, Forni, & Pezzolla, 2019).

In addition, waiting to act simply means that larger and costlier adjustments will be needed in the future. Increasing spending on adaptation early, before gradual factors have eroded the capital stock and before extreme events have damaged it further, can increase fiscal and economic resilience, reducing the need for future spending (World Bank, 2019).The South European countries at the current fiscal conditions and regulation can only proceed with caution for building up their resilience plans as new needs rise all the time since the intensity and frequency of climate related natural disasters has increased.

2.11 Fiscal Buffers

Climate related natural disasters damage capital stock and sharply reduce economic output, with recovery being slow due to adjustment costs and partly dependent on the availability of financing (World Bank, 2019). The required funds to rebuild the capital stock might surpass both available domestic resources and the country's external borrowing capacity. The drop in GDP reduces government revenues, though grants from the European community may offer some relief. Lifeline support to affected populations and reconstruction efforts increase current expenditure. Rebuilding damaged public assets raises capital expenditure, while disruptions may delay other public investment projects. This situation creates "explicit" liabilities (impact on government-owned assets) and "implicit" liabilities (expected government support without formal contracts) (Aligishiev, Bellon, & Massetti, 2022). Consequently, financing needs are likely to necessitate additional borrowing, further damaging the government balance sheet.

The World Bank (2019) advocates that preventive adaptation spending enhances the resilience of the capital stock, thereby reducing the severity of damage and economic losses from disasters, though it cannot provide complete protection. Therefore, the optimal strategy is to combine early investment in adaptation with measures to expand fiscal space.

The fiscal buffers, essentially reserves or savings that governments can draw upon during times of economic stress, are critical for managing the unexpected costs associated with climate-related disasters. For countries like Greece, Italy, Spain, and Portugal, building and maintaining these buffers is challenging due to existing fiscal constraints in EU's fiscal rules.

In 30th of April,2024 the new economic governance framework entered into force. This came after the Commission had proposed in April 2023 the most ambitious and comprehensive reform of the EU's economic governance rules since the aftermath of the economic and financial crisis (European Commission, 2024). The new framework introduced risk-based surveillance that tailors oversight to the specific fiscal conditions of each Member State. This method follows a transparent EU-wide framework supported by safeguards. These safeguards ensure that debt is reduced over time (the debt sustainability safeguard) and provide a safety margin below the 3% of GDP Treaty deficit reference value to create fiscal buffers (the deficit resilience safeguard) (European Commission, 2024).

Despite the European Commission's invitation to create necessary fiscal buffers, current conditions and future climate challenges will decrease the success chances of this initiative. Fiscal buffers can be achieved through prudent fiscal management, reducing unnecessary expenditures, and potentially re-evaluating fiscal rules to allow more flexibility for climate-related spending. The necessary measures could include lowering debt levels to create more borrowing capacity or accumulating resources in a contingency savings fund before a disaster occurs (World Bank, 2019). Strengthening fiscal buffers will not only provide a safety net during extreme weather events but also ensure that these nations can invest in long-term climate resilience without jeopardizing their fiscal stability.

2.12 Re-assessment

Concluding the second chapter of this thesis, it is crucial to re-evaluate the narrative surrounding climate change and debt sustainability for South European countries. After examining the concept of the debt loop and the mechanisms that can propel a country into it, Greece, Italy, Spain, and Portugal face significant risks due to the factors analyzed in the preceding sections.

The combination of uncertainties regarding the severity and timing of climate change, coupled with the challenges in quantifying associated risks—even among industry experts—renders the situation critical. The analysis of Climate Adaptation and Investing in Resilience highlighted the fiscal obstacles these countries must overcome to prepare for the future. It was evident that substantial investments in infrastructure, early warning systems, and emergency response capabilities are necessary to mitigate long-term economic impacts and reduce fiscal strain from climate-related disasters.

Furthermore, the discussion on the Fiscal Implications of Climate Change underscored how these impacts will affect interest rates and premiums, complicating debt financing for Southern European nations. As climate-related fiscal pressures mount, maintaining sustainable debt levels becomes increasingly challenging, particularly given the existing economic vulnerabilities of these countries.

Finally, the importance of Fiscal Buffers was demonstrated. While these buffers are crucial for addressing future challenges, building them in the current economic environment is difficult. The analysis suggests that without proactive climate action and strategic fiscal planning, Greece, Italy, Spain, and Portugal will struggle to maintain economic stability in the face of escalating climate risks.

3. Data and Methodology

In this chapter, we outline the data sources and methodological approaches used in this study to assess the debt sustainability and economic resilience of Greece, Italy, Spain, and Portugal in the face of global warming damages The analysis leverages a comprehensive set of quantitative and qualitative data to provide a robust evaluation of each country's fiscal position. Detailed descriptions of the data collection process, the criteria for selecting relevant data sets, and the specific methodologies employed are provided. This chapter aims to ensure transparency and reproducibility of the results, offering a clear framework for understanding the analytical techniques and data-driven insights that underpin the findings of this research.

3.1 Data Collection and Description

3.1.1 COACCH Project

In order to answer the complex research questions of this master thesis, the author needed to put together a set of different datasets which concerned both the fiscal and the environmental aspect of the question. The most important asset which contributed to complete analysis comes from the aggregated economic climate damage that the COACCH project has calculated. This publicly available data set evaluates the broader economic implications of climate change impacts previously assessed by COACCH sectoral impact models, utilizing the ICES macroeconomic computable general equilibrium (CGE) model. The ICES model calculates EU regional GDP performance under climate change, which is then further refined to a higher spatial resolution using statistical downscaling techniques.

Additionally, the model can monitor the effects of a "shock," whether it is a policy signal (such as a tax or quota) or induced by climate change (such as changes in the availability or quality of production factors or shifts in household expenditures). This capability allows the model to assess how such shocks may influence the overall economic performance of a country or region, as well as its sectoral production and commodity prices. The analysis also considers potential distributional effects of these economic impacts (COACCH, 2022). This Master Thesis will be focusing on only one of the multiple projections published by the COACCH project and this is the compounding economic impact of all the examined sectors on GDP.

Macroeconomic impacts are examined across the nine SSP-RCP scenarios combinations used in the COACCH project and are specified for low, medium, and high impact cases to fully capture the range of uncertainties. This range is derived by inputting the highest and lowest values from the sectoral impact assessments into the macroeconomic model for each impact, year, and region. These assessments primarily vary based on the different climate models used to influence the sectoral impact model (Bosello, et al., 2020). The combinations of Socioeconomic and Climate pathways demonstrated much different results concerning the development of the dependent variable of the research which was the Debt/GDP ratio. It is therefore important to explain how each part influences the results and also how the narrative is completed only when the background of each SSP and RCP is provided accordingly.

On the one hand, the design and use of Shared Socioeconomic Pathways (SSPs) involve several open questions, such as their effectiveness in representing global challenges, the value of different narrative types within the same challenge domain, and the potential for development pathways to transition through multiple domains over time. SSPs need to incorporate lessons from specific contexts and be adaptable to various regional and sectoral needs. They are qualitative and often require extensions to support detailed analyses of climate responses and impacts. Capturing lessons from the application and extension of SSPs is crucial for refining them and enhancing their effectiveness in integrated climate change research.

The following SSPs can be distinguished:

- SSP1 - Sustainability (Taking the Green Road)
- SSP2 - Middle of the Road
- SSP3 - Regional Rivalry (A Rocky Road)
- SSP5 - Fossil-fueled Development (Taking the Highway)

More detailed information can be found on Section A.1 of the Appendix.

On the other hand, the Representative Concentration Pathways (RCPs) mark a significant advancement in the creation of new scenarios for climate research. They offer a comprehensive and detailed set of data, particularly in terms of spatial scale, for climate model projections. These scenarios encompass various radiative forcing pathways consistent with current literature, including detailed data on greenhouse gases like CO_2, CH_4, and N_2O. Unlike previous efforts, the RCPs offer extensive information on land use and air pollution with sectoral details for various sources and explicit geographic data at a 0.5×0.5-degree resolution. The greenhouse gas emissions data have been processed through a consistent carbon cycle and climate model and harmonized with the latest historical data, ensuring a smooth transition from historical periods to future scenarios without distorting the original Integrated Assessment Model (IAM) scenarios.

Future phases in developing new climate change scenarios should focus on creating a framework for socio-economic assumptions and narratives to guide analyses of RCP-based mitigation, adaptation, and impacts. While each RCP is based on internally consistent socio-economic assumptions, the set lacks a unified internal logic and does not cover the entire range of socio-economic trajectories found in the literature. Therefore, a community effort similar to the one that defined the climate aspects of the RCPs was needed to establish the socio-economic dimensions that will complement the RCPs.

The produced dataset includes information about the magnitude of the impact (Low, Medium, High), the geographic region that will be affected, combinations of SSP and RCP as also European Union Investment Mobility level (Low, High). Every data point for the variable of compounded economic impact was given as a percental difference to a baseline scenario. It is important to mention that those impacts are calculated on a regional scale and not on a national level, which is the targeted assessment of this report. Furthermore, the horizon for the estimations is until 2070 with a step of 5 years for every projection (e.g., 2025,2030, 2035, etc.).

3.1.2 GDP Projections

The second important dataset that was used for this research was retrieved from the International Institute for Applied Systems Analysis (IIASA) and Organization for Economic Co-operation and Development (OECD). Having the climate damages (as a percentage of GDP) in respect to the baseline scenarios, allowed for calculations, under the assumption that future projections of the GDP of the countries of the South were available.

The IIASA projections are available and are based on the methodology presented by Crespo Cuaresma (2017). Specifically, by leveraging the strong correlation between educational attainment, age structure dynamics, and economic growth, Crespo Cuaresma (2017) utilizes population projections based on age, sex, and educational attainment to derive income per capita trajectories up to the year 2100 for 144 countries. This approach provided a robust and consistent methodology for examining future environmental challenges and formulating potential policy responses. IIASA integrated into the model the effects of physical capital dynamics, institutional convergence, and growth in the technological frontier to project income per capita. OECD projections on countries' GDP were also made available through the same IIASA platform which remains open for public research usage.

The projections also consider factors such as labor force participation rates, migration patterns, and health outcomes, which are crucial for understanding the broader socio-economic context. By including these variables, the model captures the multifaceted nature of economic development and its implications for fiscal policy. Furthermore, the dataset allows for scenario analysis, enabling the examination of different policy interventions and their potential effects on economic growth and fiscal stability. Therefore, multiple projections for different SSPs were available, which led to a multilevel debt sustainability analysis.

3.1.3 EUROSTAT

The datasets obtained from Eurostat were indispensable for this research due to their comprehensive and high-quality economic and demographic data. Eurostat, as the statistical office of the European Union, provides standardized and comparable data across all member states, ensuring consistency and reliability in the analysis. This consistency is crucial for accurately comparing fiscal sustainability and economic resilience across Greece, Italy, Spain, and Portugal. The national statistical services complement this by offering more detailed and specific data at the national and regional levels, enabling a deeper understanding of local economic conditions and trends. By integrating these diverse data sources, the research benefits from a robust and multi-faceted dataset that supports rigorous analysis and policy recommendations.

From Eurostat, key economic indicators such as levels of regional GDP, real interest rates, and Debt/GDP ratios were acquired. These indicators are essential for assessing the economic performance and fiscal health of each country at both national and regional levels. The regional GDP data allowed us to identify economic disparities within countries and understand the economic contributions of different regions. Real interest rates provided insights into the cost of borrowing and its impact on investment and consumption. Debt/GDP ratios were critical for evaluating the sustainability of public finances and the capacity of governments to manage and service their debt. The integration of Eurostat and national statistical data ensured a comprehensive and reliable foundation for the research, enabling precise and actionable insights into the fiscal health and economic prospects of the studied countries.

3.1.4 IMF-International Monetary Fund

The last significant source of data used in this research was the International Monetary Fund (IMF). The IMF's World Economic Outlook, published in April 2024, provided crucial insights and projections regarding the debt sustainability and fiscal performance of Greece, Portugal, Italy, and Spain. This report's projections include the Debt/GDP ratio and economic growth forecasts for these countries up to 2029. Utilizing these projections was vital for the analysis.

The IMF's data offered a reliable benchmark for evaluating the future fiscal trajectories of the studied countries. The projections on Debt/GDP ratios were instrumental in assessing the sustainability of public finances and understanding the potential fiscal challenges each country might face. Similarly, the growth forecasts provided a foundation for estimating future economic conditions, which are critical for planning and policy formulation. By integrating the IMF's projections with other datasets, the research was able to present a comprehensive and robust analysis of the fiscal health and economic outlook of Greece, Portugal, Italy, and Spain. This combination of data sources ensured a prominent level of accuracy and reliability in the research findings, bolstering the validity of the policy recommendations derived from the study (International Monetary Fund, 2024).

3.2 Methodology

All the sources mentioned in the previous sections have been utilized to the maximum extent possible to make the debt model as robust as possible. The data have been filtered and organized so that these could be used in the analysis. The following paragraphs explain step by step the methodology that was followed to secure the replicability of the research and the results. Figure 3-1 presents a summary flowchart of the completed steps for each South European Country.

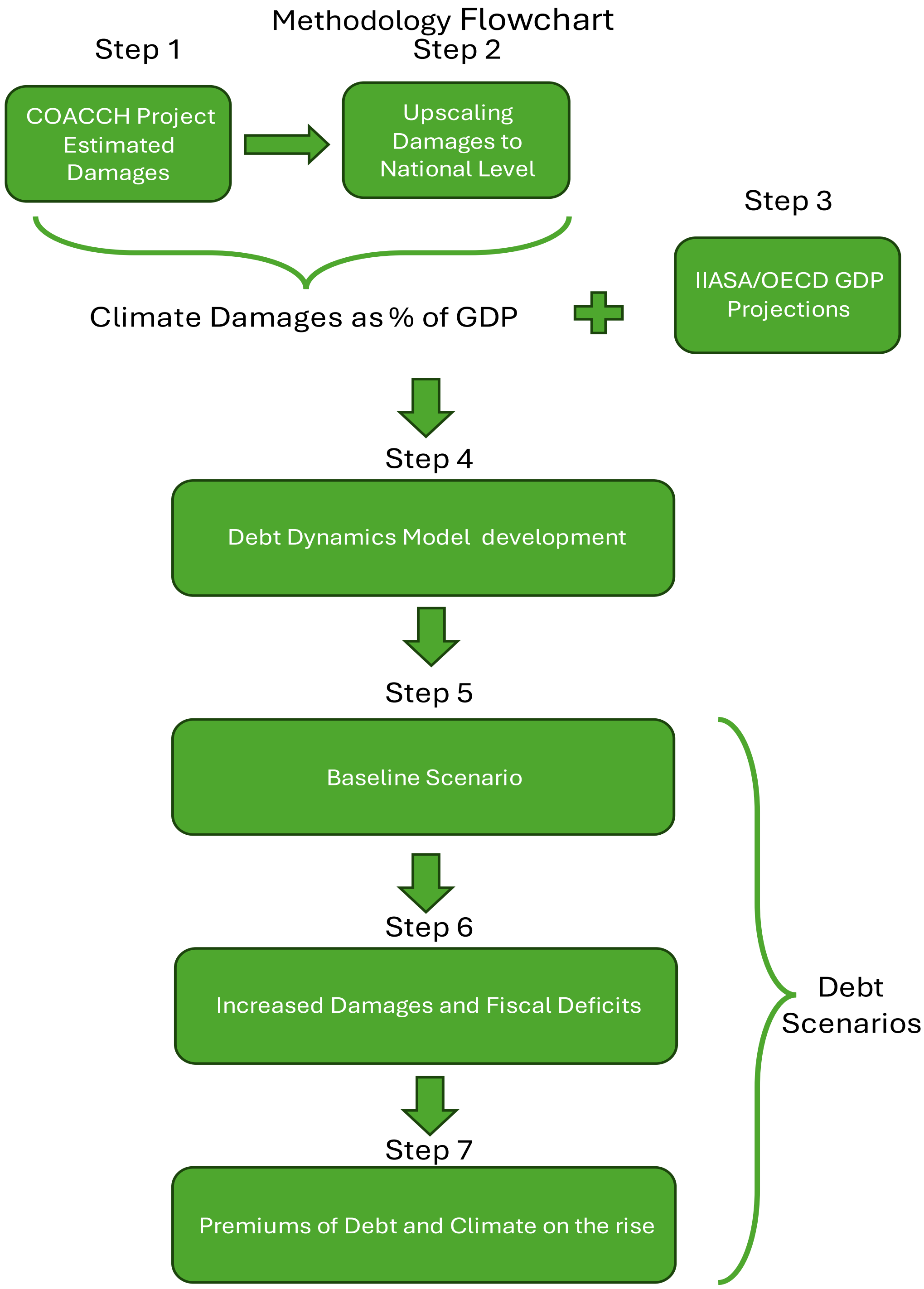

Figure 3-1 : Methodology Flowchart

3.2.1 Step 1- Data Collection and Filtering

For the first step in the methodology, the author filtered the extensive raw datasets from the COACCH Project according to predefined rules established at the outset of the research. This initial step was crucial to ensure the relevance and accuracy of the data used in subsequent analyses. The primary objective was to isolate the compounded effects calculated for each region, which were based on the NUTS-2 (Nomenclature of Territorial Units for Statistics) scale. This involved a detailed process of separating and filtering every possible combination of Shared Socioeconomic Pathways (SSP) and Representative Concentration Pathways (RCP) and their respective impacts on regional GDP for each country under study.

To enhance the precision of the dataset, each possible SSP-RCP combination was examined and filtered to capture the specific impact on regional GDP. This granular approach allowed for a detailed analysis of how different climate and socioeconomic scenarios might affect various regions within Greece, Italy, Spain, and Portugal. Additionally, the dataset included a variable for European Union Investment Mobility, which was deliberately set to a LOW value. This decision was based on the existing investment gap in resilience and mitigation policies, as previously discussed in the thesis. By setting this variable to LOW, the analysis could more accurately reflect the current investment landscape and its limitations and therefore affect the final recommendations.

Furthermore, the dataset was categorized based on the level of damage (Low, Medium, High) to provide a clear and structured view of the potential impacts. This categorization was essential for identifying the regions which are most vulnerable to economic damage and for prioritizing policy interventions. The comprehensive filtering process ensured that only the most relevant and accurate data points were included. This rigorous approach to data filtering and categorization underscores the importance of meticulous data management in conducting robust and credible research. Based on the conclusions from Bosello et al. (2020), the greater variation in results stems more from the choice of impact forcing data—whether from low, medium, or high impact cases—than from the different SSP-RCP combinations.

The high and low impact ranges are determined by selecting, for each impact, year, and region, the highest and lowest values produced by the sectoral impact assessments, which themselves primarily depend on the climate model used to influence the sectoral impact model. Consequently, model uncertainty appears significantly stronger than scenario uncertainty. By 2070, GDP impacts and their variability increase across different scenarios and impact realization cases. However, in relative terms, combination uncertainty grows more than model uncertainty. The combination uncertainty is translated to the varying trends that every combination of SSP-RCP is taking in the results which sometimes proved to be unexpected. On the other hand, model uncertainty expresses the differences between the two Integrated Assessment Models which projected the damages on a regional scale. While combinations had different outcomes for each country, models' estimations were separated by magnitude of damages in sectors such as Agriculture.

3.2.2 Step 2 – Data Transformation

Transforming the data from a regional to a national scale presented significant challenges, primarily due to the fact that the projections are available only as percentages rather than absolute numbers. To overcome this, the author employed a methodical approach utilizing historical data from the period of 2000-2022 available on Eurostat. This historical data included annual regional accounts in current market prices for Greece, Italy, Spain, and Portugal, along with their national GDP figures for the same years. Initially calculating the weight of each region in the national GDP. This was done by determining the percentage contribution of each region to the national GDP for each year within the historical period. By averaging these percentages over the 22-year period, the author established a reliable weight for each region relative to the national GDP. This average weight represented the typical economic contribution of each region within its country.

Next, these regional weights were applied to the projected impacts of climate damage. By multiplying the average regional weight by the corresponding impact (expressed as a percentage) due to climate damage, it was possible to estimate the aggregate effect of climate impacts on a national scale. This process was repeated for each region and each year from 2025 to 2070, allowing for a comprehensive national-level projection of climate impacts.

This transformation process effectively bridged the gap between regional and national data, enabling the calculation of aggregate effects on a national level. By leveraging historical GDP data and regional weights, the author ensured that the projections were grounded in actual economic contributions, providing a robust and credible basis for national-scale analysis. This approach not only facilitated the integration of regional data into the national and broader framework but also ensured the accuracy and reliability of the projections, allowing for meaningful policy recommendations and strategic planning for future climate resilience.

Nevertheless, it is crucial to highlight the assumptions that were necessary to make in order to move forward with the project. For instance, it is assumed that certain regions will on average maintain the same contribution to the national GDP for the next 50 years. Challenges include increased urbanization rate, climate disasters, technological advancements which can affect in a long horizon how a region contributes to the national economy. For instance, the islandic regions of all the countries of South Europe have an important and increasing effect on the national GDP via the tourism industry which continues to grow. Therefore, structural climate damage effects can prove to be larger than initially thought when translated to economic losses due to the increasing weight of these regions.

3.2.3 Step 3 – GDP and Economic Growth calculations

In the third step of the methodology, another dataset was employed to draw the initial conclusions about the project and the overall research. After calculating the aggregate damage, as percentages on a national level, for each possible combination of Shared Socioeconomic Pathways (SSP) and Representative Concentration Pathways (RCP), they were applied to the GDP projections from the IIASA and the OECD. This step was crucial to translate the percentage impacts into absolute economic terms and examine the projected decrease in GDP and understand the long-term economic impacts of climate change. By applying the damage percentages to these projections, it was possible to quantify the expected decrease in GDP in absolute numbers, thereby providing a clear picture of the potential economic consequences.

The analysis considered distinct levels of impact (Low, Medium, High) for each SSP-RCP combination, which resulted in significantly varied outcomes for future GDP. To smooth out the effect and see a more representative picture of how a specific combination affects the economy, the author chose to calculate the average effect and apply it on the respective projection.

3.2.4 Step 4 – Debt accumulation Model

In the fourth step, the development of the debt dynamics model began. The primary objective of this research is to explore the relationship between climate change and debt development. To achieve this, the author employed the widely used public debt accumulation equation to calculate the Debt/GDP ratio for each country within the study—Greece, Italy, Spain, and Portugal—extending the projection horizon until 2070.

$$\Delta\left(\frac{Debt}{GDP}\right)_t = Pb + [\,r - g_t] * \left(\frac{Debt}{GDP}\right)_{t-1}$$

Equation 1: Debt accumulation model

Every term is calculated and included as percentage %

Where:

- t : Referencing year
- Pb: Fiscal Deficit (excluding interest rate payments on public debt) as % of GDP
- r: Real Interest Rate based on the average value of historical data of 1996-2023
- g_t: Growth rate as % of real GDP at year t
- $Debt$: Gross Outstanding Public Debt
- GDP: Gross Domestic Product

In the equation above, $\Delta\left(\frac{Debt}{GDP}\right)_t$ calculates the difference between the Debt/GDP ratio in years t. By knowing the ratio for a specific year, it is possible to calculate the increase or decrease in subsequent years, assuming the other terms in the equation are known. The author's calculations began in 2029, as this is the last year for which the International Monetary Fund (IMF) offers projections and insights on the Debt/GDP ratio and economic growth for each country (International Monetary Fund, 2024)

Regarding real interest rates, due to the lack of projections and the current global inflation crisis, making accurate assumptions about this term is challenging. Therefore, historical data from the AMECO database, the annual macroeconomic database of the European Commission's Directorate General for Economic and Financial Affairs (European Commission, 2024), were utilized. By examining the historical deflated real interest rates for each country, it was possible to calculate an average rate. This analysis included the period from 2008 to 2017, a time when the spreads and interest rates for Southern European countries were significantly elevated due to the aftermath of the debt and financial crisis. Including these high rates in the average calculation allows for the consideration of potential future increases in interest rates, thereby enhancing the robustness and credibility of the research.

For the annual economic growth rate, another crucial term in the equation, the GDP projections from IIASA and the OECD for the years 2030-2070 were employed. A linear and evenly distributed growth rate was assumed for these calculations, ensuring a consistent and straightforward approach to estimating future economic performance. By integrating these historical and projected data points, the debt dynamics model provides a detailed and credible analysis of how climate change and natural disasters may influence the debt trajectories of Greece, Italy, Spain, and Portugal over the long term.

To better understand the potential repercussions of climate damage and related disasters, the author developed a set of three different scenarios to illustrate how the Debt/GDP ratio evolves over the years according to the growth and damage projections for each country. These scenarios are designed to provide a comprehensive view of the long-term fiscal impacts of climate change on the countries of South Europe.

3.2.5 Step 5 – The first Scenario - Baseline

The first, or baseline, scenario focuses on examining the effect of climate change from a structural damage perspective. In this scenario, the aggregate annual climate damages calculated in Step 2, were applied to the GDP projections, allowing the Debt accumulation model to be fully operationalized. More specifically, the aggregate damages include losses across several key sectors: Agriculture, Forestry, Fishery, Energy Prices, Labor Productivity, and Transportation. Unlike the immediate and abrupt devastation caused by natural disasters, these areas experience impacts in a structural and gradual manner. In agriculture, changing climate conditions can lead to decreased crop yields and increased pest infestations. Forestry faces the risk of altered growth patterns and increased vulnerability to wildfires. The fishery sector may suffer from shifts in fish populations and habitats. Energy prices can fluctuate due to changes in supply and demand dynamics influenced by climate conditions. Labor productivity might decline as extreme temperatures affect workers' health and efficiency. Lastly, transportation infrastructure can gradually degrade under persistent and extreme weather conditions, leading to increased maintenance costs and disruptions in logistics and supply chains.

To simplify the analysis and isolate the impact of climate damage, the fiscal deficit of the government was temporarily set to zero. This deliberate choice was made to exclude the influence of potential fiscal deficits or surpluses, operating under the assumption that the budget balance is maintained at zero. This approach ensures that any observed changes in the Debt/GDP ratio are solely attributable to the effects of climate change and related structural damages, without the confounding effects of fiscal policy variations.

Furthermore, by excluding potential deficits or unexpected losses caused by climate-related natural disasters, this scenario provides a clear view of how climate change alone can affect national debt levels. It abstracts from the complexities introduced by fiscal imbalances, focusing instead on the direct economic impacts of climate-induced damages. This allows for a more precise assessment of the vulnerability of each country's fiscal health to the gradual and cumulative effects of climate change.

Consequently, Equation 1 turns into:

$$\Delta\left(\frac{Debt}{GDP}\right)_t = [r - g_t] * \left(\frac{Debt}{GDP}\right)_{t-1}$$

Equation 2: Debt Dynamics model in Baseline scenario

- Pb: Fiscal Deficit is set to zero and therefore non-existent term compared to original equation
- r: Real Interest Rate remains constant and is equal to the average real interest rate of 1995-2023 for each country.
- g_t: Economic growth rate for every year, which constantly adjusts to the estimations of IIASA and OECD for 2030-2050 after the application of climate structural damages
- $\left(\frac{Debt}{GDP}\right)_{t-1}$: Debt/GDP ratio of the years before.

The change in Debt/GDP ratio is solely driven by the structural impact of climate damage on economic growth. This calculation took place for every country and every combination in Step 3. Consequently, after using the IMF projections for Debt/GDP ratio up until 2029 (first data point) and knowing the rest of the terms of the equation, it became possible to begin the iterative process until reaching the 2050 horizon.

3.2.6 Step 6 – Increased Damage Scenario

What sets the second scenario apart is the inclusion of the fiscal deficit impact from natural disasters. As there are no available datasets and projections for the horizon of this research, the author once again utilized historical data on climate-related disasters. Eurostat provided the necessary datasets, measuring annual losses for each country.

To translate these absolute values into useful percentages for the debt accumulation model, the annual losses were converted to percentages of each country's GDP in the corresponding year. This transformation allowed for a meaningful integration of disaster impacts into the debt dynamics model. A descriptive statistical analysis was conducted for each country, covering the period from 2000 to 2022. Although this sample period is relatively short for long-term projections and the data did not always exhibit a normal distribution, it provided a foundation for the analysis. The mean value of annual climate-related losses for each country was then used as the fiscal deficit value in the Debt accumulation model on an annual basis until 2050. This approach assumes that the average historical losses provide a reasonable estimate of future fiscal impacts from natural disasters.

To capture the varying severity of climate impacts, different percentages were assigned for each Representative Concentration Pathway (RCP). As climate conditions worsen, it is reasonable to assume that the average losses as a percentage of GDP will increase in more extreme scenarios. What was once considered an extensive loss could become the new average under more severe climate conditions. This adjustment allows the model to reflect the escalating fiscal impacts of climate change over time. By developing these scenarios, the thesis provides a detailed and nuanced analysis of how climate change and related natural disasters can influence the Debt/GDP ratio over time. This approach highlights the range of potential fiscal challenges and the importance of considering environmental factors in long-term economic planning.

Thus, the percentages were added accordingly to the severity of the climatic scenario:

RCP	**Fiscal Deficit value**
2.6	Mean
4.5	Mean + Standard Deviation
6.0	Mean + 2* Standard Deviation
8.5	Mean + 3* Standard Deviation

Table 1 : 2nd Scenario Fiscal Deficits distribution

This adjustment in the input conditions of the debt model led to much differentiated results from the first scenario and made the assumptions more robust as sensitivity was essentially established into the outcome. Moreover, by increasing the magnitude of the fiscal deficit to account for the growing severity of climate-related natural disasters, the model captures a more realistic scenario of escalating fiscal pressures. This adjustment reflects the likely increase in government spending required to address and recover from more frequent and severe climate events.

Consequently, Equation 1 returns to its original form with the following terms:

$$\Delta\left(\frac{Debt}{GDP}\right)_t = Pb_{RCP} + [r - g_t] * \left(\frac{Debt}{GDP}\right)_{t-1}$$

- Pb_{RCP}: Fiscal Deficit remains fixed for the whole period of 2030-2050 but changes according to the RCP examined. More damaging RCPs carry an increased Fiscal Deficit as shown in Table 1
- r: Real Interest Rate remains constant and is equal to the average real interest rate of 1995-2023.
- g_t: Economic growth rate for every year, which constantly adjusts to the estimations of IIASA and OECD for 2030-2050 after the application of climate structural damages
- $\left(\frac{Debt}{GDP}\right)_{t-1}$: Debt/GDP ratio of the years before.

The change is now driven by both fiscal deficits and structural damages endogenized in the economic growth as happened in the baseline scenario. Knowing every term of the equation by relying on the projections of IMF up until 2029 for Debt/GDP, allowed for the calculation of the years ahead with constant iteration of the process.

3.2.7 Step 7 – High Risk Premiums Scenario

In the conclusive step of the methodology, the debt and climate premium risks are incorporated into the model. Southern European countries, like all others, are constantly compared to a benchmark regarding their fiscal performance. Germany serves as this benchmark in the European Union for bond yields. As briefly explained in 2.9 section, interest rates are crucial for debt refinancing, and fiscal instability can significantly increase a country's yields, adding financial pressure.

Financial markets and credit rating agencies assess risks based on future outcomes after extensive analysis. According to an IMF report from 2017, the debt premium is calculated by adding 4 basis points (BPS) for every 1% above the threshold of a 60% Debt/GDP ratio (International Monetary Fund, 2017). For Greece, this premium would now be almost 400 BPS, translating to an additional 4% on the interest rate.

The European Commission uses a similar rule but with 3 BPS instead. Such increases could make issuing new debt almost non-viable due to the heavy toll on future interest payments, but premium rates also depend on other factors such as political stability which is not covered in this report. Literature is inconclusive regarding the climate premium that countries pay due to their vulnerability to climate challenges. While certain conclusions about downgrades in credit ratings for small developing island nations exist, these cannot be directly compared to Greece, Portugal, Spain, and Italy. Despite their fiscal challenges over the last decade, these countries are developed economies with presumably better resilience to climate change.

Nevertheless, it is reasonable to assume that repeated economic losses from climate change and related disasters will increase market pressure on Southern European countries, adding extra premium BPS over the long term. Following the losses pattern of the COACCH Project, premiums are increased every five years in alignment with assumed damages. It is important to note that the trajectory of these scenarios can vary significantly based on each country's response to economic losses, including decisions to invest in resilience and adaptation measures but also to take the necessary fiscal austerity measures to stop the debt evolvement.

By integrating these debt and climate premium risks into the model, the final scenario provides a comprehensive view of the potential long-term fiscal impacts on Southern European countries. This analysis underscores the importance of understanding how external financial pressures and climate vulnerabilities interact, influencing the overall economic stability and debt sustainability of these nations.

Thus, the third scenario introduced the following BPS to be added both for Debt and Climate Conditions, similar to the adjustment of the Increased Damage Scenario:

- Debt Premium (Every 1% increase in the Debt/GDP ratio) → 3 BPS
- Climate Premium (Added on a 5-year step in 2030-2050, 4 total additions)

RCP	Basis Points (BPS)
2.6	5
4.5	7
6.0	8
8.5	10

Table 2 : 3rd Scenario Climate Premium BPS

It is important to underscore that the less aggressive elasticity value of the EU Commission was selected instead of the elasticity value used by the IMF as the scope of the project and the scenario is more focused on the environmental aspect and its repercussions.

Consequently, Equation 1 returns to its original form with the following terms:

$$\Delta\left(\frac{Debt}{GDP}\right)_t = Pb_{RCP} + \left[\, r_{BPS_t} - g_t \right] * \left(\frac{Debt}{GDP}\right)_{t-1}$$

- Pb_{RCP}: As in the second scenario, the Fiscal Deficit remains constant for the whole period of 2030-2050 but changes according to the RCP examined. More damaging RCPs carry an increased Fiscal Deficit as shown in Table 1
- r_{BPS_t}: Real Interest Rate is adjusted every year as BPS are added based on debt development and the different premium values for RCPs in Table 2
- g_t: Varies according to the estimations of IIASA and OECD for 2030-2050
- $\left(\frac{Debt}{GDP}\right)_{t-1}$: Debt/GDP ratio of the years before.

The development of the Debt/GDP ratio is now dependent on the structural damage of climate change endogenized through the impact on economic growth, the fiscal deficits caused the repetitive natural disasters, and the premium rates added on the real interest based on the worsening of the debt and climate conditions.

This step concluded the methodology. In conclusion, the methodology employed in this research integrates a comprehensive approach to analyzing the interplay between public debt and climate change impacts in Southern European countries. By utilizing a variety of datasets from Eurostat, IIASA, OECD and the IMF, this study provides robust projections of future debt dynamics under varying climate scenarios. The inclusion of historical data to estimate real interest rates and the innovative translation of climate-related disaster losses into GDP percentages enhances the credibility and accuracy of the projections.

4. Results of the scenario Analysis

This chapter presents the evolution of the public-Debt/GDP ratio in Southern Europe (2030-2050) in a variety of relevant scenarios of future climate change. The scenarios are presented together with analysis and the narrative behind every result. Initially all the combinations are demonstrated in a single graph for each country and each one of the three described scenarios. This chapter aims to provide data-driven insights about the development of Debt – to – GDP ratio under all the assumptions that discussed during the Methodology.

4.1 Creating the baseline

First, it is necessary to clarify the produced quantity of graphs that it was possible to calculate by combining multiple datasets, projection and estimations. The diagram below shows the different combinations of IAM, SSP, RCP, GDP Projection and Country.

More specifically:

- 2 Integrated Assessment Models (EPIC, LPJmL)
- 4 Shared Socioeconomic Pathways (SSP1,2,3,5)
- 2 minimum Representative Concentration Pathways as not every RCP is available for every SSP.
- 2 GDP Projections (IIASA, OECD)
- 3 levels of Impacts for every SSP-RCP (Low, Medium, High)
- 4 Countries (Greece, Italy, Spain, Portugal)
- 3 Different Scenarios (Baseline, Increased Damage, Full Damage)

The designed scenarios are separated by the logic and methodology that was elucidated in section 3.2.5. Initially, the annual climate damages during 2025-2050 are derived from the COACCH project for both IAMs. This time-series data is next combined with projections of GDP by IIASA, OECD to result in climate-decreased economic growths. This is where the model begins its calculations on Debt/GDP ratio. The thesis considers nine different combinations under whom, every country and every scenario are tested. The number of possible scenarios and combinations comes to 480 singular graphs that resulted from the analysis.

To present a comprehensive picture of the situation, the author opted to take the average projections from both IIASA and OECD. Additionally, the average level of impact for each combination of variables was chosen, ensuring that the report provides a balanced narrative rather than focusing solely on extreme scenarios. This approach allows for a more nuanced understanding of the potential outcomes, offering a well-rounded perspective on the economic implications of climate change and natural disasters on public debt dynamics in Southern European countries. By utilizing these averaged projections and impacts, the analysis remains grounded and relevant, reflecting a realistic range of possibilities while avoiding undue emphasis on outliers. With these decisions, the total combinations come to 192 individual charts.

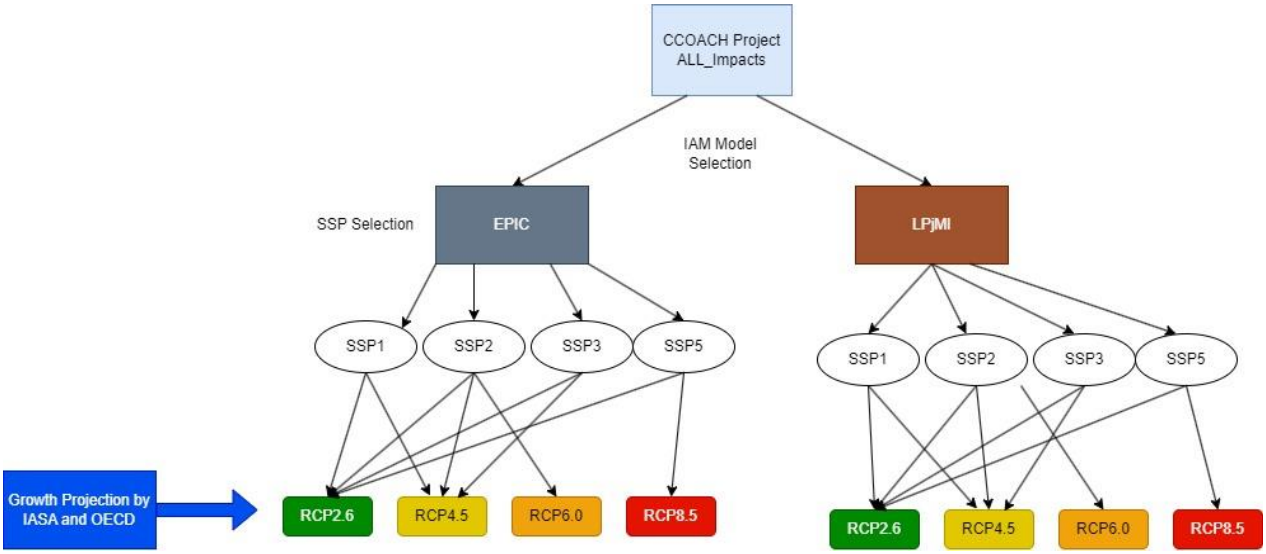

Figure 4-1: Output Graph for each country.

In Figure 4-1, the flowchart of data is illustrated. Initially, the COACCH project provided an Integrated Assessment Model. From there, SSP1 (Shared Socioeconomic Pathway 1) was selected, which then allowed for the selection of an RCP (Representative Concentration Pathway). At the final stage, growth projections were combined with the derived damage estimates to create the first scenario, which serves as a baseline for the subsequent scenarios.

The possible combinations were:

- SSP1-RCP2.6
- SSP1-RCP4.5
- SSp2-RCP2.6
- SSP2-RCP4.5
- SSP2-RCP6.0
- SSP3-RCP2.6
- SSP3-RCP4.5
- SSP5-RCP4.5
- SSP5-RCP8.5

The results for every country follow in the next sections of this chapter.

4.2 Greece (2025-2050)

Before presenting the results for each scenario, it is important to showcase the aggregated damages that were calculated for each combination of SSP-RCP in order to be able to incorporate and explain the development of the debt ratios.

4.2.1 Aggregate Climate Damage

The projected climate damages (as a percentage of GDP) for Greece during 2025-2050 appear in Figure 4-2 for nine future climate scenarios.

Figure 4-2: Greece GDP structural losses on a national level until 2050.

The projections underscore that Greece's future economic resilience is intricately linked to the level of climate action and the stability of its socioeconomic environment. Scenarios featuring robust climate policies combined with sustainable development practices, such as SSP1-RCP2.6, present the most favorable outcomes. These scenarios effectively minimize GDP losses and enhance economic stability by prioritizing renewable energy sources and fostering international cooperation.

In stark contrast, scenarios characterized by insufficient climate action and significant geopolitical challenges, such as SSP5-RCP8.5 and SSP3-RCP4.5, pose substantial risks to Greece's economic stability. SSP5-RCP8.5, despite its strong economic growth driven by non-renewable resources, results in high environmental costs that could undermine long-term fiscal health. Meanwhile, SSP3-RCP4.5, with its focus on regional rivalries and protectionist policies, exacerbates debt growth due to stagnating economic performance, even with moderate climate action. Moreover, the spread between the “best” and “worst” outcomes for the Greek economy is approximately 0,6% in GDP losses by 2050, translating to a significant economic impact.

4.2.2 Baseline for the Greek public Debt/GDP ratio (2030-2050)

Growth of debt is solely impacted by the financial damages caused by climate change under various combinations, which sequentially lower growth and lead to an unsustainable increase in debt. In this scenario, the fiscal deficit is assumed to be zero, highlighting the gap between interest rates and the real rate of growth. The baseline scenario for Greece is presented in Figure 4-3.

Note that in this scenario, the public-Debt/GDP in Greece will be affected by climate damages in two ways. First, because climate damage as a proportion of GDP rises over time, it will negatively affect the growth rate g_t in the debt dynamics equation. Second, because climate damage lowers the level of GDP, it will contribute to a rise in the debt-GDP ratio in the debt dynamics equation. Via these two channels, climate change does affect the evolution of the public-Debt/GDP ratio over time.

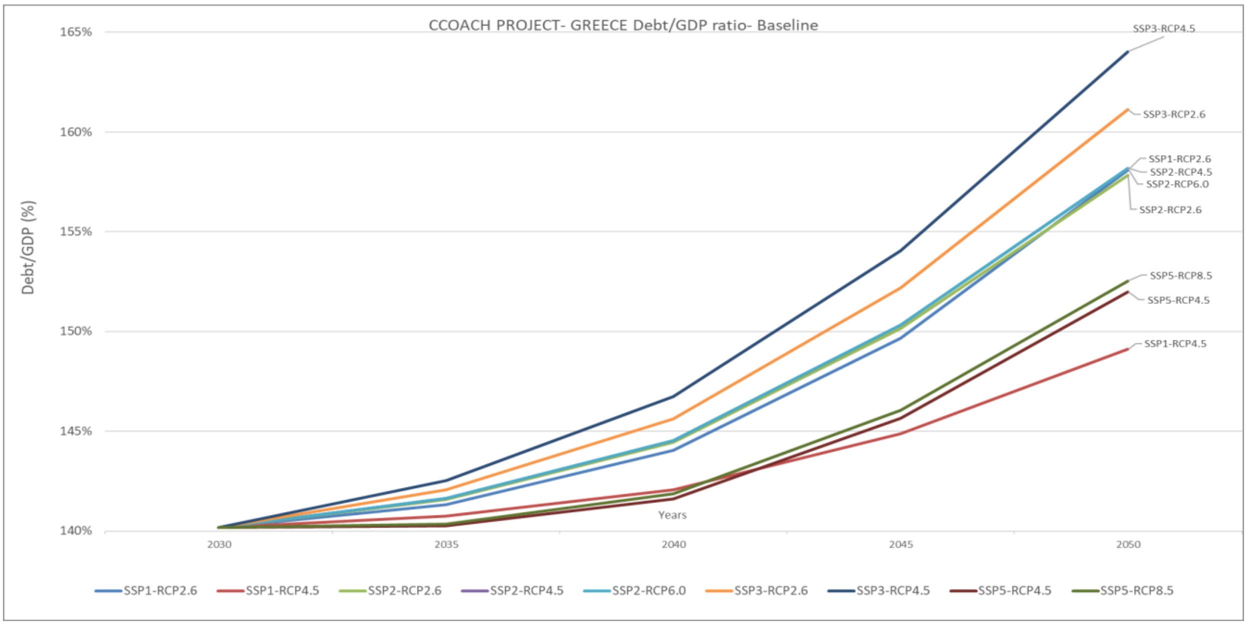

Figure 4-3: Greece Debt/GDP Baseline

In this scenario, it is evident that the combination of SSP3-RCP2.6 and SSP3-RCP4.5 are leading as the least favorable outcome for Greece's economy and debt sustainability. Scenarios like SSP3, which involve regional rivalries, exhibit significant debt growth even with strong climate action, highlighting the impact of geopolitical stability on fiscal sustainability. The spread between SSP3-RCP4.5 and SS5-RCP8.5 is approximately 12% in the Debt/GDP ratio in 2050 which constitutes a rather significant difference.

Another worth noting fact is that already by 2035 the structural damage of climate change is distinguishing the more conservative/mild outcomes from the extremes. In addition, it is noticeable that combinations which include severe climate damage such as SSP5-RCP8.5, have performed much better in this context due to economic growth achieved by focusing on oil and gas instead of renewables. This result is surprising as Figure 4-2 is showing contrasting directions for combinations which include SSP5 in relation to the damage inflicted to the GDP and the actual Debt/GDP ratio. This interesting observation is explained by the strong economic growth in SSP5 which keeps the Debt/GDP ratio lower than the leading combination.

4.2.3 Climate damages lead to fiscal deficits

In this scenario, the model encompasses the climate damages as the fiscal deficit term of Equation 1 . The deficit adjusts according to the examined combination, with more destructive RCPs having increased deficits following Table 1. The results for the second scenario are presented in Figure 4-4.

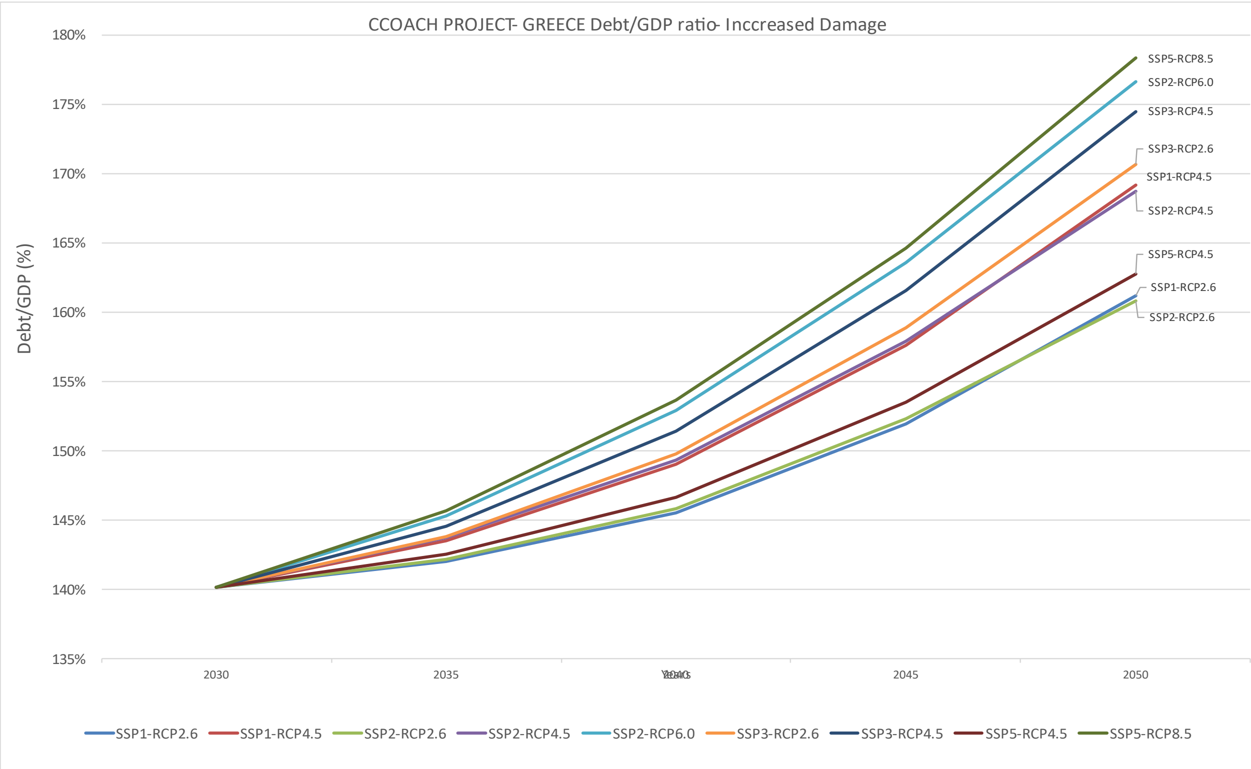

Figure 4-4: Greece Debt/GDP ratio Increased Damage

Combination\Years	2030	2035	2040	2045	2050
SSP1-RCP2.6	140,16%	142,09%	145,77%	152,43%	161,98%
SSP1-RCP4.5	140,16%	143,65%	149,28%	158,09%	170,04%
SSP2-RCP2.6	140,16%	142,33%	146,15%	152,89%	161,70%
SSP2-RCP4.5	140,16%	143,89%	149,68%	158,57%	169,75%
SSP2-RCP6.0	140,16%	145,44%	153,26%	164,21%	177,57%
SSP3-RCP2.6	140,16%	143,96%	150,16%	159,58%	171,84%
SSP3-RCP4.5	140,16%	144,72%	151,89%	162,43%	175,97%
SSP5-RCP4.5	140,16%	142,66%	146,87%	153,91%	163,43%
SSP5-RCP8.5	140,16%	145,84%	154,13%	165,34%	179,24%

Table 3: Greece Debt/GDP ratio Increased Damage

After the introduction of fiscal deficit for Greece based on the historical data from the years 2000-2022, the scenario outcome changes considerably. Now the least favorable outcome for Greece is the combinations with increasing climate damages such as those that include RCP8.5 and 6.0. The spread between the last and the first in order combination is almost 18% difference as SSP5-RCP8.5 accumulated debt was calculated to 179,24% of GDP while the combination of SSP1-RCP2.6 which includes adequate political action, and the mildest environmental scenario was calculated to 161,98% of Greece's GDP in 2050.

It is becoming evident enough that when repeated catastrophes are incorporated into the model then suddenly the situation revolves around. The damages that are caused due to the inaction for mitigating the losses and fortifying the resilience of the country, were much greater than the actual economic growth that is projected for SSP5 which is focused on Non-Renewable sources of energy as the engine of the economies.

In addition, the second least favorable combination SSP2-RCP6.0, is projecting a rather high Debt/GDP ratio, due to the economic losses that can be caused from repeated disasters. It is worth noting that in contrast to the leading SSP5-RCP8.5, the combinations with SSP2 are more favorable towards climate action and mitigation but if current projections about climate change and time are wrong then possibly even scenarios which are pushing for Zero Emissions and climate action may not be capable of reversing reverse the situation. The various levels of RCP under the same SSP, showcase how impactful the disasters can be for the sustainability of Greece debt, as the combinations SSP2-RCP2.6, SSP2-RCP4.5, SSP2-RCP8.5 have 8% difference in the terminal year of our analysis (2050).

Overall Scenarios with strong climate policies (SSP1-RCP2.6) offer the more favorable outcomes, minimizing the increase in Debt/GDP ratios. Conversely, scenarios with minimal climate action (SSP5-RCP8.5) lead to severe fiscal stress and unsustainable debt levels. Integrating comprehensive climate resilience strategies with economic policies is essential for ensuring long-term fiscal health and mitigating the economic impacts of climate-related damages.

4.2.4 Risk Premiums on the rise

The third set of scenarios is similar to the second set of scenarios, except for the fact that in the third set of scenarios, the risk premiums paid on public debt and climate deterioration have been endogenized. In specific, the BPS of climate and debt are added to the historic average real interest rate used since the Baseline scenario. In that way it is possible to investigate the compounding effect of rising premiums on the Debt/GDP rise. 3rd scenario results are presented in Figure 4-5.

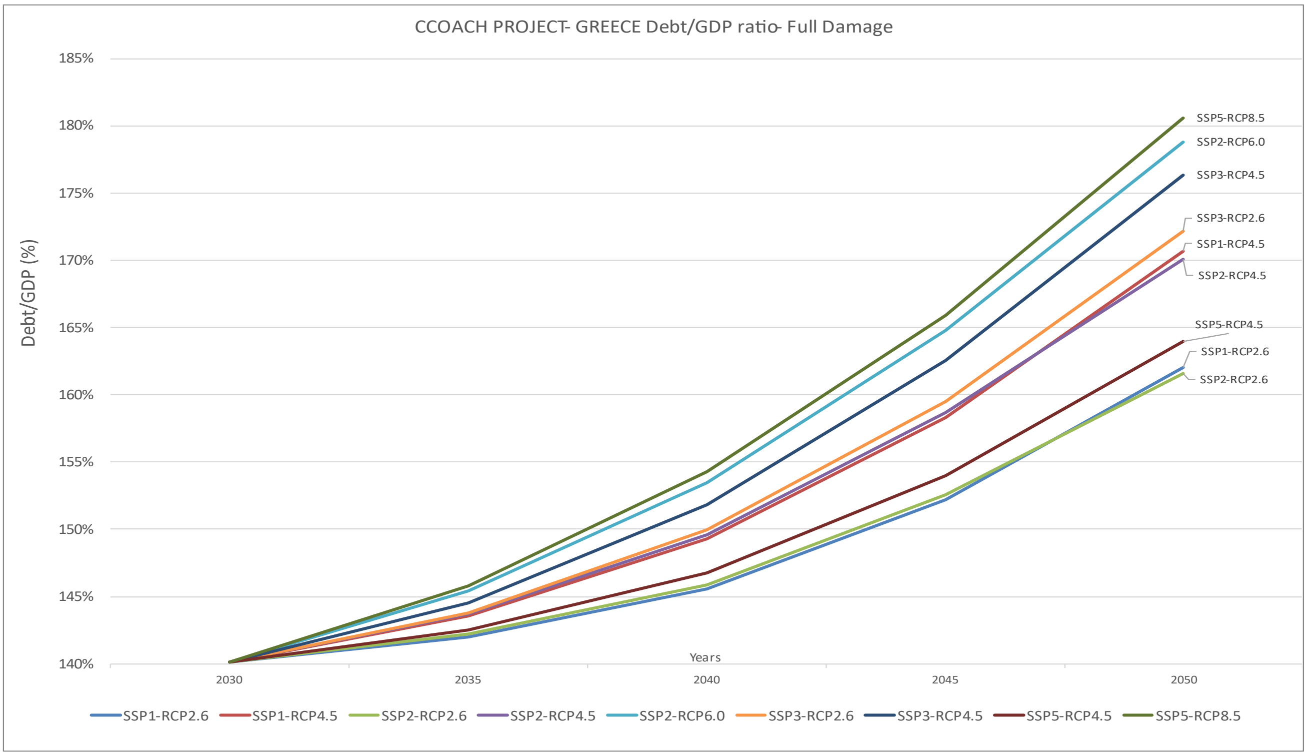

Figure 4-5: Greece Debt/GDP-Full Damage

Combination\Years	2030	2035	2040	2045	2050
SSP1-RCP2.6	140,16%	142,09%	145,84%	152,77%	162,89%
SSP1-RCP4.5	140,16%	143,65%	149,51%	158,82%	171,58%
SSP2-RCP2.6	140,16%	142,33%	146,23%	153,26%	162,66%
SSP2-RCP4.5	140,16%	143,89%	149,91%	159,30%	171,14%
SSP2-RCP6.0	140,16%	145,57%	153,87%	165,45%	179,75%
SSP3-RCP2.6	140,16%	143,96%	150,37%	160,30%	173,35%
SSP3-RCP4.5	140,16%	144,72%	152,31%	163,46%	177,91%
SSP5-RCP4.5	140,16%	142,66%	146,97%	154,44%	164,58%
SSP5-RCP8.5	140,16%	145,97%	154,77%	166,64%	181,50%

Table 4:Greece Debt/GDP - Full Damage

After incorporating the debt and climate premiums, the results presented in Figure 4-5 indicate that the rankings remained consistent despite the addition of more risks. Specifically, the leading and least favorable combination for Greece's debt sustainability remained unchanged, with the SSP5-RCP8.5 scenario exhibiting the worst Debt/GDP ratio, closely followed by the SSP2-RCP6.0 scenario. This consistency suggests that the rise in interest rates, driven by worsening fiscal conditions and repeated climate-related losses, did not significantly alter the projected scenario outcomes up to 2050 in comparison to the 2nd Scenario and the addition of deficits into the model. The resilience of these rankings highlights that even under increased financial pressures, the relative severity of different climate scenarios on debt sustainability remains stable.

This finding underscores the vulnerability of Greece's fiscal position to high-impact climate scenarios, reaffirming the critical importance of addressing both environmental and economic factors in long-term fiscal planning. Furthermore, it is worth noting that once more the combinations that gain advantage from 2035, they end up keeping the pace until the end of the horizon. This is aligning with the Baseline scenario in Figure 4-3 which also points out that the first symptoms of economic losses will start to be visible from 2035. Finally, the compounding effect or snowballing effect is present in all the unsustainable combinations, as it is evident that the rise is more direct than during the first years of the period of analysis.

More specifically the differences between scenario of Increased damage and Full Damage are presented as follows:

2050

Combination	2nd Scenario	3rd Scenario	Δ
SSP1-RCP2.6	161,98%	162,89%	0,91%
SSP1-RCP4.5	170,04%	171,58%	1,54%
SSP2-RCP2.6	161,70%	162,66%	0,96%
SSP2-RCP4.5	169,75%	171,14%	1,38%
SSP2-RCP6.0	177,57%	179,75%	2,18%
SSP3-RCP2.6	171,84%	173,35%	1,51%
SSP3-RCP4.5	175,97%	177,91%	1,95%
SSP5-RCP4.5	163,43%	164,58%	1,15%
SSP5-RCP8.5	179,24%	181,50%	2,26%

Table 5: Differences between 2nd and 3rd Scenario

4.3 Italy (2025-2050)

The results highlight key trends, vulnerabilities, and the relative impacts of different climate scenarios on Italy's fiscal stability.

4.3.1 Aggregate Climate Damage

In order to better grasp the magnitude of the structural damages caused by climate change in all the possible combinations of SSP-RCP, Figure 4-6 provides a visual representation of the projected damages as % of GDP for Italy during 2030-2050. In this case the difference in Debt/GDP ratio is solely driven by the differential between Italy's historic average real interest rate and the IIASA/OECD projected economic growth.

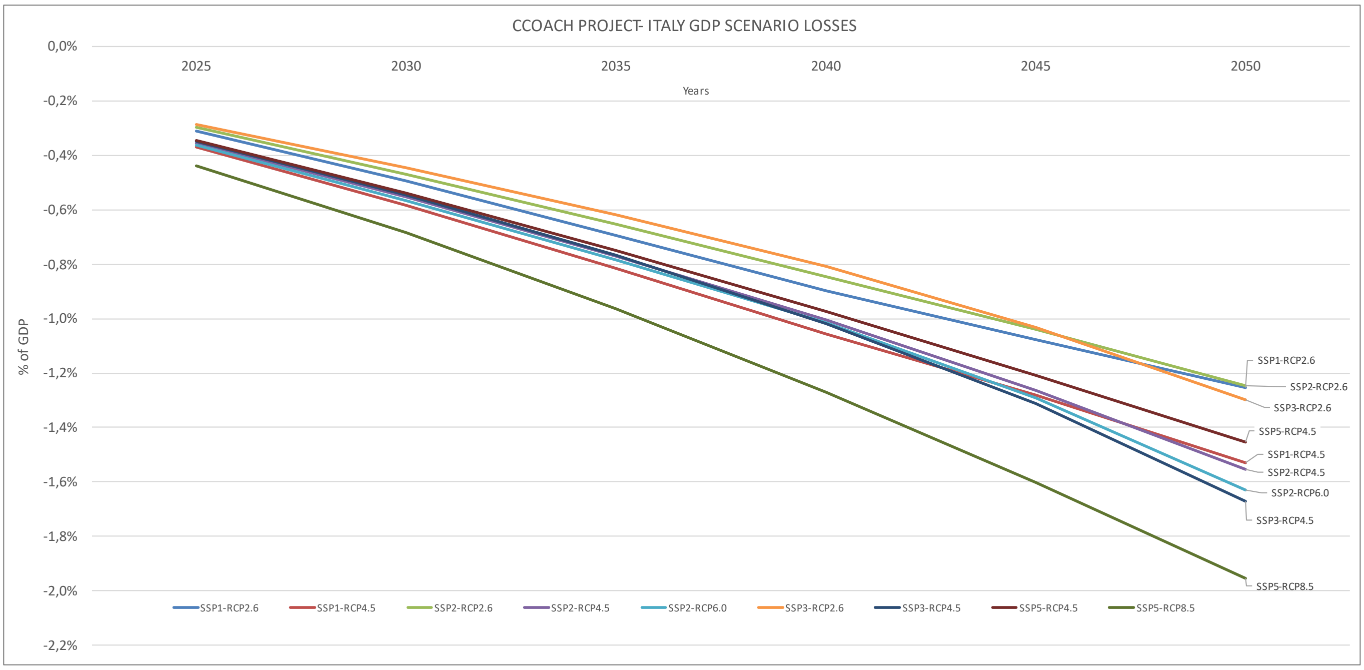

Figure 4-6:Italy GDP structural losses on a national level until 2050

It is evident that losses are greater in combinations that either lack significant climate action or experience severe climate consequences. The SSP5-RCP8.5 scenario, characterized by limited climate mitigation efforts and high emissions, consistently shows extensive damage from the outset, with these damages becoming more pronounced as years progress. Moreover, it is important to highlight the relatively small margin of difference between SSP1-RCP2.6 and SSP1-RCP4.5. Despite representing pathways with strong climate action, the slightly higher emissions and less stringent mitigation efforts in SSP1-RCP4.5 led to noticeable, though not drastically higher, economic losses compared to SSP1-RCP2.6. This comparison illustrates how even modest differences in climate policies can have significant economic consequences for a whole country due to the aggregation and compounding of the damages.

In addition, the SSP2-RCP6.0 scenario remains an unfavorable outcome for Italy's economy. Although SSP2 includes moderate climate resilience and mitigation policies, the relatively high emissions associated with RCP6.0 result in substantial economic losses. This scenario highlights the inadequacy of middle-ground approaches where policies are neither aggressive enough to prevent significant climate impacts nor sufficient to buffer the economy against such damages. Lastly, it is noticeable that the development of the losses is taking place in a gradual and almost even way for all the combinations until 2050. This off course cannot be reassuring for future and possible natural disasters that can cause a financial crisis through the mechanisms that were mentioned in Causes of a 'Debt Loop', as a spike in the losses can also activate a snowfall effect.

4.3.2 Baseline for the Italian public Debt/GDP ratio (2030-2050)

The baseline of the public-Debt/GDP in Italy for the different scenarios is given in

Figure 4-7. As for Greece, we assume that climate damages affect the debt-GDP ratio by lowering the growth rate (g) and by raising the debt-GDP ratio in the debt dynamics equation. The Italian fiscal deficit is assumed to be zero during 2030-2050 in the baseline.

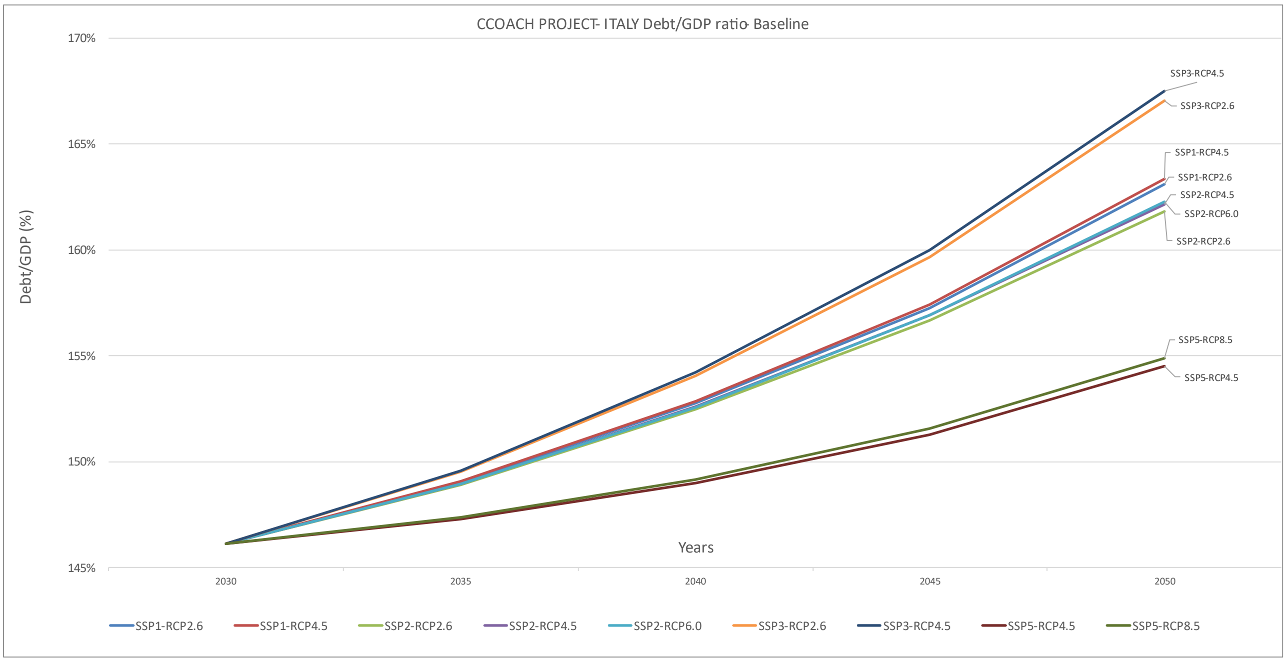

Figure 4-7: Italy Debt/GDP ratio - Baseline Scenario

The Baseline scenario for Italy verifies the findings observed for Greece, indicating that under the assumption of no fiscal deficits for the government, the least favorable combinations for debt sustainability are those that do not take a decisive approach but rather opt for a middle path. More specifically, SSP3 and RCPs 2.6, 4.5 exhibit the highest Debt/GDP ratios. Similarly, combinations including SSP1 and SSP2 also show unfavorable outcomes, though they are slightly better than SSP3 combinations. This suggests that while these pathways incorporate more robust climate action and resilience measures, the adaptation challenges and costs associated with implementing these actions can still lead to considerable fiscal strain. The need for substantial investment in mitigation and adaptation under these scenarios adds to the economic burden, thereby impacting debt sustainability.

Lastly, an interesting observation is the approximately 10% difference between the best and worst outcomes in the projected Debt/GDP ratios. This spread highlights the significant impact of varying economic growth rates and climate change consequences under different SSP-RCP scenarios. Notably, combinations involving SSP5, despite being associated with severe climate impacts, show relatively favorable outcomes for public debt sustainability. This can be attributed to the strong economic growth that characterizes SSP5 scenarios, which appears to outweigh the economic losses caused by climate change.

This finding presents a contrasting view, somewhat contradicting the results depicted in Figure 4-6, where the most damaging combination from a climate impact perspective ends up being the most favorable for debt sustainability. This paradox underscores the complex interplay between economic growth and climate-related damage. While SSP5-RCP8.5 scenarios involve significant environmental costs, the robust economic growth inherent in these pathways provides a buffer, mitigating the negative effects on the Debt/GDP ratio.

4.3.3 Climate damages lead to fiscal deficits

In the second set of scenarios for the Italian economy, it is assumed that the fiscal deficit of Italy (as a proportion of GDP) during 2030-2050 is equal to the average climate related economic losses of Italy during 2000-2022. Figure 4-8 demonstrates the following results:

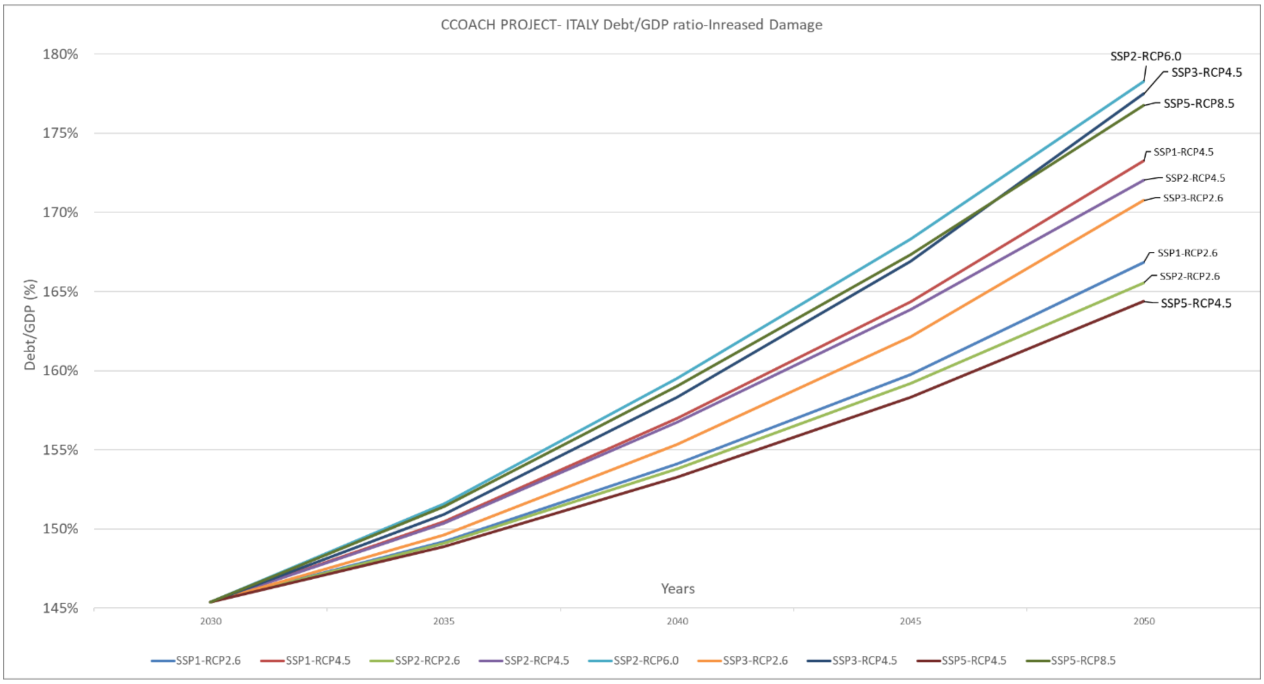

Figure 4-8: Italy Debt/GDP ratio - Increased Damage Scenario

Combination/Year	2030	2035	2040	2045	2050
SSP1-RCP2.6	145,4%	149,2%	154,1%	159,8%	166,9%
SSP1-RCP4.5	145,4%	150,5%	157,0%	164,3%	173,2%
SSP2-RCP2.6	145,4%	149,1%	153,8%	159,2%	165,6%
SSP2-RCP4.5	145,4%	150,4%	156,7%	163,9%	172,0%
SSP2-RCP6.0	145,4%	151,6%	159,5%	168,3%	178,3%
SSP3-RCP2.6	145,4%	149,6%	155,3%	162,1%	170,8%
SSP3-RCP4.5	145,4%	150,9%	158,3%	166,9%	177,5%
SSP5-RCP4.5	145,4%	148,9%	153,3%	158,3%	164,4%
SSP5-RCP8.5	145,4%	151,4%	159,0%	167,3%	176,8%

Table 6: Italy Debt/GDP ratio-Increased Damage Scenario

After incorporating the economic losses caused by the natural disasters as fiscal deficit in the model the results are presented greatly differentiated from the Baseline Scenario. First the least favorable combination is SSP2-RCP6.0 which despite the adequate climate action, is also assuming significant losses. Already from the baseline scenario it was possible to foresee that the losses from RCP6.0 can put extended fiscal pressure in Italy's economy which will also need to adequately face the adaptation risks that accompany SSP2. An interesting observation is the percentage difference between 2030 and 2050 which is calculated to be 32,9%, a rather substantial increase for a 20-year period.

Following, the combinations SSP3-RCP4.5 and SSP5-RCP8.5 are projecting closely similar Debt/GDP ratio for the year 2050. An explanation for this is the given by Figure 4-7 as SSP3-RCP4.5 turns out to be very damaging for the public debt and the magnitude of the debt problems were even more reinforced by the addition of a mild economic losses effect in the debt dynamics model Equation 1. Furthermore, it is evident that SSP5-RCP4.5 looks like the most promising for the development of public debt due to its strong economic growth and mild economic damages coming from RCP4.5.

4.3.4 Risk Premiums rise for Italy

The third set of scenarios is similar to the second set of scenarios, except for the inclusion of risk premiums paid on public debt and climate damage. The results of the calculation exercise are shown in Figure 4-9. In this case, the development of debt is relied on the fiscal deficits' adjustment and the compounding effect of higher risk premiums.

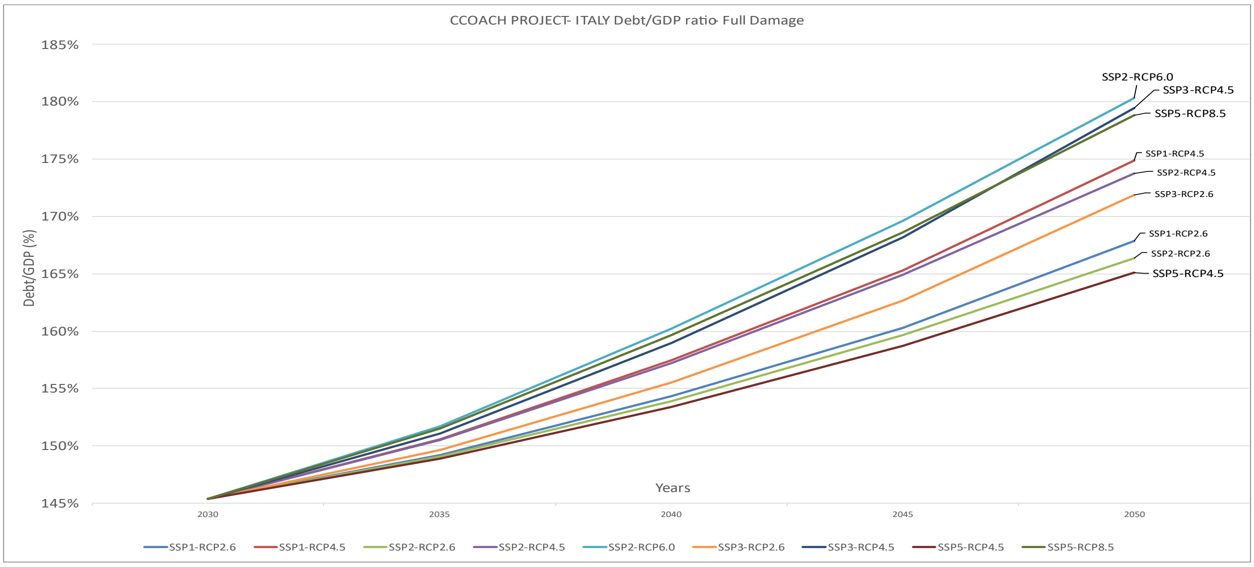

Figure 4-9: Italy Debt/GDP - Full Damage Scenario

Combination\Year	2030	2035	2040	2045	2050
SSP1-RCP2.6	145,4%	149,2%	154,3%	160,3%	167,9%
SSP1-RCP4.5	145,4%	150,6%	157,4%	165,3%	174,9%
SSP2-RCP2.6	145,4%	149,1%	153,9%	159,6%	166,3%
SSP2-RCP4.5	145,4%	150,5%	157,2%	164,9%	173,7%
SSP2-RCP6.0	145,4%	151,7%	160,2%	169,6%	180,3%
SSP3-RCP2.6	145,4%	149,6%	155,5%	162,7%	171,9%
SSP3-RCP4.5	145,4%	151,1%	158,9%	168,2%	179,4%
SSP5-RCP4.5	145,4%	148,9%	153,4%	158,7%	165,1%
SSP5-RCP8.5	145,4%	151,5%	159,7%	168,6%	178,8%

Table 7: Italy Debt/GDP ratio - Full Damage Scenario

Including high premium risks for debt and climate change did not alter the rankings for the least favorable combination, as SSP2-RCP6.0 remained at the top. This persistence can be attributed to the significant climate premium risk associated with RCP6.0, which amplifies the economic consequences of climate disasters on public debt. The elevated risk premiums exacerbate the fiscal impact, leading to a higher Debt/GDP ratio despite the scenario's inherent resilience and mitigation measures.

No other notable changes were observed in the rankings. Since the clear separation of the trend lines in 2035, the projections remained consistent for the rest of the period. This stability suggests that the introduction of high premium risks reinforces the existing trajectory rather than altering it. The figure below illustrates how SSP2-RCP6.0 continues to be the most detrimental to debt sustainability, highlighting the compounded effects of climate risks and premium costs on fiscal health. This reinforces the critical need for comprehensive climate and fiscal policies to manage long-term economic resilience. It is clear then that for Italy's case the rise in premium risks did not have the assumed effect in the final results as the differences with Table 8 are only marginal for the length of the examined horizon. Moreover, it is observed that combination with very mild climate change consequences performed much better than the rest with the exception of SSP3-RCP4.5 which is among the least favorable in all of the designed scenarios.

Combination	2nd	3rd	Δ
SSP1-RCP2.6	166,9%	167,9%	1,0%
SSP1-RCP4.5	173,2%	174,9%	1,6%
SSP2-RCP2.6	165,6%	166,3%	0,8%
SSP2-RCP4.5	172,0%	173,7%	1,7%
SSP2-RCP6.0	178,3%	180,3%	2,0%
SSP3-RCP2.6	170,8%	171,9%	1,1%
SSP3-RCP4.5	177,5%	179,4%	2,0%
SSP5-RCP4.5	164,4%	165,1%	0,8%
SSP5-RCP8.5	176,8%	178,8%	2,1%

Table 8: Difference between 2nd and 3rd Scenario for Italy in 2050

4.4 Spain (2025-2050)

The results underscore key trends, vulnerabilities, and the relative impacts of different climate scenarios on Spain's fiscal stability.

4.4.1 Aggregate Climate Damage

To better understand the extent of structural damages caused by climate change across various SSP-RCP combinations, Figure 4-10 presents of the projected damages as a percentage of GDP for Spain up to the examined horizon.

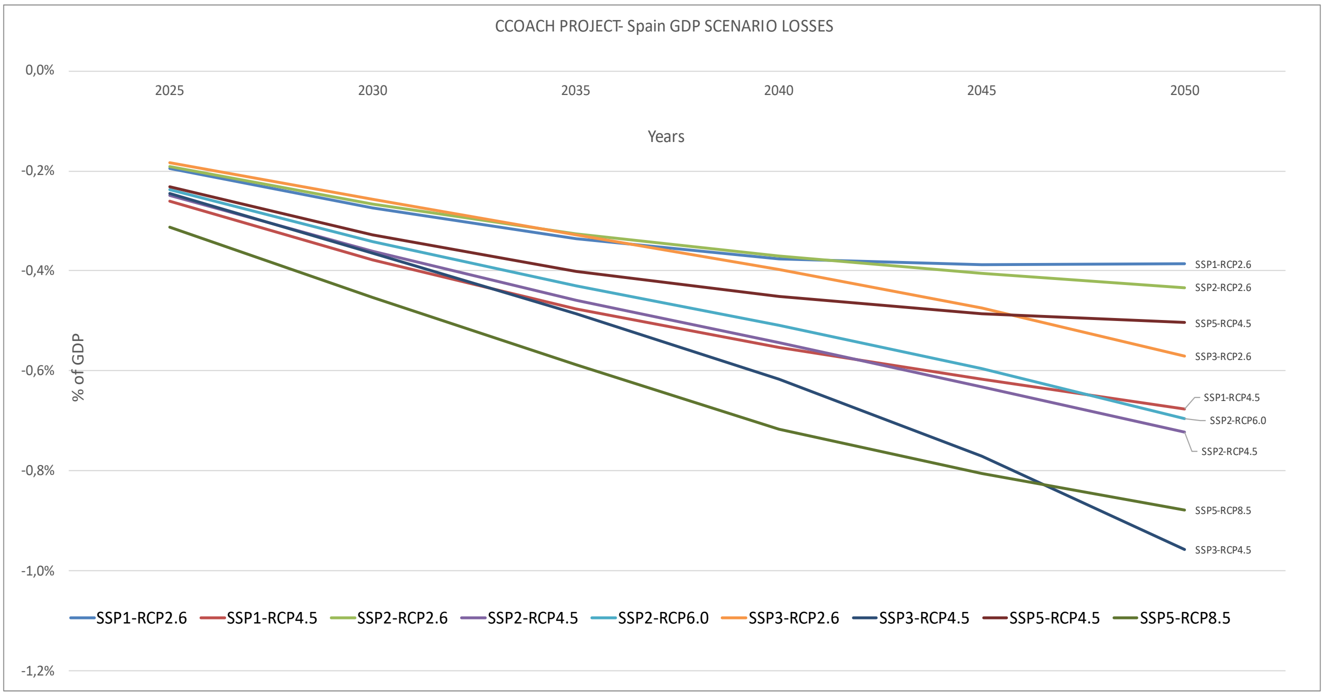

Figure 4-10: Spain GDP structural losses on a national level until 2050

Many findings have been observed in the case of Spain which demonstrate different results than Greece and Italy. First, it is important to highlight that overall, the losses are decreased with comparison with the other countries as the most impactful combination SSP-RCP4.5 is barely reaching 1% of GDP by the year of 2050. Moreover, it is noticeable that many combinations change the line trend inclination between 2040 and 2050 as pace is becoming much smoother to the point that almost zero.

Another important observation is that the combination of SSP3-RCP4.5 is projected to cause the greatest economic losses by the year 2050, surpassing even SSP5-RCP8.5, which is associated with more severe climatic conditions. This outcome can be attributed to the inadequate and inconsistent climate policies inherent in SSP3, combined with moderate but still impactful climatic changes under RCP4.5. The moderate climate action under SSP3 fails to mitigate the adverse effects adequately, leading to substantial economic damage over time. This stabilization can be explained by the lower climate-related losses and the benefits of sustainable growth strategies that are central to SSP1 and SSP2. These pathways prioritize strong climate action, resilience, and sustainable economic development, which mitigate the adverse impacts of climate change and foster steady economic growth.

4.4.2 Baseline for the Spanish public Debt/GDP ratio (2030-2050)

In this scenario the Debt/GDP ratio is solely driven by the difference in real interest rates and economic growth after the inclusion of climate structural damages for Spain. The baseline results are presented in Figure 4-11.

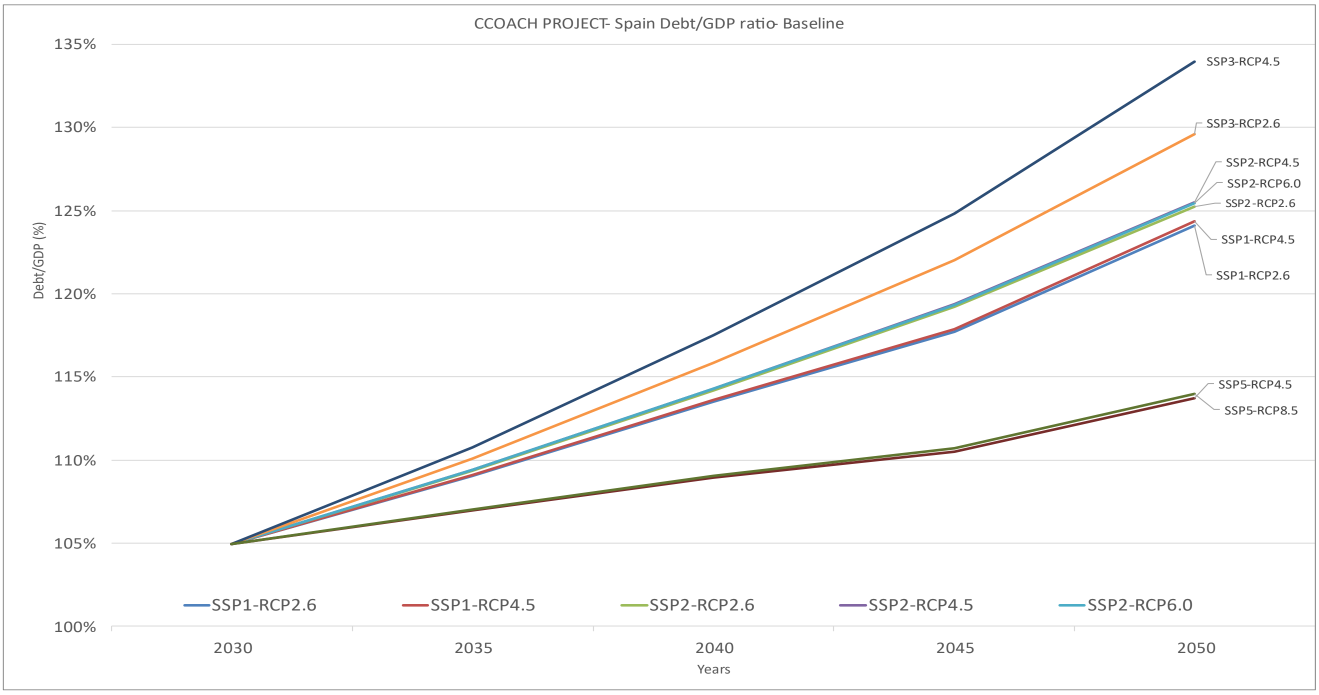

Figure 4-11: Spain Debt/GDP ratio - Baseline scenario

In the first scenario of the debt dynamics model, the least favorable combinations for Spain's public debt are SSP3-RCP4.5 and SSP3-RCP2.6, with only a marginal difference between them. Without the fiscal deficit included in the debt dynamics the best outcome for Spain's public debt would be combinations SSP5-RCP4.5 and 8.5 due to adding only 10% roughly in the debt ratio after 20 years examined.

Additionally, combinations that require significant investments in resilience and mitigation policies, such as those under SSP1 and SSP2, are located in the middle of the rankings. These scenarios show small marginal differences between them, reflecting the balance between the costs of climate action and the benefits of reduced climate impacts. The moderate economic growth and proactive climate policies in these pathways help to manage the Debt/GDP ratio more effectively than scenarios with minimal or inconsistent climate actions.

4.4.3 Fiscal deficits deteriorate the circumstances

In this case, the fiscal deficits of the government are incorporated into the debt dynamics model and therefore this becomes the basic driver of the Debt/GDP ratio. Every combination of includes a different deficit as an adjustment to the difference between the RCP's. According to historical data for 2000-2022 Spain's mean average of climate related disaster as percentage of GDP comes to 0,12% while the standard deviation is 0,17%. The results are presented in Figure 4-12.

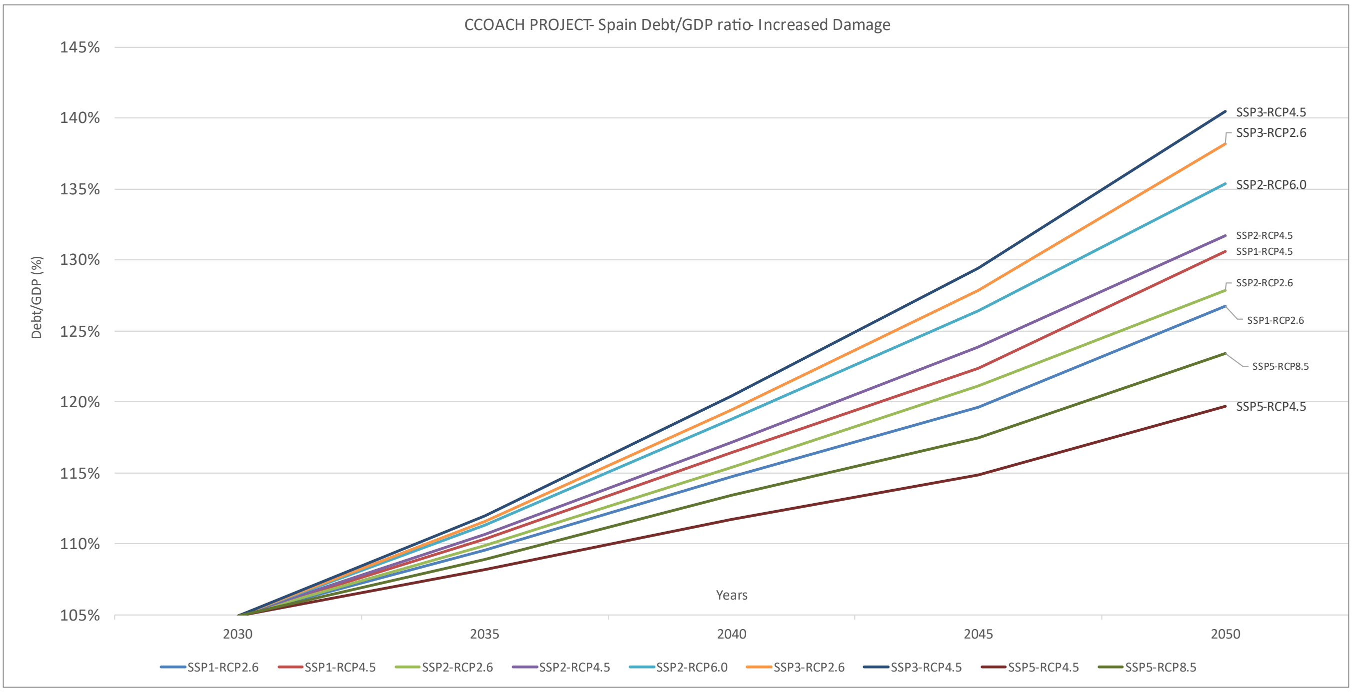

Figure 4-12:Spain Debt/GDP ratio – Increased Damage scenario

Combination\Year	2030	2035	2040	2045	2050
SSP1-RCP2.6	105,2%	109,9%	115,1%	120,0%	127,1%
SSP1-RCP4.5	105,2%	110,7%	116,8%	122,7%	131,0%
SSP2-RCP2.6	105,2%	110,2%	115,7%	121,4%	128,2%
SSP2-RCP4.5	105,2%	110,9%	117,4%	124,2%	132,1%
SSP2-RCP6.0	105,2%	111,7%	119,1%	126,8%	135,7%
SSP3-RCP2.6	105,2%	111,7%	119,6%	128,0%	138,4%
SSP3-RCP4.5	105,2%	112,1%	120,5%	129,6%	140,6%
SSP5-RCP4.5	105,2%	108,8%	112,3%	115,4%	120,3%
SSP5-RCP8.5	105,2%	109,5%	114,0%	118,1%	124,0%

Table 9: Spain Debt/GDP ratio - Increased Damage scenario

In the second scenario of the debt dynamics model, the least favorable combinations for Spain's public debt are SSP3-RCP4.5 and SSP3-RCP2.6, with only a marginal difference between them. This outcome can be attributed to the stagnating growth projected under SSP3, driven by regional competition and protectionist policies, which negatively impact economic performance. As fiscal deficits are now included in the debt model, someone would expect combinations SSP5-RCP4.5/8.5 to be amongst the least favorable outcomes for Spain's debt sustainability. Nevertheless, the adverse effects of climate-related disasters did not prove impactful enough, making the stagnation in growth and adaptation risks as the primary driver of the increasing Debt/GDP ratio. Closely following, the SSP2-RCP6.0 combination reaches a Debt/GDP ratio of 135%, representing almost a 30% spike over 20 years. This significant increase highlights the strain placed on public finances due to moderate climate actions that are insufficient to counterbalance the impacts of climate change effectively. SSP2 scenarios include some level of climate resilience and mitigation policies, but the high emissions pathway of RCP6.0 leads to substantial economic and fiscal pressures.

Additionally, examining the two most favorable combinations in this scenario, SSP5-RCP4.5 and SSP5-RCP8.5, we observe that despite the strong economic growth projected under SSP5, there is still a notable increase in the Debt/GDP ratio. The smaller increase, however, is around 20% from 2030, equating to approximately 1% annual growth. This slower rate of increase can be attributed to the robust economic expansion inherent in SSP5 scenarios, which helps to offset some of the fiscal pressures despite severe climate impacts. Interestingly, the graph reveals that combinations with adequate climate action in socio-economic pathways, such as SSP1 and SSP2 with lower RCPs, are positioned between the extremes of SSP3 and SSP5. These pathways balance regional competition and the aggressive exploitation of non-renewable resources as the primary economic drivers. SSP1 and SSP2 scenarios incorporate more sustainable and cooperative approaches, which moderate the Debt/GDP ratio increases by promoting resilience and sustainable growth.

4.4.4 Premiums deteriorate the debt conditions

The last scenario endogenizes the risk premiums into the calculation of the real interest rate. The premiums are related to the climate and debt risks which are considered as country specific type. In consequence, the Debt/GDP ratio is driven now by both fiscal deficits and endogenous premium risks in accordance with the combination's RCP. The results of the third scenario are demonstrated in Figure 4-13.

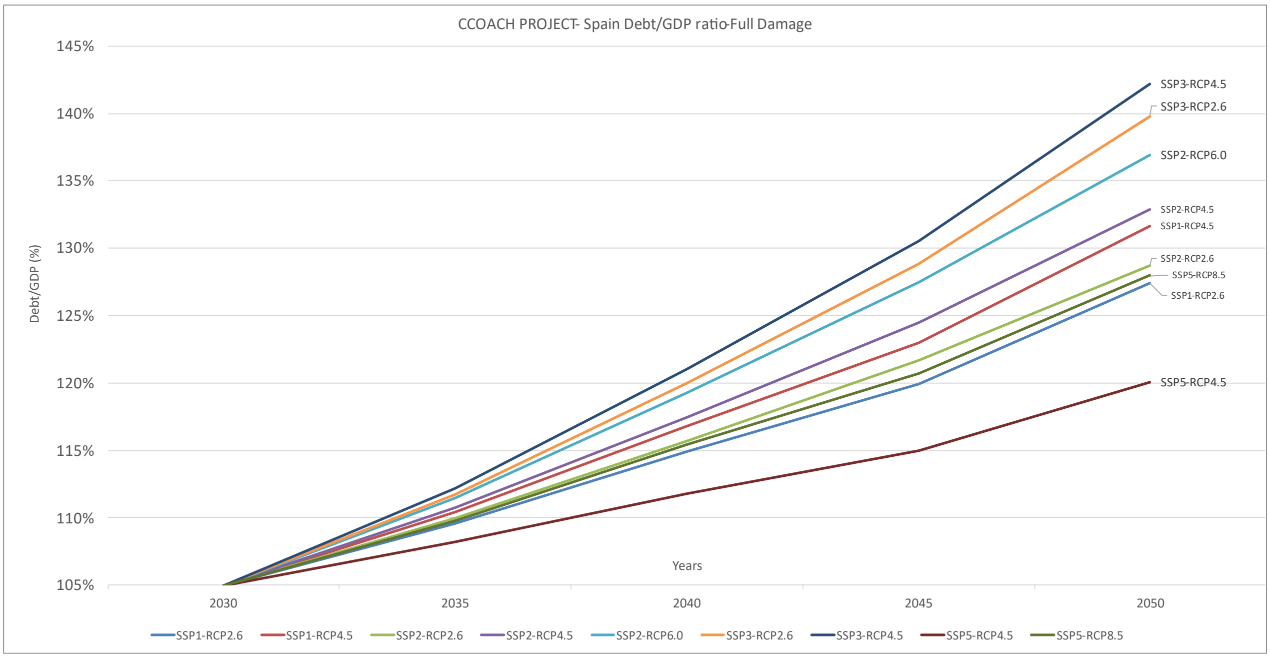

Figure 4-13: Spain Debt/GDP ratio - Full Damage scenario

Combination\Year	2030	2035	2040	2045	2050
SSP1-RCP2.6	105,2%	109,9%	115,3%	120,3%	127,8%
SSP1-RCP4.5	105,2%	110,7%	117,1%	123,3%	132,1%
SSP2-RCP2.6	105,2%	110,3%	116,0%	122,0%	129,1%
SSP2-RCP4.5	105,2%	111,0%	117,8%	124,8%	133,2%
SSP2-RCP6.0	105,2%	111,8%	119,6%	127,8%	137,3%
SSP3-RCP2.6	105,2%	111,9%	120,1%	129,0%	140,0%
SSP3-RCP4.5	105,2%	112,3%	121,2%	130,7%	142,4%
SSP5-RCP4.5	105,2%	108,8%	112,3%	115,6%	120,7%
SSP5-RCP8.5	105,2%	110,3%	116,0%	121,3%	128,6%

Table 10: Spain Debt/GDP ratio - Full Damage scenario

After incorporating higher interest rates to account for debt and climate risks, there was no change in the ranking of the combinations. This suggests that SSP3-RCP4.5, despite having a lower climate premium risk, remains the least favorable scenario for the Spanish economy. Observing Table 11, it is evident that the largest increases in the Debt/GDP ratio occurred in combinations characterized by stagnating growth or significantly increased climate premiums, such as SSP5-RCP8.5. An interesting observation is the potential snowballing effect of high-risk premiums over time. This effect can significantly worsen a country's debt sustainability, as higher interest rates compound the fiscal burden. If left unchecked, the escalating costs associated with these premiums can lead to a severe deterioration in debt stability.

Combinations	2nd Scenario	3rd Scenario	Δ
SSP1-RCP2.6	127,1%	127,8%	0,7%
SSP1-RCP4.5	131,0%	132,1%	1,1%
SSP2-RCP2.6	128,2%	129,1%	0,9%
SSP2-RCP4.5	132,1%	133,2%	1,1%
SSP2-RCP6.0	135,7%	137,3%	1,6%
SSP3-RCP2.6	138,4%	140,0%	1,6%
SSP3-RCP4.5	140,6%	142,4%	1,7%
SSP5-RCP4.5	120,3%	120,7%	0,4%
SSP5-RCP8.5	124,0%	128,6%	4,5%

Table 11 : Differences between 2nd and 3rd Scenarios in 2050

4.5 Portugal (2025-2050)

Finaly, the analysis of Portugal case begins with the presentation of the aggregate economic losses on a national level while all the designed debt scenarios are following.

4.5.1 Aggregate Climate Damage

The projected climate damages (as a percentage of GDP) for Portugal during 2025-2050 appear in Figure 4-14 for nine future climate and socio-economic scenarios.

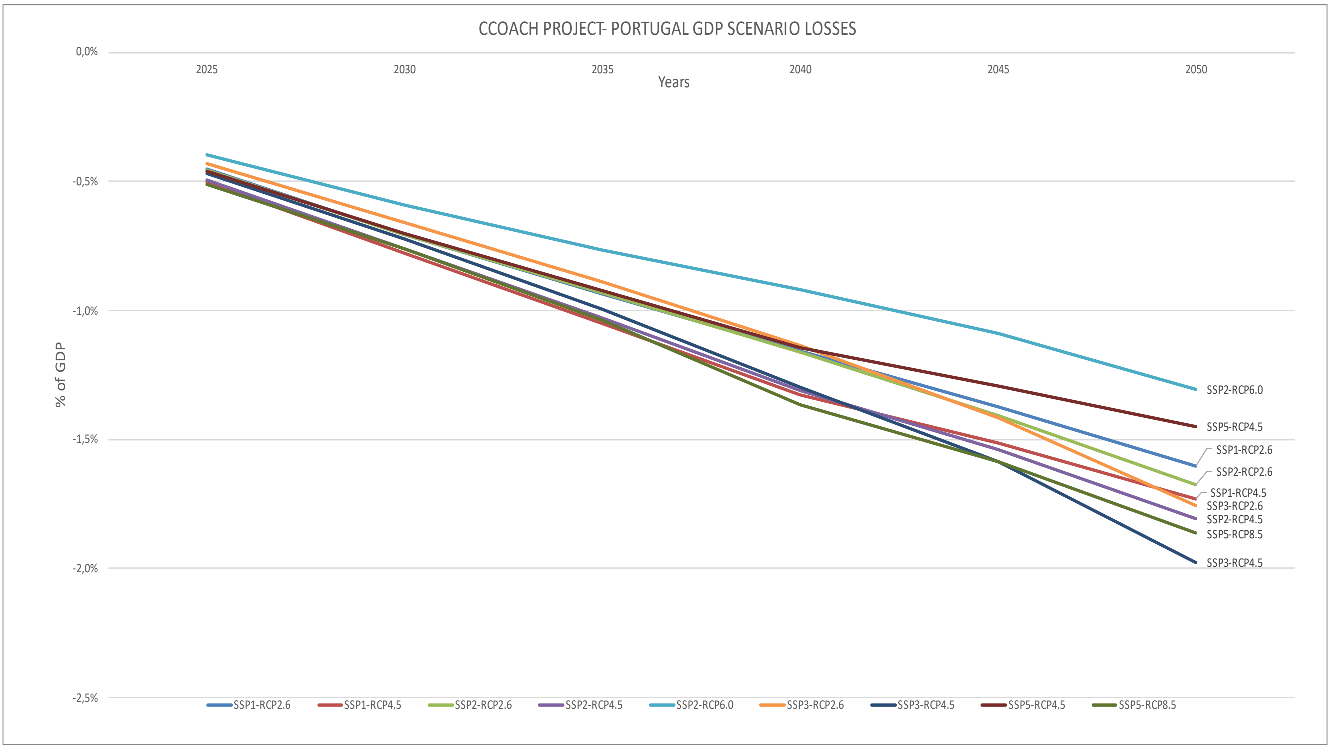

Figure 4-14: Annual Portugal GDP Structural Losses

Beginning the analysis of the chart, it is noted that already from 2025 for all the possible combinations the projected losses account for 0,5% of GDP which is significant. The spread between the most damaging combination of SSP3-RCP4.5 and the least damaging combination of SSP2-RCP6.0 is close to 0,7 % and is also considered significant. Unsurprisingly, SPP5-RCP8.5 is projected to lead to greater financial losses from SSP5-RCP4.5 due to the severity of consequences that RCP8.5 incorporates.

Additionally, an interesting observation is that despite the increased damages that are included in RCP 6.0, the combination ended up being the most favorable in the damage context. A possible explanation for this is the mitigation policies that are associated with SSP2 and the overall climate action strategy.

4.5.2 Baseline for the Portuguese public Debt/GDP ratio (2025-2050)

As in the previous cases, growth in this scenario is only driven by the financial damages of climate change under different combinations, which as a result lowers growth and create an unsustainable debt rise. In this case the fiscal deficit is set to zero and therefore the difference between interest rates and real rate of growth. The baseline scenario for Portugal is presented in Figure 4-15.

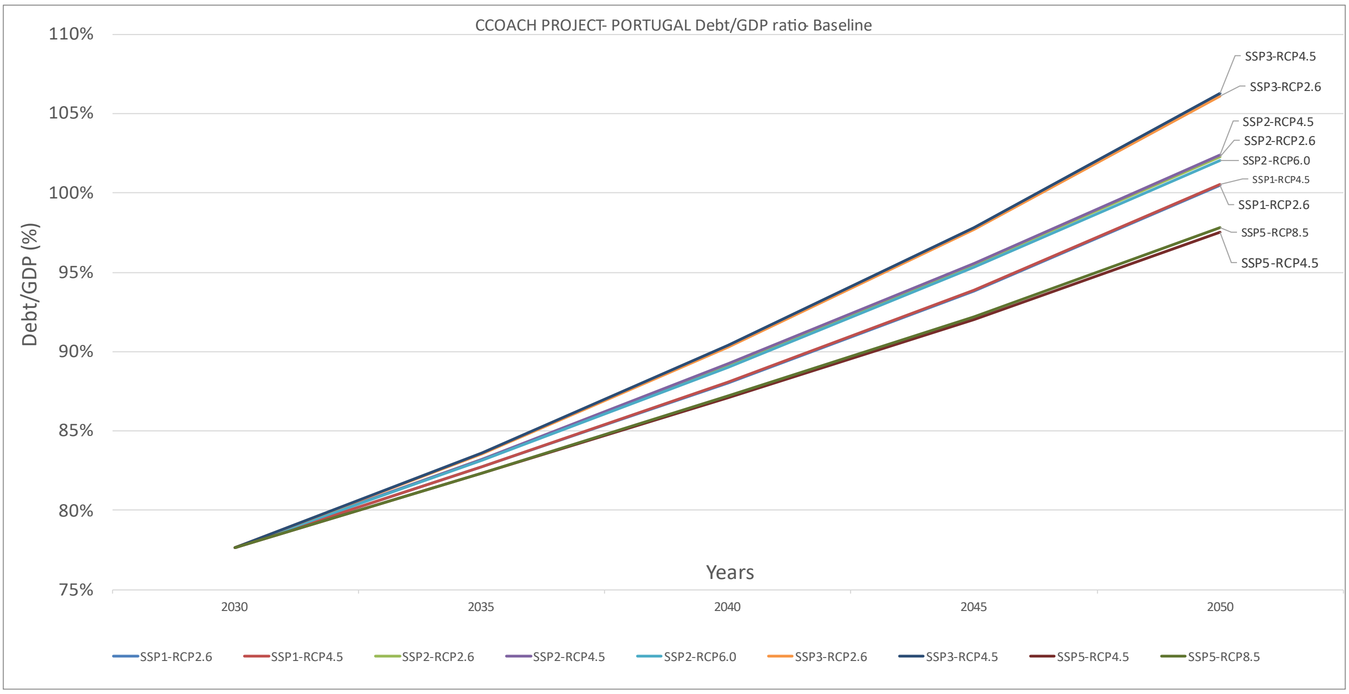

Figure 4-15 : Portugal Debt/GDP Baseline scenario

In this scenario, the least favorable combinations for Portuguese public debt are SSP3-RCP2.6 and SSP3-RCP4.5, which are projected to reach approximately 106% of GDP by 2050. This unsustainable debt level can be attributed to the stagnating growth projected under SSP3, where regional competition and protectionist policies hinder economic progress. The disparity between low economic growth and the relatively higher interest rates exacerbates the Debt/GDP ratio, pushing it to such critical heights.

Following closely are all the SSP2 combinations, with a difference of roughly 5%. These scenarios, while incorporating moderate climate resilience and mitigation efforts, still face significant economic challenges due to their relatively high emissions pathways and the associated climate impacts. The economic growth in SSP2 scenarios is not robust enough to fully counterbalance the adverse effects of climate change, leading to elevated debt levels. On the other hand, SSP5-RCP4.5 and SSP5-RCP8.5 scenarios show a more favorable outcome for Portuguese public debt. The strong economic performance projected under SSP5, characterized by rapid technological advancement and economic expansion, more than compensates for the losses incurred from the severe climate impacts of RCP4.5 and RCP8.5. In these scenarios, robust growth effectively mitigates the fiscal pressures arising from climate-related damages, resulting in a more stable Debt/GDP ratio. Last but not least, it is evident already from the baseline scenario an increase of 30% between 2030 and 2050 is worrying under the specific conditions.

4.5.3 Increased Damage

The second scenario includes in the debt dynamics the repercussions of climate disasters as fiscal deficits expressed in percentage of GDP. In this case, the development of public debt is mainly rising due to the fiscal deficits magnitude while growth and interest rates remain constant throughout the examined horizon. The Increased Damage scenario results are presented in Figure 4-16 and in Table 12.

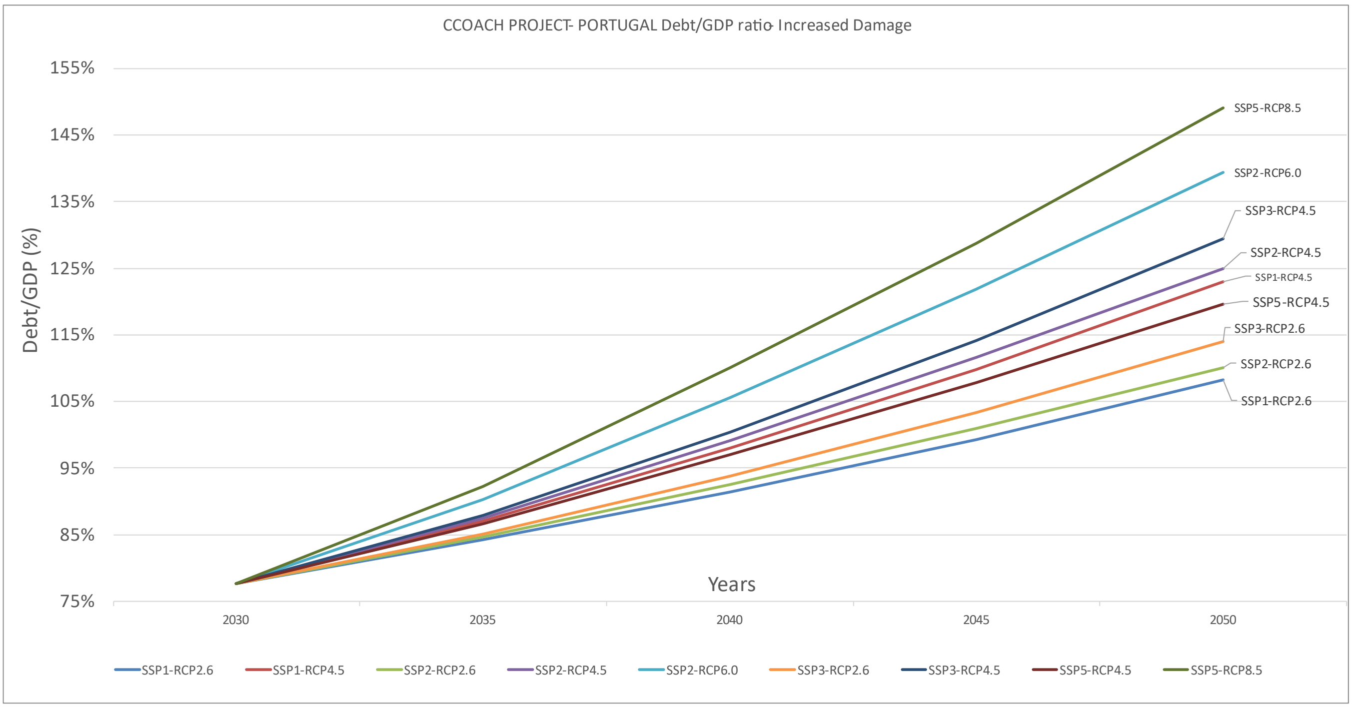

Figure 4-16 : Portugal Debt/GDP ratio - Increased Damage scenario

Combination\Year	2030	2035	2040	2045	2050
SSP1-RCP2.6	77,6%	84,2%	91,4%	99,3%	108,2%
SSP1-RCP4.5	77,6%	87,0%	98,0%	109,8%	123,0%
SSP2-RCP2.6	77,6%	84,7%	92,5%	101,0%	110,0%
SSP2-RCP4.5	77,6%	87,5%	99,2%	111,6%	125,0%
SSP2-RCP6.0	77,6%	90,2%	105,6%	121,9%	139,5%
SSP3-RCP2.6	77,6%	85,0%	93,7%	103,3%	114,0%
SSP3-RCP4.5	77,6%	87,9%	100,4%	114,1%	129,4%
SSP5-RCP4.5	77,6%	86,6%	97,0%	107,8%	119,6%
SSP5-RCP8.5	77,6%	92,2%	110,1%	128,8%	149,1%

Table 12 : Portugal Debt/GDP ratio – Increased Damage scenario

The inclusion of fiscal deficits in the model has significantly distinguished the various combinations to a larger extent than the baseline scenario. It is now evident that combinations with more severe RCPs have risen to the top of the graph, with SSP5-RCP8.5 emerging as the worst outcome for Portugal's economy. The repeated losses from natural disasters have dramatically deteriorated the Debt/GDP ratio, with SSP5-RCP8.5 showing an 82% increase in absolute numbers from 2030, and more than a 100% rise in relative terms.

In contrast, combinations with RCP2.6 and RCP4.5 have benefited from the relatively modest impact of disasters on the economy. These scenarios exhibit a more favorable Debt/GDP ratio, highlighting the advantages of less severe climate impacts. Additionally, SSP3-RCP4.5 continues to be among the least favorable outcomes. This is justified by the combination of modest yet significant damages from natural disasters and stagnating economic growth, which had already ranked poorly in the baseline scenario. Severe scenarios (like SSP5-RCP8.5) illustrate how high growth alone cannot offset the compounded damages from frequent natural disasters. Meanwhile, scenarios with moderate climate impacts demonstrate the relative fiscal stability that can be achieved with effective disaster mitigation and slower but steady economic growth.

4.5.4 Increasing risk Premiums for Portugal

Finally in this scenario, the main factors that affect the development of public debt differentiate with the addition of premium risks for the rise of debt and worsening of climatic conditions. The debt growth is accelerated by a mild increase in the interest rates that is caused by the incorporation of the premiums in Figure 4-17.

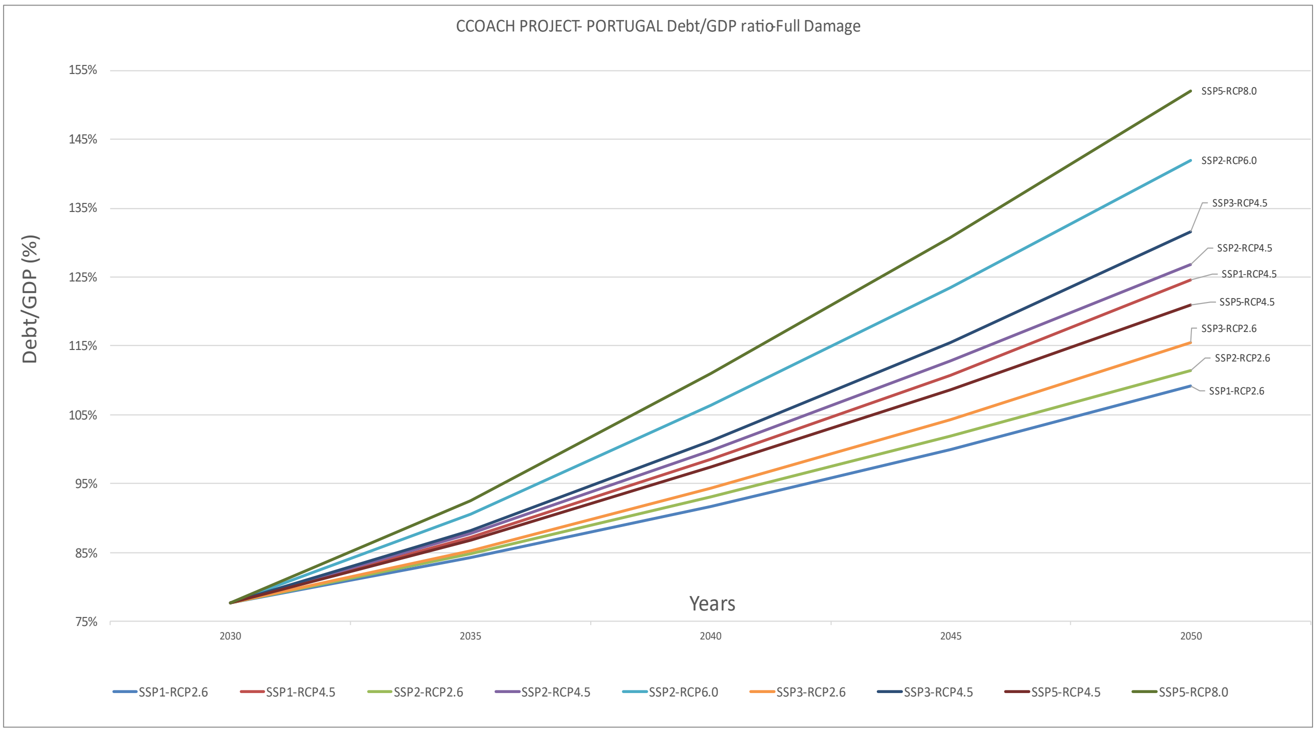

Figure 4-17 : Portugal Debt/GDP ratio - Full Damage Scenario

Combinations\ Year	2030	2035	2040	2045	2050
SSP1-RCP2.6	77,6%	84,3%	91,7%	99,9%	109,2%
SSP1-RCP4.5	77,6%	87,2%	98,5%	110,8%	124,6%
SSP2-RCP2.6	77,6%	84,9%	93,1%	101,9%	111,4%
SSP2-RCP4.5	77,6%	87,7%	99,8%	112,8%	126,9%
SSP2-RCP6.0	77,6%	90,6%	106,4%	123,4%	142,0%
SSP3-RCP2.6	77,6%	85,3%	94,3%	104,3%	115,5%
SSP3-RCP4.5	77,6%	88,2%	101,2%	115,5%	131,5%
SSP5-RCP4.5	77,6%	86,7%	97,4%	108,7%	121,0%
SSP5-RCP8.5	77,6%	92,5%	111,1%	130,7%	152,1%

Table 13: Portugal Debt/GDP ratio - Full Damage Scenario

Concluding the scenario analysis for Portugal, the higher interest rates resulting from the addition of debt and climate premium risks did not significantly alter the broad picture from the previous scenario. This stability is largely due to the fact that premiums already amplified the disparity between interest rates and growth for combinations such as SSP5-RCP8.5, which assume extensive environmental damages and consequently higher premium risks.

The impact of these premiums is evident in the severe outcomes for SSP5-RCP8.5, where the compounded effects of high growth and significant environmental damage result in elevated premium risks. These elevated risks further widen the gap between growth and interest rates, exacerbating the Debt/GDP ratio. This consistency in outcomes is clearly demonstrated in Table 14, where the differences between the two scenarios can be better understood. The table highlights how the inclusion of premium risks maintains the relative rankings of the different SSP-RCP combinations, reinforcing the findings from the baseline scenario.

Combinations	2nd Scenario	3rd Scenario	Δ
SSP1-RCP2.6	108,2%	109,2%	1,0%
SSP1-RCP4.5	123,0%	124,6%	1,6%
SSP2-RCP2.6	110,0%	111,4%	1,4%
SSP2-RCP4.5	125,0%	126,9%	1,9%
SSP2-RCP6.0	139,5%	142,0%	2,5%
SSP3-RCP2.6	114,0%	115,5%	1,5%
SSP3-RCP4.5	129,4%	131,5%	2,2%
SSP5-RCP4.5	119,6%	121,0%	1,4%
SSP5-RCP8.5	149,1%	152,1%	3,0%

Table 14 : Differences between 2nd and 3rd Scenario in 2050

4.6 Summary of scenario results

4.6.1 Greece

The projections for Greece's Debt/GDP ratio highlight the critical importance of climate action and socioeconomic stability for future economic resilience. Scenarios with robust climate policies and sustainable practices, like SSP1-RCP2.6, result in the most favorable outcomes by minimizing GDP losses and enhancing stability. In contrast, scenarios with insufficient climate action and significant geopolitical challenges, such as SSP5-RCP8.5 and SSP3-RCP4.5, pose substantial risks, leading to higher debt levels and fiscal instability. The introduction of fiscal deficits and climate premiums further exacerbates these challenges, underscoring the need for comprehensive climate resilience strategies. Overall, integrating proactive climate policies with economic measures is essential to ensure long-term fiscal health and mitigate the adverse impacts of climate change on Greece's economy.

4.6.2 Italy

In Italy, the baseline scenario indicates that moderate climate actions lead to high Debt/GDP ratios due to significant adaptation costs. When fiscal deficits from natural disasters are included, scenarios like SSP2-RCP6.0 and SSP5-RCP8.5 exhibit the worst debt sustainability due to high economic losses and fiscal pressures. Even with high premium risks, SSP2-RCP6.0 remains the least favorable, emphasizing the need for comprehensive climate and fiscal policies. Strong economic growth in SSP5 scenarios provides a buffer against climate impacts, illustrating the complex interplay between economic growth and climate-related damages.

4.6.3 Spain

The analysis for Spain reveals that climate-related economic losses are generally lower compared to Greece and Italy, with the most impactful scenario, SSP3-RCP4.5, barely reaching 1% of GDP by 2050. The least favorable combinations for Spain's public debt are SSP3-RCP4.5 and SSP3-RCP2.6, driven by regional competition and protectionist policies, which result in stagnating growth and significant fiscal pressures. In contrast, SSP5-RCP4.5 and SSP5-RCP8.5, despite severe climate impacts, show relatively favorable outcomes due to strong economic growth, resulting in a more manageable Debt/GDP ratio. The addition of higher interest rates for debt and climate risks did not alter the rankings, reinforcing the detrimental impact of SSP3-RCP4.5. The scenarios highlight the importance of robust climate policies and sustainable economic growth to mitigate long-term fiscal risks, with SSP1 and SSP2 pathways offering a balanced approach to managing debt sustainability through proactive climate action and resilience.

4.6.4 Portugal

The analysis of Portugal's structural damages and debt sustainability across various climate scenarios reveals that even modest initial losses of 0.5% of GDP in 2025 escalate significantly under more severe climate conditions. SSP3-RCP4.5 consistently projects the highest economic losses, while SSP2-RCP6.0, despite high emissions, benefits from effective mitigation policies. The first scenario shows SSP3-RCP2.6 and SSP3-RCP4.5 leading to unsustainable debt levels due to stagnating growth, while SSP5-RCP4.5 and SSP5-RCP8.5 demonstrate more favorable outcomes due to robust economic growth. Incorporating fiscal deficits in the second scenario highlights the severe impact of repeated natural disasters, with SSP5-RCP8.5 showing the worst Debt/GDP ratio increase, whereas moderate scenarios like SSP2-RCP4.5 exhibit relative stability. The third scenario confirms that higher interest rates from debt and climate premiums do not significantly alter the outcomes, reinforcing the need for proactive climate action and economic strategies to maintain fiscal stability amidst escalating climate risks.

5. Discussion and Analysis

The Discussion and Analysis chapter dives into the implications of the findings presented in the previous section, providing a comprehensive examination of how climate change and natural disasters impact public debt sustainability in Southern European countries, specifically Greece, Italy, Spain, and Portugal. This chapter aims to interpret the results of the various scenarios analyzed, drawing connections between climate policies, economic growth, and fiscal stability.

5.1 National Comparisons

Beginning with the interpretation of the results, it would be wise to see how each combination of SSP and RCP is developing for each country during the period 2030-2050. The chosen combinations of SSP and RCP are selected to represent each socio-economic level of impact but also the different effects of climatic scenarios. The examined period is 2030-2050 as the 2050 is the target year for EU to reach the environmental targets that were set during the EU Green Deal (European Commission, 2024). Subsequently discussing the debt rise until 2050 highlights the fiscal challenges that lie ahead for the countries of the South. Finally, the presented diagrams concern the third and conclusive designed debt scenario in which the rate of increase was affected by structural climate damage on economic growth, fiscal deficits caused by natural disasters and higher debt and climate premium risks incorporated into the interest rates.

5.1.1 SSP1-RCP2.6 – 3rd Scenario

In this combination, the best environmental and socioeconomic scenarios present a mild but steadily inclining rate of Debt/GDP ratio for all the countries analyzed. In such circumstances, countries of South Europe will be up against adaptation challenges that constrain their economic growth. The results for SSP1-RCP2.6 are presented in Figure 5-1.

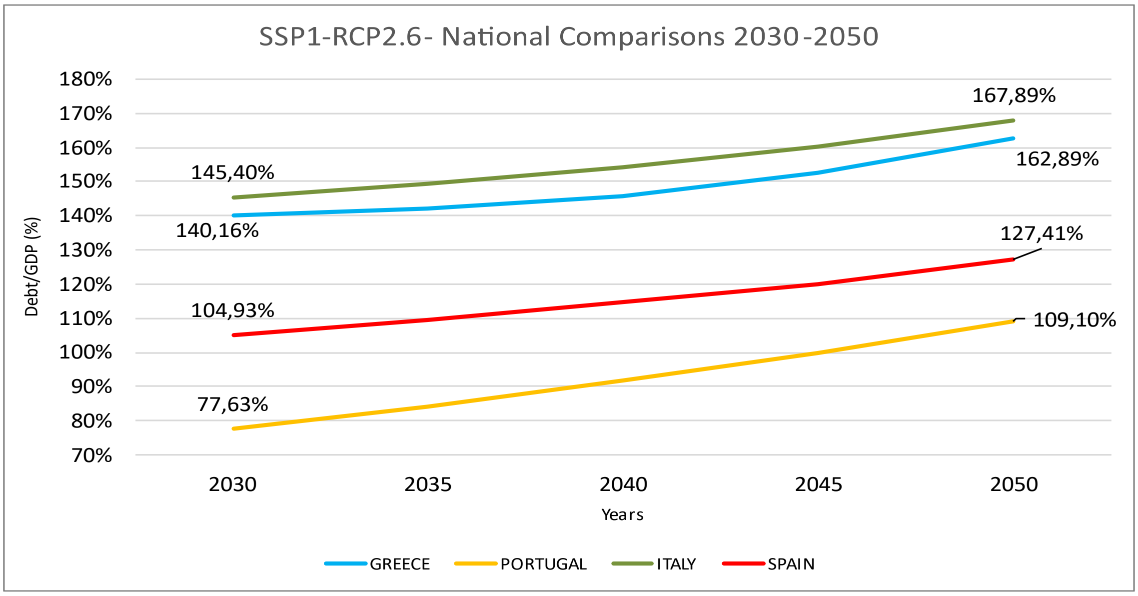

Figure 5-1: SSP1-RCP2.6 - National Comparisons Debt/GDP 2030-2050

Portugal is projected to experience the most significant increase in its Debt/GDP ratio, driven by extended fiscal deficits and stagnating growth. Meanwhile, Italy maintains a relatively stable position throughout the 20-year period, reflecting its balanced approach to economic and climate policies. Greece follows a similar path to Italy, with its Debt/GDP ratio returning to 2023 levels by 2050. Spain mirrors the growth rates of Greece and Italy, showcasing a consistent but moderate increase. In contrast, Portugal's compounded annual growth rate is much higher, indicating more substantial fiscal challenges despite intensified climate action and mitigation policies.

Overall, it is noticeable that under a scenario where climate action and mitigation policies are intensified to meet environmental targets, all the countries have seen their Debt/GDP ratios increase by over 22%. Portugal, in particular, exhibits a much steeper increase due to its extended fiscal deficits and relative economic stagnation. This analysis highlights the complex interplay between robust climate policies and fiscal sustainability, emphasizing the need for balanced strategies that address both environmental and economic objectives.

2030-2050	GREECE	PORTUGAL	ITALY	SPAIN
CAGR	0,75%	1,72%	0,72%	0,98%
Δ	22,7%	31,5%	22,5%	22,5%

Table 15 : SSP1-RCP2.6 - Compounded Annual Growth Rate of Debt and Difference

5.1.2 SSP3-RCP4.5 – 3rd Scenario

In SSP3-RCP4.5 where there is moderate climate action and many challenges to sustainable development it is evident that all the countries of the South are significantly increasing their debt ratios. Portugal like in the previous scenario is having the biggest rate of increase in this 20-year period. The difference from Spain by the end of 2050 is only 9% compared to the initial 27% difference projected in 2030.

In addition, it is important to highlight the Greek debt growth under this combination which is almost equal to the Italian ratio of 179,52 %. In the fragmented world that the SSP3 scenario assumes, the regional rivalry is causing growth rates to decrease while the toll on fiscal deficits increased from RCP2.6 causing Portugal to almost double its debt under the fiscal pressures caused by natural disasters. Italy on the other hand despite the clear gradual increase in its Debt/GDP ratio, is the one affected the least both by the natural disasters' fiscal consequences and by the deteriorating economic growth projected in SSP3.

The results of national for SSP3-RCP4.5 are illustrated in Figure 5-2.

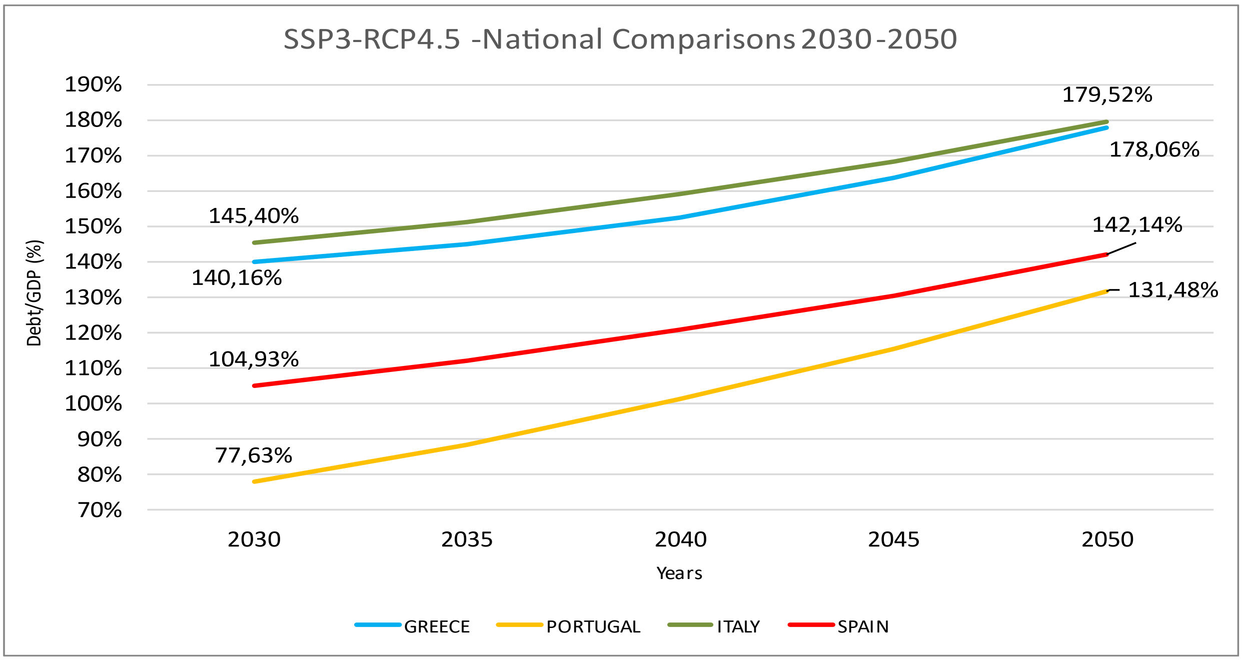

Figure 5-2: SSP3 - RCP4.5 - National Comparisons Debt/GDP 2030-2050

Moreover, another important observation is that the snowballing effect is much less intensive for Italy, despite being on top of the rest of the countries regarding the Debt/GDP ratio. That can be attributed to the fact that the fiscal damages from natural disasters are much less compared to the other nation and that premiums on interest rates are less compared to the inclining rate of Portugal. The differences between 2030-2050 and the compounded annual growth rate is presented in Table 16.

2030-2050	GREECE	PORTUGAL	ITALY	SPAIN
CAGR	1,20%	2,67%	1,06%	1,53%
Δ	37,9%	53,9%	34,1%	37,2%

Table 16 : SSP3-RCP4.5 - Compounded Annual Growth Rate of Debt and Difference

5.1.3 SSP5-RCP8.5 – 3rd Scenario

In the most extreme combination of both climate consequences and socio-economic scenarios, Greece surpasses Italy by 2050 to hold the highest Debt/GDP ratio among the analyzed countries, while Portugal doubles its ratio and overtakes Spain. This outcome highlights the severe fiscal impact of extreme climate scenarios, where extended fiscal deficits resulting from natural disasters significantly strain Portugal's economic resilience. By 2040, Portugal and Greece had already converged with Spain and Italy, indicating that their compounded debt growth rates on an annual basis are higher than those in the previously examined combinations. This rapid convergence underscores the accelerating impact of climate-induced fiscal pressures, which exacerbate debt accumulation at an alarming rate.

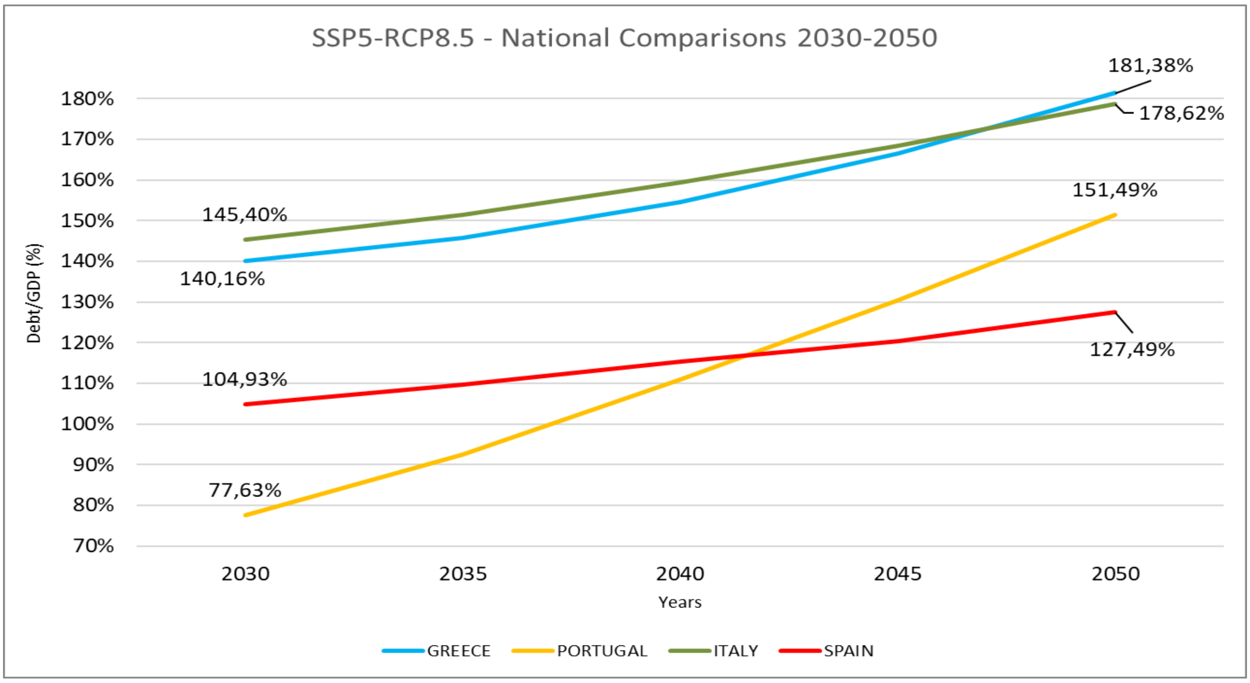

Figure 5-3 : SSP5 - RCP8.5 - National Comparisons Debt/GDP 2030-2050

Notably, Spain demonstrates remarkable performance in this extreme scenario. Its economic growth remains robust, unaffected by structural damage or the fiscal deficits caused by climate-related disasters. This resilience suggests that Spain's economic framework is better equipped to handle severe climate impacts compared to its Southern European counterparts. The data also reveals a critical insight: increasing debt growth rates are consistently accompanied by higher premiums for debt and climate risks. This relationship triggers the snowballing effect, leading to the so-called "Debt Loop" described in section 2.2. As premiums rise, the cost of servicing debt escalates, further amplifying the fiscal burden and accelerating the debt accumulation process. Moreover, it becomes evident that despite the strong economic growth that is assumed for SSP5 by focusing fossil fuel technologies, the damages are far greater for the public finances of all the countries apart from Spain which in this scenario is proportionally less affected.

In summary, this extreme scenario analysis underscores the profound and varied impacts of climate change on fiscal sustainability. Greece and Portugal face significant challenges, with rapidly escalating Debt/GDP ratios driven by severe climate impacts and associated fiscal deficits. Spain, on the other hand, exhibits a notable degree of economic resilience, managing to sustain growth despite the adverse conditions. These findings emphasize the importance of robust and adaptive economic policies to mitigate the risks of climate-induced fiscal instability and prevent the detrimental effects of the Debt Loop. The differences in results are presented in Table 17.

2030-2050	GREECE	PORTUGAL	ITALY	SPAIN
CAGR	1,30%	3,40%	1,03%	0,98%
Δ	41,2%	73,9%	33,2%	22,6%

Table 17 : SSP5-RCP8.5 - Compounded Annual Growth Rate of Debt and Difference

5.2 European Fiscal Rules

The analysis of the results made clear that under the current assumptions included in each of the designed scenarios, the countries of South Europe are going to face significant fiscal challenges in a medium to long term horizon. There are differences between the examined countries in the economy structure, interest rates, credit ratings, population dynamics and other factors that play an important role in how the debt is going to develop in the next years. However, despite their systemic differences, Greece, Italy, Spain and Portugal are all bounded by the same European Laws when it comes to economic governance and fiscal budgets. In addition, their presence in the zone of the Euro (€) is making the situation even more turbulent as monetary policy on the common currency exchange is dictated by the European Central Bank and not by their own National Banks.

Taking a closer look at the renewed fiscal rules of December 2023 there are a few things to consider before moving forward. First, these rules are part of the Stability and Growth Pact (SGP) designed to coordinate fiscal policies among member states and ensure the sustainability of public finances (European Commission, 2024).

Established in 1997 and reformed during the eurozone crisis of the 2010s, the SGP rules were suspended in 2020 to enable countries to spend as necessary to combat the Covid-19 crisis and later to mitigate the economic effects of the Russian invasion of Ukraine. However, this suspension was temporary, and the rules must now be reinstated. In 2023, there were intense debates about reforming the existing rules, which were criticized for being overly restrictive, non-transparent, and inflexible. Specifically, the rules mandated that member states with a Debt/GDP ratio above 60 percent reduce their debt by 1/20 per year, necessitating extremely austere policies.

On December 20, 2023, the Council of the European Union reached an agreement on new fiscal rules, set to be discussed with the European Parliament in the first quarter of 2024 and implemented later in the year (European Commission, 2024). The new EU fiscal rules represent a compromise between the fiscally conservative countries of central and northern Europe, led by Germany, and the southern countries, led by France, which emphasized avoiding a return to austerity that could trigger a recession and allowing fiscal space for investments in climate transition, defense, and industrial policy (Steinberg & Feás, 2024).

The changes concerned reducing debt ratios and deficits in a gradual, realistic, sustained and growth-friendly manner while protecting reforms and investment in strategic areas such as digital, green, social or defense. At the same time, the framework will provide appropriate room for counter-cyclical policies and address macroeconomic imbalances. The revised fiscal rules will also contribute to achieving common medium and long-term policy objectives such as achieving a fair digital and green transition, ensuring energy security, supporting open strategic autonomy, addressing demographic change, strengthening social and economic resilience and sustained convergence, and implementing the strategic compass for security and defense.

More specifically the new rules (European Commission, 2024) (Steinberg & Feás, 2024) state that member states' fiscal path must lead to the ultimate objective of a deficit below 3 percent of GDP and a public debt below 60 percent of GDP. Countries with excessive debt will be required to achieve the following targets:

1. A minimum annual structural deficit reduction rate of 0.4%, limited to 0.25% with reforms or investments, and 0.5% if under Excessive Deficit Procedure (EDP).

2. A "deficit resilience safeguard" to reduce structural deficits to 1.5% even after meeting the 3% rule.

3. A "debt sustainability safeguard" requiring an average annual debt reduction of 0.5% for countries with 60%-90% Debt/GDP and 1% for those above 90%, applicable once the deficit falls below 3%.

4. For countries inducted in Excessive Deficit Procedure (EDP), a maximum deviation of expenditure from the planned adjustment path is set to avoid systematic errors.

Flexibility has improved with customized adjustment plans, but rigid benchmarks and safeguards limit it. Credibility is fragile due to the arbitrary nature of the 3% deficit and 60% debt benchmarks, ineffective compliance mechanisms, and reduced sanction amounts. The rules also fail to align with the need for a permanent EU fiscal capacity, risking reduced public investment and increased divergences within the EU (Steinberg & Feás, 2024). The new frameworks require significant fiscal adjustments, especially for high-debt countries like Greece, Italy, Spain and Portugal, though these adjustments are generally less stringent than those previously mandated (Darvas, Welslau, & Zettelmeyer, 2024). The numerical safeguards enforce a minimum pace of debt and deficit reduction, potentially introducing some pro-cyclicality and limiting public investment.

But the question that arises is: How are the countries of South Europe going to adjust to this fiscal reality while facing the environmental challenges that lie ahead?

There is also ambiguity regarding the largely unchanged Excessive Deficit Procedure and how the new framework is going to affect current Debt Sustainability Analysis as it can interfere with successful application of it (Darvas, Welslau, & Zettelmeyer, 2024). Battling the imminent climate deficits will require significant investments in order to both restructure what's lost from the disasters but also avoid future damage by adopting more mitigation policies and doing more on the climate front. The effectiveness of the framework will hinge on the successful negotiation and implementation of medium-term fiscal structural plans (MTFSPs) by member states (Steinberg & Feás, 2024). Moreover, there is a risk that the new rules could constrain public investment, particularly in green projects essential for achieving EU climate goals, potentially hindering long-term economic growth and climate sustainability.

For Greece, Italy, Spain and Portugal there is no simple answer to the questions and the fiscal challenges. On the one hand, by adjusting to the newly reformed framework means that they would have to put fiscal constraints to reach the numerical thresholds on both Debt/GDP ratio, Fiscal Deficits and subsequently lower public investments on "green" policies and mitigation techniques to avoid the repeated natural disasters but also the structural damages projected from combinations that include socio-economic pathways like SSP3 and SSP5.

On the other hand, if governments invest in climate change action policies, they will need extra funds and increased public expenditure on infrastructure. Then they can potentially mitigate the structural damages that COACCH projected but they will have to be inducted into EDP and at the same time increase their Debt/GDP ratios with possible implications on the financial markets such as downgrading due to the rise of debt. As EU Green Deal has set ambitious targets on Greenhouse Emissions and broad renewable energy use and infrastructure, it is interesting to see how the European Commission is going to address this pragmatic and practical fiscal dilemma that will become increasingly evident the next decade.

Avoiding the Debt Loop that was described in Section 2.2 requires early action both from the country's side but also from the European Commission as the main institution of power in the European Union, and from the European Central Bank in the Monetary Union. The reform of the European fiscal framework represents a major shift from the existing rules and is certainly a move in the right direction. It is highly probable that the proposed reform will be implemented largely as it stands now. However, it is not a long-term solution for the next 25 years. Instead, it serves as a testbed for an innovative approach to fiscal policy coordination and oversight in the EU, which can be further refined and developed in the coming years.

5.3 Fiscal Deficits in Reality

This research relies heavily on the assumptions that underpin the Debt Dynamics Model and its results. It is crucial to highlight the potential variations in public deficits, as these are key factors in the model's equation. Public deficits are influenced by broader economic decisions tied to a country's financial development. For instance, a surge in revenues from a thriving national sector (e.g. Tourism) can significantly alter the trajectory of public deficits, potentially turning them into surpluses.

At the same time though, a sudden change in the world environment can also impact the financial planning. As it was recently proven by the COVID-19 pandemic and the conflict in Ukraine there are exogenous events that deeply affect the economic course of a countries. This dynamic interaction underscores the importance of considering various economic scenarios to accurately predict fiscal outcomes. If these circumstances are added to the deteriorating climate conditions, then the fiscal effect on deficits and debt will be difficult to assess due to the multiple interactions of cornerstone factors such as energy prices or raw materials prices for manufacturing. The projected results in Chapter 4 can only become worse under the weights of increased deficits (due to external events) that will likely also lead to decreased economic growth, decreased government revenue and expenditure to mitigate the losses as dictated by SGP.

The debt model's robustness can be challenged also by the debt premium and climate premium rates that are incorporated into it and are volatile enough to alter the debt service cost in the case of an exogenous event that applies pressure to European economies. Nevertheless, as projections for interest rates and fiscal deficits are sensitive to multiple factors, modeling the whole process will require even more analysis in order to adequately include the climate change fiscal consequences.

5.4 The fiscal multiplier effect

Despite the exogenous factors and projections provided by IIASA and OECD, it is essential to consider the potential implications of increased deficits on the economic growth of the countries analyzed, under the view of the fiscal multiplier effect. Increased spending on relief efforts and long-term reconstruction can positively impact the economy. Fiscal multipliers measure the impact of increased government spending or changes in tax revenue on GDP (Batini, Eyraud, Forni, & Weber, 2014).

Essentially, they represent the ratio of a change in output to a change in government spending or tax revenue. The fiscal multiplier effect suggests that public spending can boost economic activity, even in the aftermath of natural disasters. As government spending increases, it stimulates economic growth by generating demand for goods and services, thereby potentially offsetting the downturn caused by these disasters. This theory indicates that, despite the initial economic shock from natural disasters, increased fiscal spending can possibly lead to a net positive impact on economic growth. Given this perspective, the projections used in this thesis might trend more favorably due to the fiscal multiplier effect. However, this optimistic outlook must be filtered by the practical challenges of financing such recovery efforts. Increased spending to provide relief and fund reconstruction can detonate another increase in already high Debt/GDP ratios, especially in countries with limited fiscal space and stringent fiscal rules. Considering that countries could possibly decide to decrease spending due to the repeating nature of the disasters, that can lead to the multiplier having the opposite of the desired effect on economic growth and therefore strain economic resources even further. Furthermore, implications would be different for every SSP that was included in the model since the magnitude of impeding climate disasters changes and in consequence the public spending adjusts accordingly.

Understanding these dynamics is crucial, as countries in a financial stalemate may find it challenging to mobilize the required resources without exacerbating their fiscal vulnerabilities. In summary, while the fiscal multiplier effect provides a theoretical basis for potential economic recovery following increased government spending, the practical implications of financing such efforts in the context of high debt levels and limited fiscal buffers require careful consideration and further investigation.

5.5 SSPs impact Fiscal Sustainability

Following the extended analysis for every combination of SSP-RCP for every country, it is now possible to take a step back and examine the broader implications of climate change by reflecting on the Shared Socioeconomic Pathways. In Figure 5-4 the results of the average difference between the Debt/GDP ratio of every country are presented for the period of 2030-2050 and under the distinction of SSP.

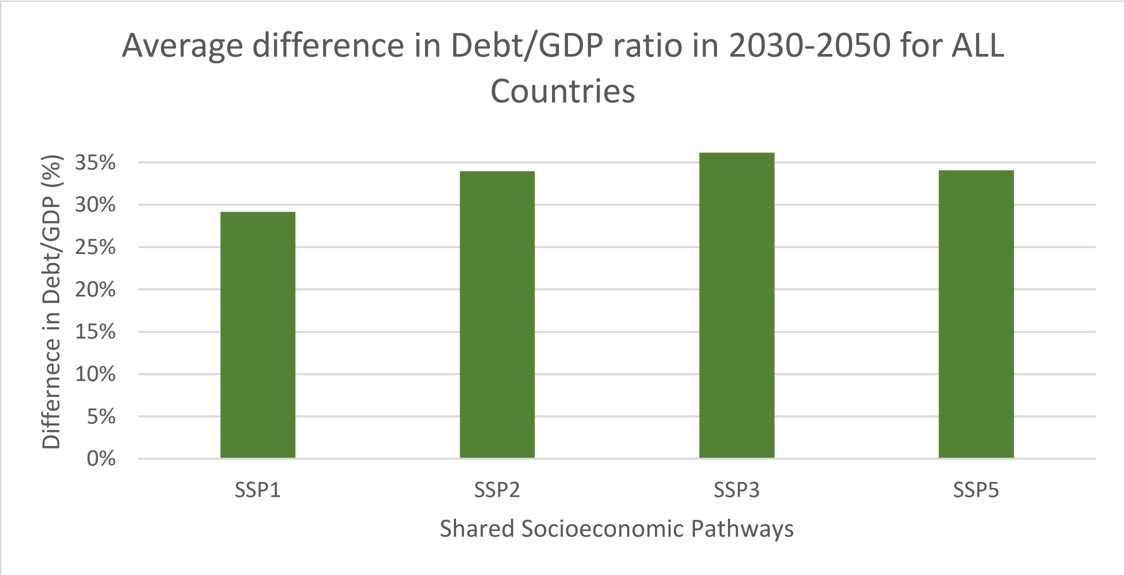

Figure 5-4: Average difference in Debt/GDP for every country per SSP

The results make evident that the socio-economic scenario SSP1 is the most favorable for the South European economies as the average difference in Debt/GDP ratio is significantly lower than the second-best difference which is SSP2. A possible explanation for this is attributed to the fact that SSP1 is assuming very intensive actions to fight climate change and the adoption of mitigation policies that secure a smooth transition towards a sustainable future. It is important to notice that SSP2 is almost equal to SSP5 despite the huge differences in assumptions for these two scenarios.

While SSP2 hypotheses a moderate but continuous climate action, SSP5 assumes continuous development on Fossil Fuel. This discrepancy is attributed to the fact that economic growth is notably bigger in SSP5 combinations in comparison to SSP1 and SSP2 as it was explained in the previous sections. Nevertheless, what brings SSP5 and SSP2 in the same levels of average difference of Debt in 2030-2050 is the increasing public deficits which are assumed to follow increasing trends as severity in RCP increases. SSP3 is averaging the biggest difference as it assumes regional rivalries between countries which decreases climate initiatives and lowers economic growth.

In Table 18, the average difference in Debt/GDP ratio for 2030-2050 is presented. These averages are creating the average difference seen in Figure 5-4.

	RCP2.6	RCP4.5	RCP6.0	RCP8.5
SSP1	24,79%	33,55%	-	-
SSP2	25,24%	34,05%	42,64%	-
SSP3	31,53%	40,77%	-	-
SSP5	-	25,48%	-	42,72%

Table 18: Average Difference in Debt/GDP ratio for every country for 2030-2050

It is evident that RCP2.6 causes the mildest increase in the Debt/GDP ratio for Greece, Italy, Spain, and Portugal, as expected based on the analysis of the results in Chapter 4. However, the differences between scenarios do not fully capture the complexities of Debt/GDP ratio development. For instance, while the SSP5-RCP4.5 scenario may show a similar average difference to SSP2-RCP2.6 in absolute numerical terms, the underlying narratives regarding climate change are vastly different.

While uncertainty over the development and the implications of climate change is still considered high due to the difficulties that explained in Chapter 2, the necessary steps towards achieving the targets of European Green Deal are still within the reach of Europe and more specifically of the South. It is important to underscore that socio-economic scenarios that include more mitigation efforts, project a much milder increase in the public Debt of the South under the assumptions of the existing model.

As explained in the National Comparisons, every combination leads to different results for every country based on its special characteristics. Nonetheless, mitigating the consequences of climate change and completing a transition to a sustainable future can have important fiscal benefits for all the countries as the average differences depict in

Figure 5-4. Cooperation between countries and the European Commission needs to be intensified in the light of the new fiscal rules as the adaptation efforts will require adequate funding from the countries' side. More calculation and graphs are presented in A.3.

5.6 A Comparison of Southern Europe and Germany

The new fiscal framework is standing for every member of the EU which is obliged to closely follow the commission’s practices and adjust to instructions. Nevertheless, while the fiscal risks are connected to the union, the physical risks projected to materialize by climate change are differentiated from country to country. As mentioned in section 1.4, the current financial performance of the South Europe countries has improved in the last years with falling Debt/GDP ratios and constant upgrades in credit ratings by the agencies.

However, there is still a lot of ground to be covered in the financial context before the Southern European countries will be able to reach the debt levels of economic leaders such as Germany. This does not relate only to absolute GDP numbers where Italy and Spain are 3rd and 4th after only Germany and France, but also to GDP per capita and public debt in which categories performance of the Southern European countries is below the EU average (Eurostat, 2024).

The European Union's fiscal rules are designed to provide a uniform framework for economic governance across all member states, promoting fiscal discipline and stability. However, while these fiscal constraints are uniform, the impacts of climate change are not equally distributed across the continent. Southern European countries, such as Greece, Italy, Spain, and Portugal, face disproportionately higher climate-related damages compared to their northern counterparts. The difference in damages can be seen in three different combinations presented in heatmaps for the years 2030,2040 and 2050 in Figure 5-5, Figure 5-6,Figure 5-7.

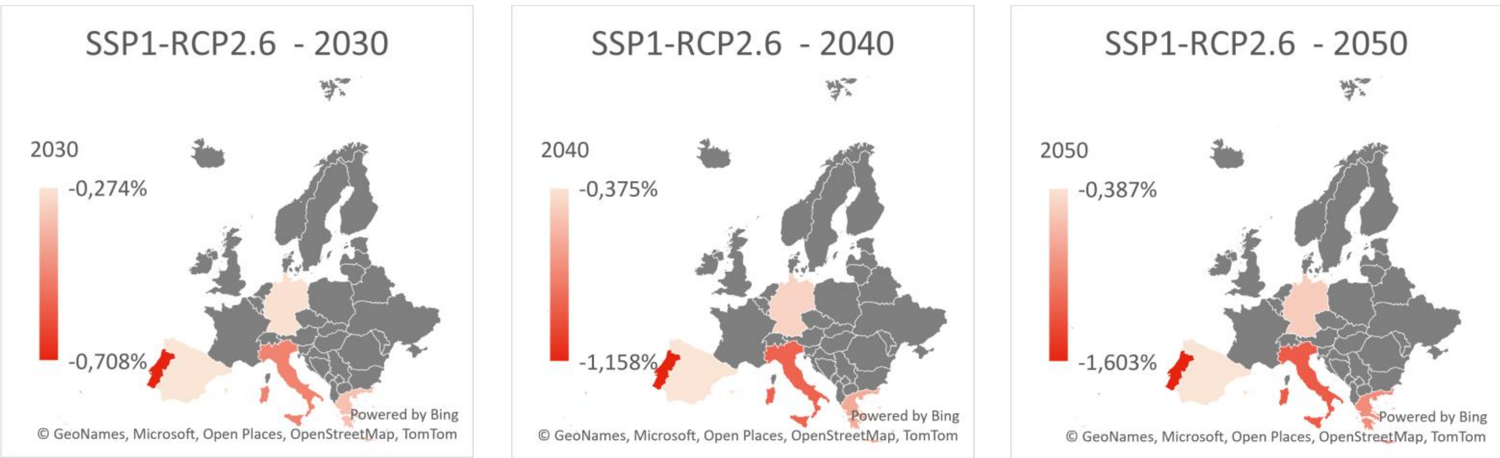

Figure 5-5 : SSP1-RCP2.6 Germany VS South

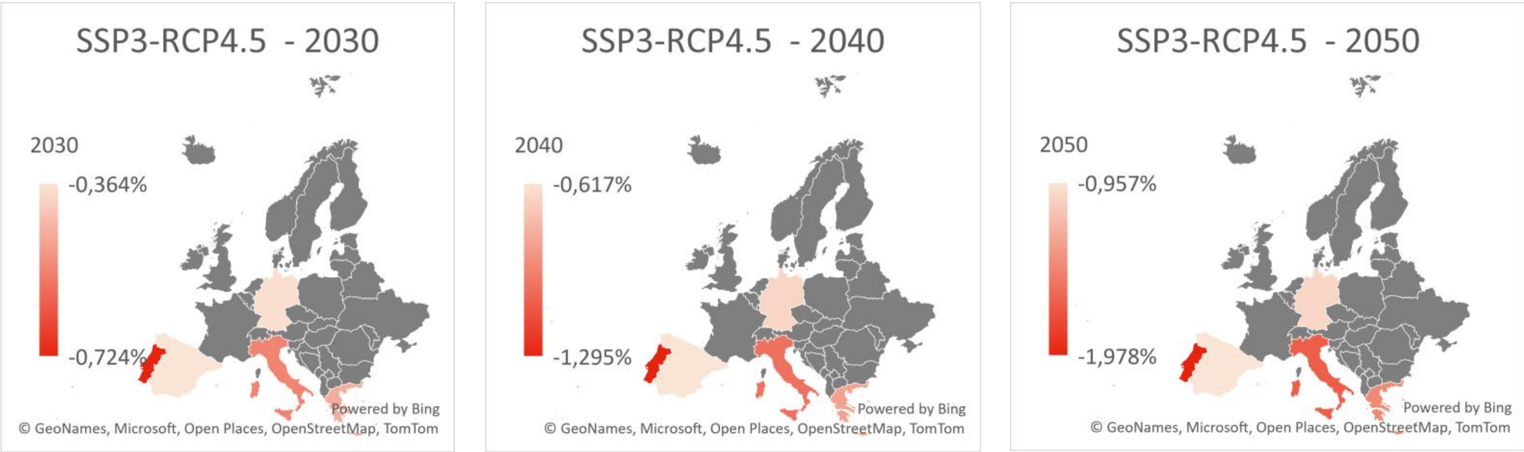

Figure 5-6 : SSP3-RCP4.5 Germany VS South

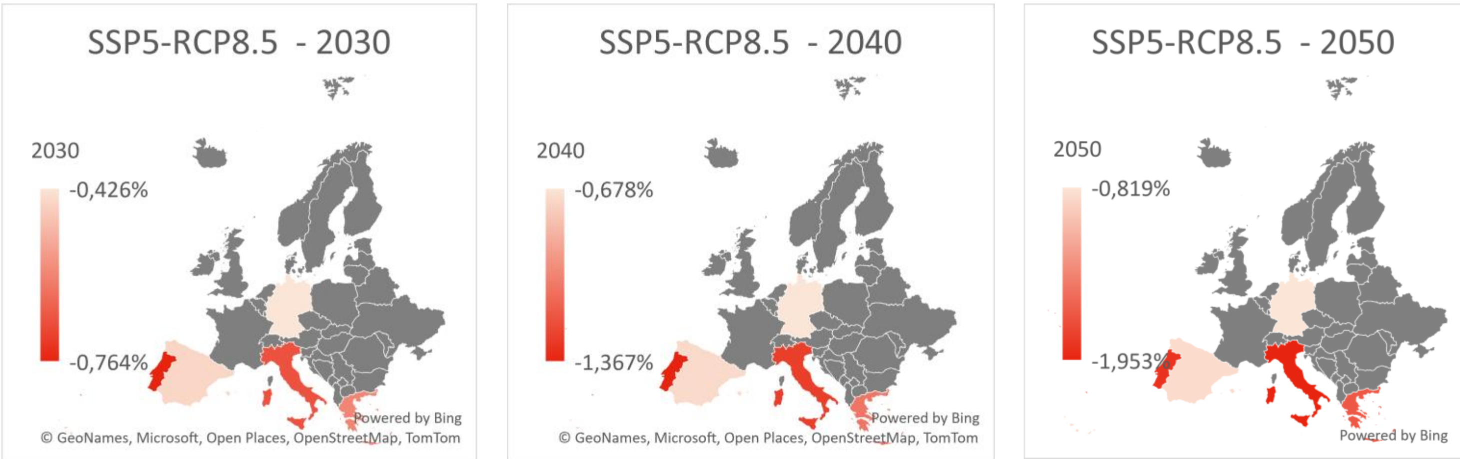

Figure 5-7 : SSP5-RCP8.5 Germany VS South

It becomes clear that Germany is projected to have decreased climate damages than the Southern European Countries in all the examined cases until 2050. In specific cases, Portugal is expected to experience the heaviest climate effects in GDP structural damages as the spread with Germany is more than 110 BPS in SSP5-RCP8.5 and 130BPS in SSP1-RCP2.6.

These projections highlight the unequal distribution of climate damage across the Eurozone, contrasting sharply with the uniform application of fiscal rules. While fiscal regulations enforce consistent standards on debt, growth, and deficits for all member states, the economic losses due to climate change are far from evenly distributed. Southern European countries, facing more severe climate impacts, are compelled to make larger (climate adaptation) investments and incur higher public expenditures to mitigate these effects and bolster their economies against future climate risks. This situation is creating significant fiscal challenges for these southern nations.

On one side, some countries advocate for stringent fiscal rules with specific thresholds, arguing for the importance of maintaining strict standards on debt and deficits. These countries will experience relatively smaller climate-related damages, while enjoying better financial conditions. On the other side, southern European countries are grappling with substantial fiscal difficulties, which are projected to intensify due to forthcoming climate impacts which are larger than the climate damage suffered by the Northern economies of the EU. Despite these challenges, the Southern countries are required to adhere to the same fiscal rules as their less-affected northern counterparts.

This is not a typical North-South divide, but it underscores the need for policymakers to recognize and address the diverse challenges faced by different countries. If the distinct difficulties of southern European nations are not considered, there is a risk of exacerbating inequality within the Union for decades to come. While providing substantial financial aid to nations in need is essential for mitigating the immediate effects of natural disasters, the European Union must also focus on proactive measures rather than reactive ones. This means prioritizing preparation and resilience-building to better manage the imminent challenges of climate change. Policymakers must consider these disparities and adjust regulations to ensure a fair and balanced approach that supports all member states in achieving both fiscal stability and climate resilience.

5.7 Research Similarities

Another point that is worthy of adding to the discussion is how this Thesis is compared to the research of Zenios (2022). That research work was one of the initial intriguing points to further explore the topic of fiscal impact of climate damage on sovereign debt. Therefore, the scenario analysis presented earlier can be compared up to a certain extent to the research work of Zenios. Despite some structural differences in the methodology, it is noticeable that results are converging to the same output regarding the debt sustainability analysis of Italy. In Figure 5-8 Debt/GDP ratio of Italy is impacted by the climate effect till 2080.

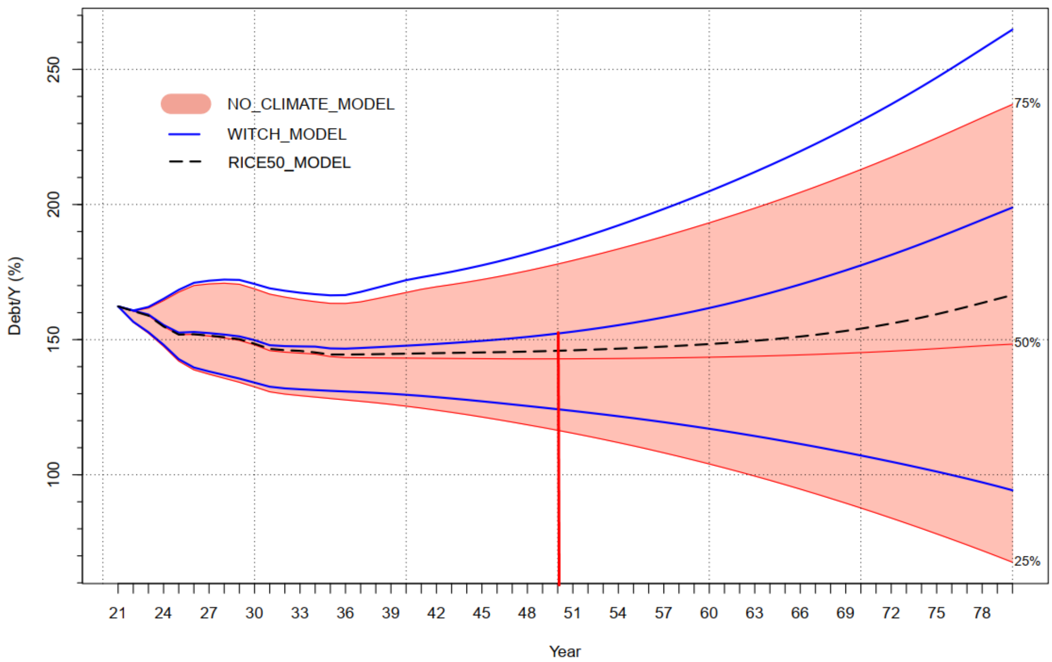

Figure 5-8: SSP2-RCP2.6 Italy Debt/GDP 2020-2080 (Zenios, 2022)

The pink-shaded fan chart illustrates debt dynamics without considering climate risks, with the median debt ratio stabilizing just below 150% of GDP but showing significant upside risk. The uncertainty in the fan chart (represented by the 25/75 percentiles) stems from the volatilities and correlations of GDP growth, output gap, inflation, primary balance, and risk-free rates, all calibrated from historical data.

Next, the research incorporates climate change effects using the SSp2-RCP2.6 scenario, which aligns with the Paris Agreement. Climate adjustments to GDP growth are projected using two different IAMs (WITCH, RICE50+), and these adjustments are then applied to IMF World Economic Outlook projections The blue lines indicate the median and 0.25/0.75 quantiles with WITCH adjustments, and the dashed line shows the median with RICE50+ adjustments. Both sets of climate-adjusted debt dynamics shift upwards, indicating that climate risks materialize significant from approximately 2030 to 2050.

It is noticeable that for the year 2050, the WITCH model projects a rise in the Italian Debt/GDP ratio which is similar to the levels of Debt/GDP ratio that are projected in the thesis analysis. More specifically, for the examined socio-economic and climatic scenario of SSP2-RCP2.6, if the interest premiums are neglected then Italy is projected to have a Debt/GDP ratio of 165,6% (Table 6) while the results from the Zenios analysis is projecting a ratio of almost 155%.

This minor discrepancy can be possibly attributed to the different starting points of the Italian Debt, as the used data for this research included IMF projections of 2021 which of course doesn't include important external factors which deeply impacted world economies such as the Ukraine-Russia Conflict and the Energy Crisis. Furthermore, it is noteworthy that considering the climate effects, totally transforms the Italian debt sustainability as the median results for both IAMs is significantly higher than the no-effects trendlines in the long-term horizon.

Nevertheless, it becomes evident that both analyses conclude to the same outlook regarding the debt sustainability of Italy despite the differences in data and the debt dynamics model which each corresponding analysis relied to. Moreover, both analyses underscore the critical link between climate change and fiscal stability while advocating for necessary measures in adaptation and mitigation.

5.8 Recommendations

The Discussion and Analysis section with some recommendations regarding the fiscal rules of the Stability and Growth Pact. After this extended discussion and analysis of the results and the implications, it is now possible to revisit the initial mechanisms that can possibly detonate the Debt-Loop and better examine their connection.

The first mechanism which relates to revenues and consequently to GDP, is evident even in moderate climate scenarios like RCP 4.5, where increased debt servicing costs, exacerbated by climate disasters, threatens to push Debt/GDP ratios into unsustainable territory, especially for countries with limited fiscal space. Second, the pervasive uncertainty surrounding climate risks complicates their assessment and incorporation into financial planning. The thesis attempted to depict that through the different socio-economic and climate combinations that capture the different developments of debt but also through different model assumptions. This uncertainty is magnified by the tendency of investors and intermediaries to overlook low-probability risks, which, when realized, can destabilize the economy by triggering a flight to safety and a sharp decline in asset values. Third, the interconnection between the banking sector and the real economy creates a feedback loop, where negative impacts on one further strain the other, deepening fiscal instability. As section 2.4 mentioned, stress testing on climate scenarios can better prepare the financial system to deal with possible repercussions and the extended uncertainty. The recommendations of the thesis are intended for the leadership of the European Union to consider when revising fiscal rules, with the goal of protecting climate and debt-vulnerable countries from the mechanisms previously described.

The first recommendation focuses on reducing uncertainty by establishing a "safety net" that enables countries to build essential fiscal buffers. These buffers would provide the financial flexibility needed to address and repair damages resulting from climate-related events, thereby mitigating the immediate economic impact. The second recommendation looks to the longer term, advocating for policies that enhance the resilience of European Union economies through comprehensive adaptation strategies and effective mitigation measures. By strengthening public revenues to better align with the evolving climate dynamics, these measures will ensure that economies are better equipped to manage the fiscal challenges posed by climate change, ultimately leading to greater economic stability and sustainability across the region.

1. The current debt model assumes that external events such as growing climate damages can be neglected in the calculation of fiscal deficits for the government. In reality this cannot be the case as the damages from natural disasters are going to be added to the fiscal deficit of the government. Corresponding to the revised fiscal rules, countries with excessive debt will be required to reduce it on average by 1% per year if their debt is above 90% of GDP, and by 0.5% per year on average if it is between 60% and 90%. If a country's deficit is above 3% of GDP, it would have to be reduced during periods of growth to reach 1.5% and build a spending buffer for difficult economic conditions. According to the results of this thesis, the revised fiscal rules do not provide adequate fiscal policy space to allow the fiscal buffer needed to battle both climate change and other external events at the same time. In consequence, the proposal is to change the rules of the Growth and Stability Pact to allow the fiscal deficit to be larger than the current threshold and most importantly to exclude possible climate related economic

losses. This proposal concerns mostly the repairing aspect of the fiscal rules as in that way indebted governments acquire the safety net needed to balance out the losses and restructure what is lost.

2. The second point that the thesis proposes is that public investments in green technology and in mitigation and adaptation policies should also be excluded from the calculation of the fiscal deficit for countries that are facing debt ratios of over 90%. Planning and investing in resilience should be fostered at an even greater pace than currently in the European Union. As this suggestion focuses more on the proactivity aspect of the fiscal rules, every European country is facing different challenges that require different investment plans and tactics and therefore limiting the expenditure for "Green" growth as part of the Excessive Deficit Procedure can be catastrophic for the Future.

Fiscal policy tools are essential for climate change mitigation by shaping government budgets and expenditures to promote sustainable development. Key tools include carbon pricing mechanisms, such as carbon taxes and cap-and-trade systems, which internalize the external costs of carbon emissions, exemplified by Sweden's carbon tax and the EU Emissions Trading System (ETS) (Krogstrup & Oman, 2019).

Additionally, public guarantees, such as loan commitments and credit guarantees, encourage private sector participation in climate-related projects by reducing financial risks (Krogstrup & Oman, 2019). By utilizing these fiscal tools, governments can create the economic conditions necessary for a large-scale transition to a low-carbon economy, addressing both immediate and long-term climate challenges. The European Union needs to carefully reassess current policy views under the pressing climate change consequences and re-adjust the fiscal weights accordingly in order to succeed in those goals set for 2050.

6. Conclusions

The report concludes the research with a brief summary of the analyzed countries and providing answers to the initial research question that were set as the scope for this project.

6.1 Summary of the Results

The projections for Greece, Italy, Spain, and Portugal underscore the critical importance of robust climate policies and socioeconomic stability in ensuring future economic resilience and debt sustainability. In Greece, scenarios with strong climate actions like SSP1-RCP2.6 minimize GDP losses and enhance stability, while insufficient climate action and geopolitical challenges in scenarios like SSP5-RCP8.5 will lead to higher debt levels and fiscal instability. Italy faces high Debt/GDP ratios under moderate climate actions due to significant adaptation costs, with scenarios like SSP2-RCP6.0 and SSP5-RCP8.5 showing the worst debt sustainability when fiscal deficits from natural disasters are included. Strong economic growth in SSP5 scenarios provides some buffer against climate impacts, illustrating the complex interplay between growth and climate-related damages.

In contrast, Spain is projected to experience lower climate-related economic losses compared to Greece and Italy, with the most impactful scenario, SSP3-RCP4.5, barely reaching a loss of 1% of GDP by 2050. Scenarios like SSP3-RCP4.5 and SSP3-RCP2.6, driven by regional competition and protectionist policies, result in stagnating growth and significant fiscal pressures. However, SSP5-RCP4.5 and SSP5-RCP8.5 show favorable outcomes due to strong economic growth. Portugal faces significant debt sustainability challenges, with modest initial losses escalating under severe climate conditions. SSP3-RCP4.5 consistently projects the highest economic losses, while SSP2-RCP6.0 benefits from effective mitigation policies. Incorporating fiscal deficits highlights the severe impact of repeated natural disasters, with SSP5-RCP8.5 showing the worst Debt/GDP ratio increase.

The scenarios highlight the necessity of integrating proactive climate policies with economic measures to ensure long-term fiscal health and mitigate the adverse impacts of climate change on these southern European economies. Strong climate action and sustainable growth strategies are essential to manage debt sustainability and enhance economic resilience amidst escalating climate risks.

Projections indicate that Germany will face significantly less climate damage compared to Southern European countries like Portugal, which is expected to experience the heaviest impacts, with spreads over Germany of more than 110 BPS in SSP5-RCP8.5 and 130 BPS in SSP1-RCP2.6. This contrasts the uniform fiscal rules across the Eurozone, which enforce consistent standards on debt, growth, and deficits regardless of uneven climate impacts. Southern European countries, facing more severe climate effects, must invest more in climate adaptation and public expenditures, intensifying their fiscal challenges.

While some countries with less climate damage advocate for stringent fiscal rules, Southern nations, already under fiscal strain, must follow the same regulations, potentially increasing inequality within the Union.

The thesis concludes the project and the analysis with two recommendations for the Stability & Growth Pact. One point has more of a repairing nature while the other focuses on the proactiveness aspect of the fiscal rules.

6.2 Answering The Research Questions

Trying to provide a holistic answer to the questions asked in the beginning of the Thesis, it is reasonable to assume that current results and indications are pointing unanimously in only one direction. The public debt of the South European countries is clearly going to be affected by climate change over the next decades and it lies solely with the EU and national governments to avoid the Debt Loop.

The climate effect will be different in magnitude and severity for each country, but the results under certain assumptions, indicate a detrimental effect with inclining damage trends until 2050. The damages as percentage of GDP are considered serious enough to threaten the economic growth of the southern countries under any SSP. In consequence, stagnating growths in combination with climate related natural disaster will have a compounded and severe impact on the Debt/GDP ratio of Greece, Italy, Spain and Portugal.

Deteriorating economic and environmental conditions will apply significant pressure on the spreads of South European countries in comparison to Europe's leading economy, Germany which according to the projections, will receive minor climate losses. Therefore, the spread difference will also push country specific risk premiums in higher levels and will make debt financing and new debt issuances much more expensive for South European governments. Then, the feedback drives Debt/GDP ratio increases, and the loop starts from the beginning.

Regarding the final sub-question of the Thesis, the argumentation line that was presented in the sections of European Fiscal Rules and Recommendations showcase the reasons that the current fiscal policy framework (the revised Growth and Stability Pact) does not adequately correspond to the fiscal challenges of the future in relation to the climate change, especially for the Southern European economies.

6.3 MOT relation

By integrating the fields of management, innovation, technology, and economics, the thesis topic addresses a comprehensive approach to fiscal governance in the context of climate change. It highlights the need for strategic management of fiscal policies, innovative financial instruments, technological advancements, and robust economic analysis to create a resilient and sustainable economic framework for the European Union. This multidisciplinary approach aligns well with the objectives of a Master's degree in Management of Technology, providing valuable insights and practical solutions for contemporary global challenges.

Furthermore, by incorporating different datasets into one multifaceted debt dynamics model in order to address policy changes, an innovative approach was introduced which shows how technological advancements like Integrated Assessment Models can become practical tools in battle for alleviating climate change repercussions. Lastly, the topic and the author encourage the development of novel financial instruments and mechanisms to support green investments and climate adaptation projects.

6.4 Limitations

The research has faced some limitations due to its nature as a financial model. In order to proceed to the results of the model, a certain number of assumptions needed to be made. Starting from the weighted averages contribution of each region of each country it was assumed that no major change will take place on how some areas contribute to the national GDP. For example, if the largest contributing region takes a massive economic loss from a natural disaster, then the balance will change and with it the projected structural loss from climate change.

In addition, in the designed scenarios that were tested, many assumptions are included about the projection such as the severity and frequency of the climate related disasters. Moreover, the data quality needed to be explored adequately before incorporating the datasets into the model. The availability and quality of data on climate impacts and fiscal policies can vary significantly across different countries. This inconsistency may affect the accuracy and reliability of projections and analyses.

Furthermore, historical data on climate-related damages and economic impacts might be incomplete or unreliable, making it challenging to establish accurate baselines and trends. Lastly, the research may not fully capture indirect economic effects of climate change, such as changes in migration patterns, social unrest, or shifts in global trade dynamics, which could have significant implications for fiscal policies. Acknowledging these limitations is crucial for interpreting the findings and formulating robust and adaptable policy recommendations. Future research should aim to address these gaps, enhance data collection and modeling techniques, and explore comprehensive approaches to integrate climate and fiscal policies effectively.

6.5 Suggestions for Future Research and Reflections

The contribution of this Thesis to the literature is focused on exploring the climate change economic effects on Debt of already indebted and developed economies which also follow common fiscal and monetary policy. Furthermore, the Mediterranean area will be severely affected by climate change and therefore discovering the fiscal implications is an important finding for future researchers and policy regulators.

Nevertheless, there are still significant gaps in this research topic as climate risks are not yet widely covered both by credit rating agencies and financial institutions. Some suggestions regarding research of the future could be to add in the debt dynamics model an even more accurate and mathematically calculated fiscal deficit to better depict the consequences of Natural disaster of the countries of the South. In addition, exploring the role of European Central Bank in the handling of climate vulnerable countries bonds and monetary policies is of an increasing role. Another interesting topic would be to explore how different mitigation policies and fiscal instruments can change the trends projected in the results of this thesis and to discover the more efficient strategies under the different socio-economic and climate scenarios dataset.

Finally, investigating the potential benefits and challenges of regional cooperation among Southern European countries to enhance climate resilience under the guidance of the EU. This research could propose collaborative strategies and shared investment models to address common climate-related challenges.

A. Appendix

A.1 RCP

- **RCP2.6**: This pathway aims to limit the increase in global mean temperature to below 2°C above pre-industrial levels. It represents a low emissions scenario where greenhouse gas concentrations peak and then decline, requiring significant mitigation efforts and carbon removal technologies.

- **RCP4.5**: This pathway assumes that emissions will peak around 2040, then decline. It represents a stabilization scenario where policies are implemented to stabilize radiative forcing at 4.5 W/m^2 by 2100 without overshooting the target. It includes moderate mitigation efforts and significant changes in energy production and land use.

- **RCP6.0**: This pathway assumes that radiative forcing will stabilize at 6.0 W/m^2 by 2100. It represents a stabilization scenario where emissions peak around 2080 and then decline, requiring some mitigation but less aggressive than RCP4.5. It includes moderate economic growth and technological advancements.

- **RCP8.5**: This pathway represents a high emissions scenario with no significant efforts to curb emissions, leading to a radiative forcing of 8.5 W/m^2 by 2100. It is often referred to as the "business-as-usual" scenario, assuming continued high greenhouse gas emissions due to high population growth and fossil fuel use without major changes in technology or behavior.

A.2 SSP

- **SSP1 - Sustainability (Taking the Green Road)**: This scenario envisions a world that shifts gradually towards a more sustainable path, emphasizing inclusive development, environmental protection, and equality. Strong investments in education and health improve human capital. Green technologies and policies are widely adopted, reducing carbon emissions and environmental impacts.

- **SSP2 - Middle of the Road**: This scenario represents a world that follows historical patterns of development, with no major deviations from current trends. Economic growth and technological progress occur at moderate rates. Social, economic, and technological trends do not change markedly, leading to moderate challenges for mitigation and adaptation.

- **SSP3 - Regional Rivalry (A Rocky Road)**: This scenario depicts a fragmented world characterized by nationalism and regional conflicts. Countries focus on self-sufficiency, leading to slow economic growth and technological development. There is limited cooperation on global challenges, resulting in high challenges for both mitigation and adaptation due to insufficient global coordination.

- **SSP5 - Fossil-fueled Development (Taking the Highway)**: This scenario describes a world that prioritizes economic growth and development through intensive use of fossil fuels. Rapid technological advancement and high energy demands drive growth, but environmental and social sustainability are not prioritized. This leads to high challenges for mitigation due to substantial greenhouse gas emissions.

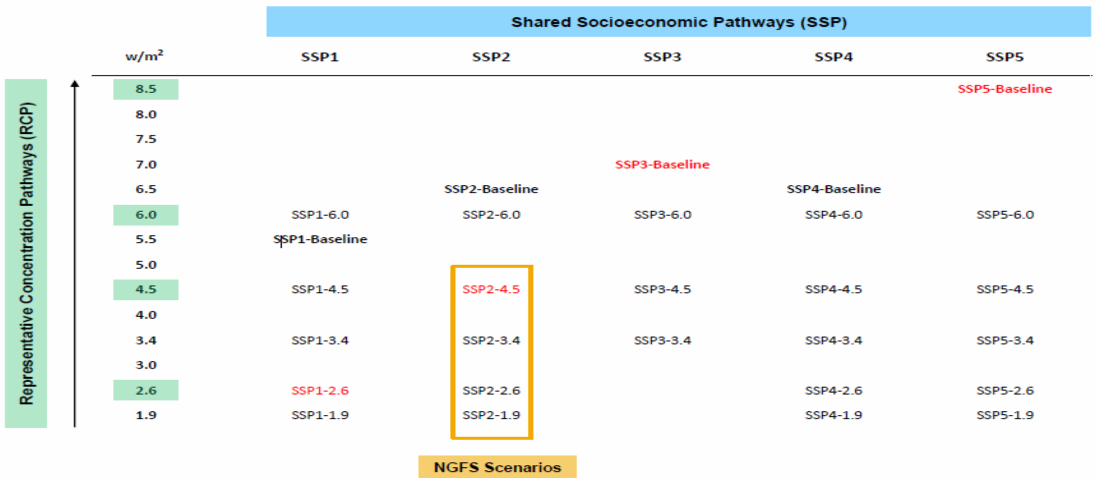

Figure A-1: RCP-SSP possible Combinations (Mohaddes & Raissi, 2024)

A.3 Average Differences in Debt/GDP

The following figures present the difference between the Debt/GDP ratio for every country under all the possible combinations explored in the main text of the thesis. The examined horizon is 2030-2050 and the distinction is based on the socio-economic scenarios SSP and in the second stage in every climatic scenario RCP. This section is targeting into supporting the argumentation line that was built in Discussion and Analysis section.

SSP1

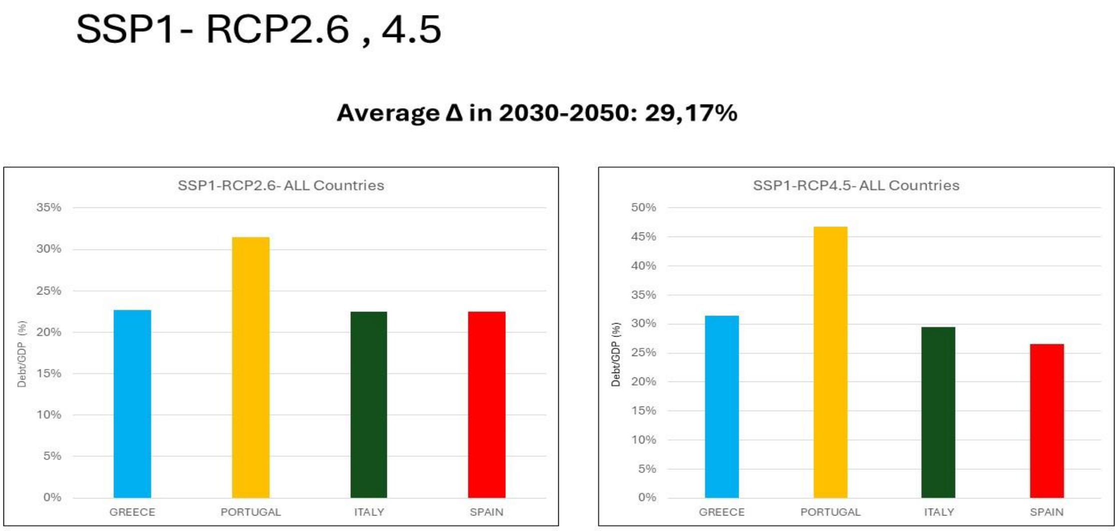

Figure A-2: Differences in Debt/GDP ratio between all countries in 2030-2050 under SSP1

SSP2

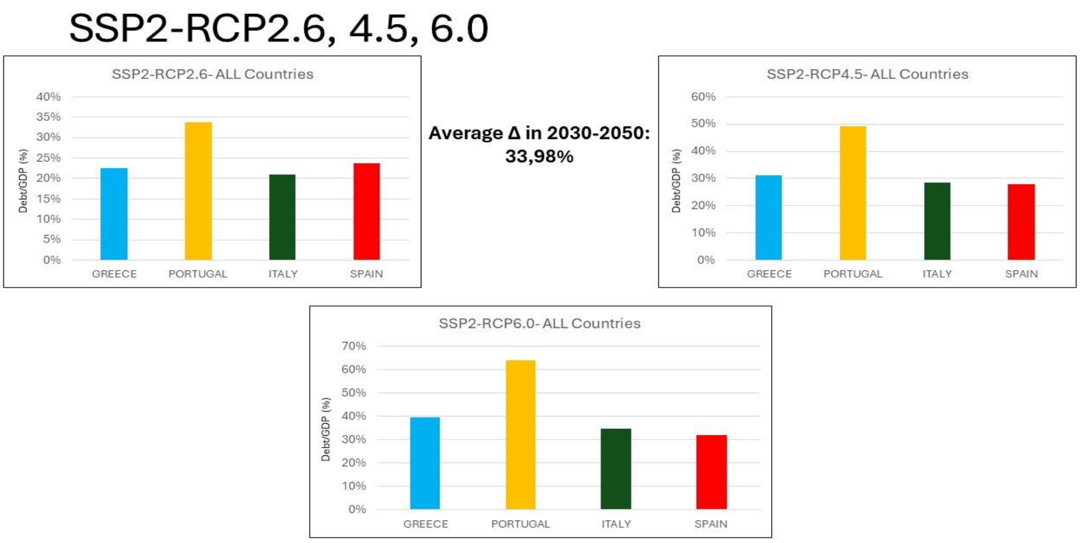

Figure A-3: Differences in Debt/GDP ratio between all countries in 2030-2050 under SSP2

SSP3

SSP3-RCP2.6, 4.5

Average Δ in 2030-2050: 36,15%

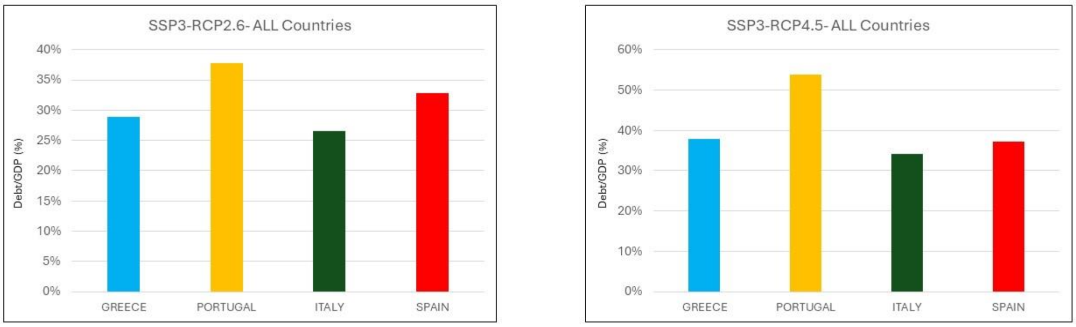

Figure A-4: Differences in Debt/GDP ratio between all countries in 2030-2050 under SSP3

SSp5

SSP5-RCP4.5, 8.5

Average Δ in 2030-2050: 34,1%

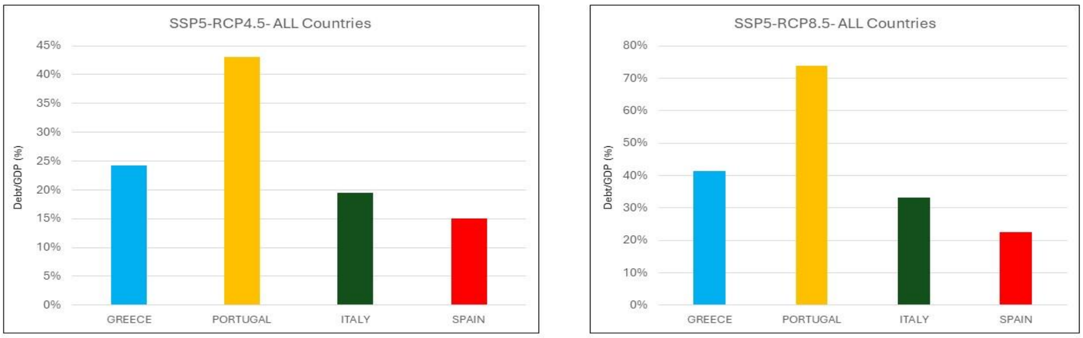

Figure A-5: Differences in Debt/GDP ratio between all countries in 2030-2050 under SSP3

A.4 Damages after 2050

The European Union has set an official target to achieve its environmental mission by 2050. Beyond this time horizon, the complexity of making accurate estimations increases, and the assumptions required become more significant. Despite these challenges, the author extends the investigation to longer time horizons to emphasize the contrasting trajectories of aggregate climate damages under various scenario combinations. The following figures illustrate how certain combinations experience a reversal in GDP damages post-2050, shedding light on the long-term implications of different climate action strategies.

Greece

Figure A-6 presents the projected economic losses for Greece as percentage of GDP in the period 2025-2070.

Figure A-6: Greece GDP losses 2025-2070

While most of the combinations continue to cause extended damage after 2050 only two of them totally reverse their course and return to the level of damage that were in 2040. In contrast, it is noticeable that in 2050, SSP5-RCP8.5 and SSP3-RCP4.5, increase the steepness of their trend, ending up to 3,5% and 3% losses accordingly. A possible explanation for this is that sustainable growth is accelerating after 2050 under the assumption of a milder RCP and therefore less damages. On the other hand, regional rivalries, fossil fuel energy and decreased climate action will double economic losses after 2050.

Italy

The case of Italy is even more interesting than Greece as is shows interesting results that include changes in the rankings of most detrimental combination. The results for Italy's GDP losses are presented in Figure A-7.

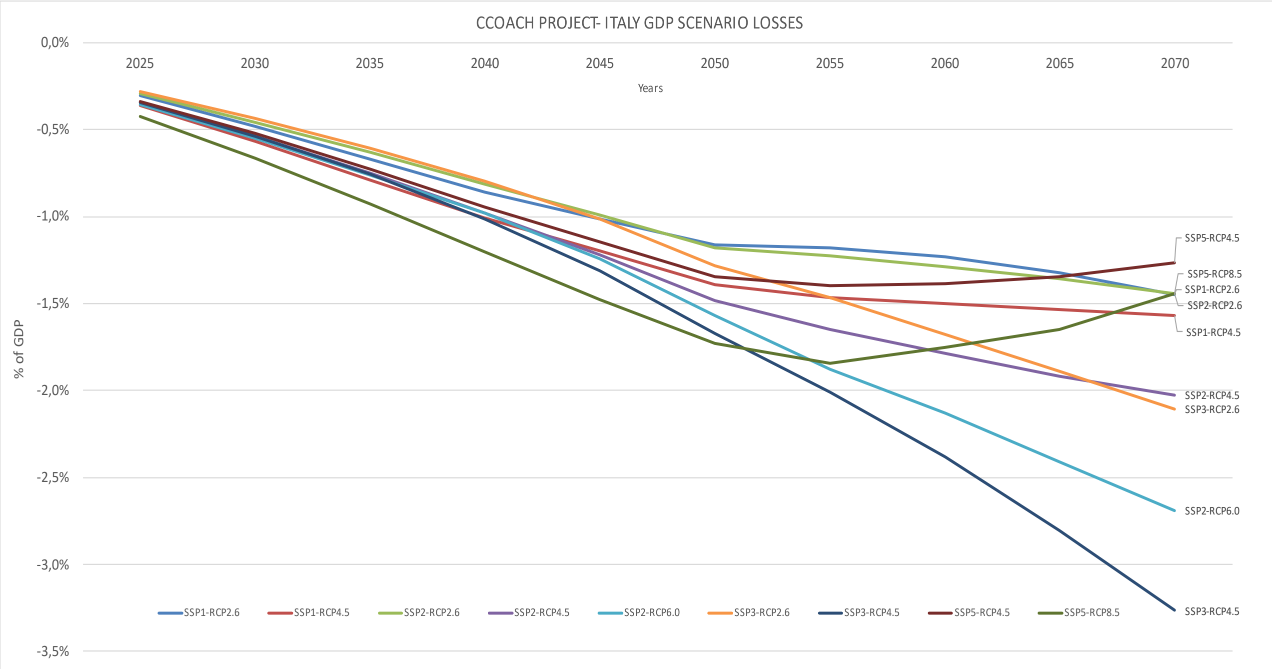

Figure A-7: Italy GDP Losses 2025-2070

It is evident that after 2050 there are major changes in the rankings of the combinations. First, it should be highlighted that in 2070, four out of total nine combinations have changed their damage course either in full or partially. It is worth noting that SSP5-RCP8.5 move completely antisymmetric to its original trend until 2050 and ends up being only second in the rankings as the most favorable towards Italian economy. Furthermore, SSp5-RCp4.5 changes its trend and returns in 2070 to damages equal to 2045. This result is surprising as climate inflicted damage is in general larger in magnitude in more severe RCPs. Nevertheless, this can potentially be justified with the strong economic growth on SSP5 that is projected by IIASA and OECD on Italy's case.

Spain

Spain GDP losses present significant diversification across the multiple combinations. After 2050 there are some combinations which not only reverse their trend but also turn economic losses to economic profits. The results are projected in Figure A-8.

Figure A-8: Spain GDP Losses 2025-2070

Beginning from combination SSP5-RCP4.5, it is highly interesting how the downbound trend completely changes after 2050 and turns losses into marginal profits. Closely following SSP1-RCP2.6, manages to reach almost zero losses in 2070. On the other hand, SSP3-RCP4.5 and SSP3-RCP2.6 continue their detrimental course with steady rate. Overall, Spain is the country less affected (in GDP context) by the climate damages in comparison to Greece, Italy and Portugal. Despite that, it is important to underscore that combination which include strong climate action and mitigated climate damages, are projected to be less detrimental to Spain's economy and in sequence for its debt sustainability.

Portugal

Portugal demonstrates interesting results after 2050. In Figure A-9, the drastic changes that take place after 2050, result in differences in the final rankings of combinations.

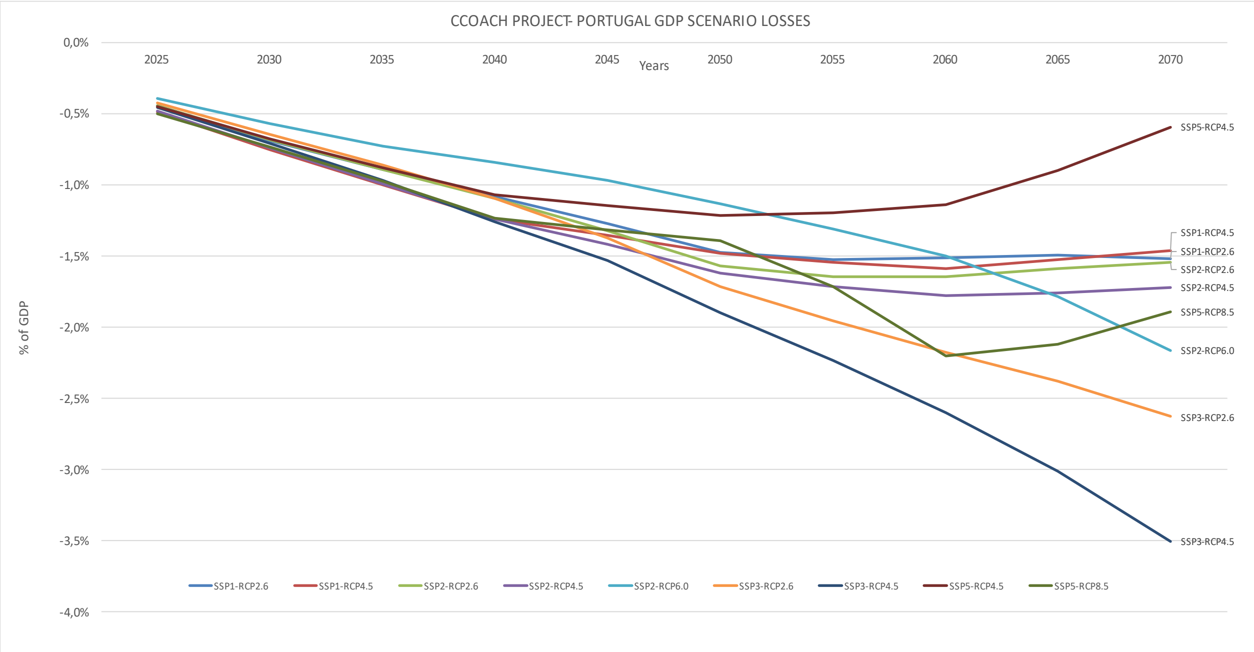

Figure A-9: Portugal GDP losses 2025-2070

First, it is noticeable how SSP5-RCP4.5 changes its trend and almost turns into a smooth curb. The damages are getting to a peak in 2050 and thereafter continue to decrease until 2070 where it has returned to the damage levels of 2025. In addition, it is worth noting that combinations with strong climate action and mild climate consequences such as SSP1-RCP4.5, have minor differences regarding their final place and result as their common trendline decreases in rate from 2050. Moreover, SSP3-RCP2.6, 4.5 continues to increase in damage as percentage of GDP. A common element between all the examined countries is the performance combinations which include SSP3 as a socio-economic scenario. This is justified by the fact that regional energy rivalries and moderate climate action are assumed to carry decreased economic growth rates and therefore the climate damage effect will be magnified even at a structural level.

A.5 Alternative Hypothesis on Deficits

To better explore the economic repercussions of climate change on public debt and compliment the current debt model, a different hypothesis on the fiscal deficit's adjustment was assumed. In the original methodology in 3.2.6, deficits are adjusted to historical data to calculate the average economic as result of climate related natural disasters. This time, the alternative narrative hypotheses that the annual public deficit in a year is equal to the projected climate damage (as % of GDP) according to the COACCH Project. To achieve this, as COACCH does not present data on an annual basis but rather on a 5-year step, it was assumed that the years in between the original steps are connected in a linear way. More specifically, the increase or decrease in deficits is taking place gradually and not abruptly. In Table 19, is presented an example of the distribution of deficits in this alternative hypothesis. The deficits correspond to each socio-economic and climate combination (SSP-RCP) presented in the main text of the thesis. In conclusion, this hypothesis does not alter any other assumptions in the model except for the public deficits' formulation.

2030	-0,3582%
2031	-0,3806%
2032	-0,4044%
2033	-0,4297%
2034	-0,4566%
2035	-0,4851%

Table 19: Deficits example distribution

In consequence, as the years 2030 and 2035 are known, the rest of the years for every step are calculated in a linear way.

Continuing with the analysis of the alternative, the results of the third debt scenario are presented in Figure A-10. In this scenario, the risk premiums are included in the interest calculation as climate damage and debt keep rising year after year.

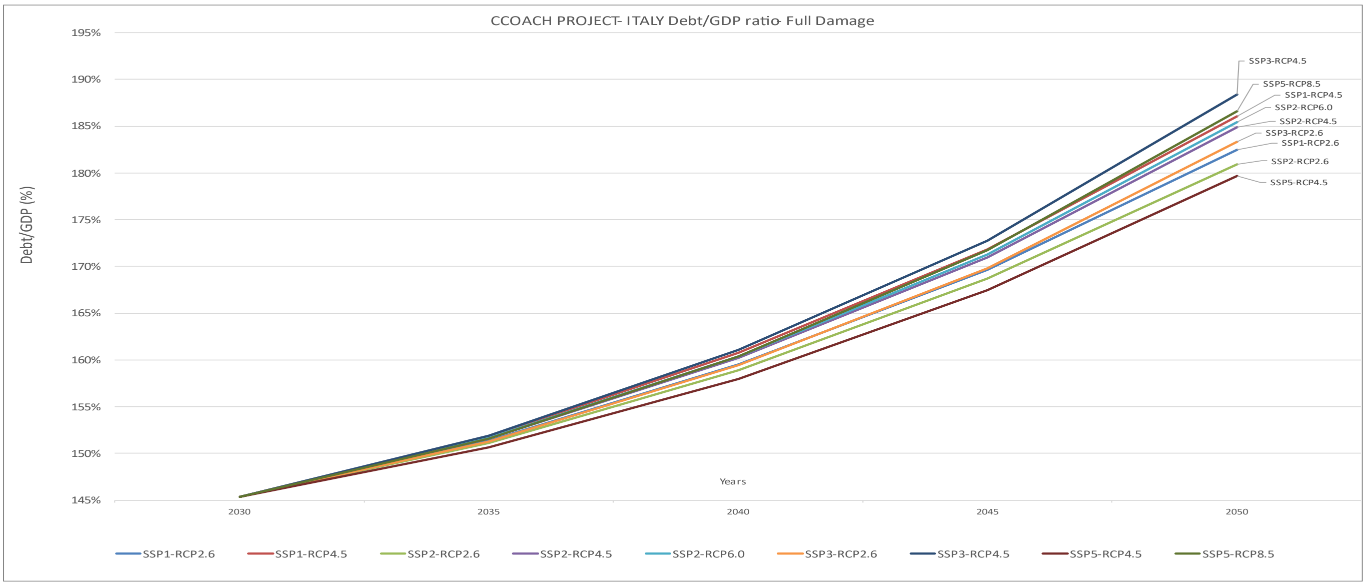

Figure A-10 : Debt/GDP Italy-Alternative Deficits Hypotheses

This alternative analysis demonstrates similar results regarding the most favorable combination. In accordance with the original calculation and analysis in Figure 4-9, it is noticeable that SSP3-RCP4.5 is the worst outcome for the Italian economy. In comparison with the original model, SSP2-RCP6.0 fell to 4th place. Another interesting observation is that combinations with RCP4.5 and above, are located in the first places in comparison with every RCP2.6 combination that is falling behind. The exception for this trend is only SSP5-RCP4.5 which assumes strong economic growth and moderate climate damages due to further development of fossil fuel and therefore is noticeable how climate premiums and debt premiums are have a minor effect on the Debt/GDP for this combination. In addition, it is highlighted that every combination of reached higher Debt/GDP levels than the original calculated model. The increased economic damage from non-cooperative practices between the nations can have detrimental effect in the long-term financial horizon. The exact differences are presented in Table 20.

Combination	Original Model	Alternate Model	Δ
SSP1-RCP2.6	168%	183%	15%
SSP1-RCP4.5	175%	186%	11%
SSP2-RCP2.6	166%	181%	15%
SSP2-RCP4.5	174%	185%	11%
SSP2-RCP6.0	180%	185%	5%
SSP3-RCP2.6	172%	183%	11%
SSP3-RCP4.5	179%	188%	9%
SSP5-RCP4.5	165%	180%	15%
SSP5-RCP8.5	179%	187%	8%

Table 20: Differences between Original and Alternative Deficit Hypotheses on the Full Damage Scenario in 2050

In conclusion, both assumptions regarding the public deficit of a country have strengths and weaknesses. The original model, which utilizes historical data of only a short period of time, can lack quality due to the relatively small sample and therefore can alienate the combinations picture solely based on the magnitude of the repeated natural disasters according to each assumed RCP scenario. Nevertheless, the projections are based on actual climate events of the past, which adds an essence of reality and robustness to the model.

On the other hand, in the alternative hypothesis for deficits, it is observed that the average public deficit can be significantly higher than the corresponding combination's deficit in the original hypothesis. Despite the inclusion of linear calculation of deficits, it is important to highlight that deficits grow annually, which in essence is translated to disasters of larger magnitude up to a specific threshold. This indicates that over time, the financial burden on the country could be much more severe if larger and more frequent natural disasters occur. Additionally, this approach accounts for the cumulative effect of climate impacts, showing a more comprehensive view of potential fiscal challenges. Integrating both approaches provides a more nuanced understanding of the fiscal impacts of climate change. The historical data approach offers a grounded perspective based on real events, while the alternative hypothesis highlights the potential escalation of costs over time.

A.6 Selected Combinations for Greece

After exploring the main results and better understanding the context it is now possible to explore the combinations that showcase the most interesting results by comparing the three created debt scenarios for a singular combination. This format is repeated for all the countries of the South in this master thesis. Comparing the results between the GDP projections from the average IIASA, OECD with the projections after the deduction of the damage shows how the structural damage is slowly but steady affecting the economies.

SSP1-RCP2.6

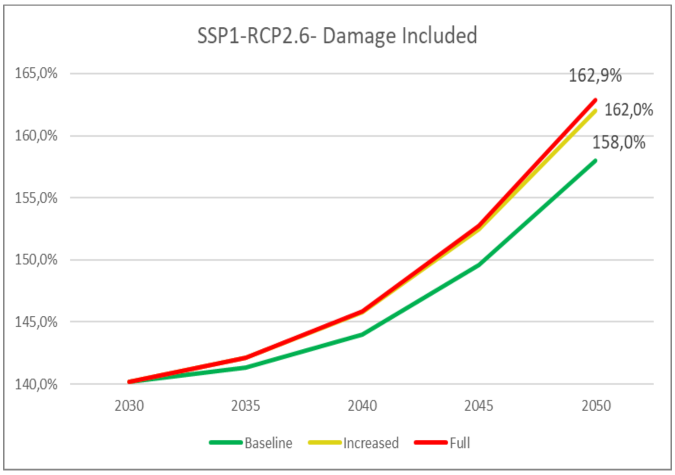

Figure A-11: SSP1-RCP2.6-Damage Included

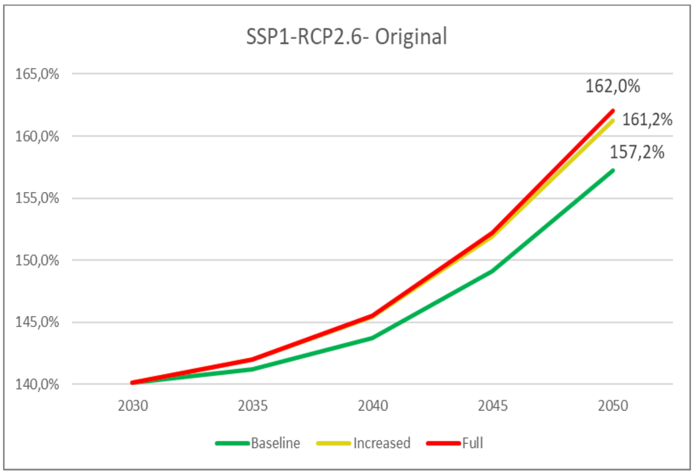

Figure A-12:SSP1-RCP2.6-Original Projections

In the mildest combination of both climate action and climate sequences, it is noticeable that despite being on the first place for least favorable outcome among all the combinations in the baseline scenario, it ends up as in the last place for Full damage scenario. Another interesting observation is that after the inclusion of fiscal deficits and incorporation of high premium risks the final difference is roughly 5% in both cases. Subsequently, once again the limited impact of RCP2.6 on the economy is visible as the burden of natural disasters for Greece is much lower in this outcome

SSP3-RCP4.5

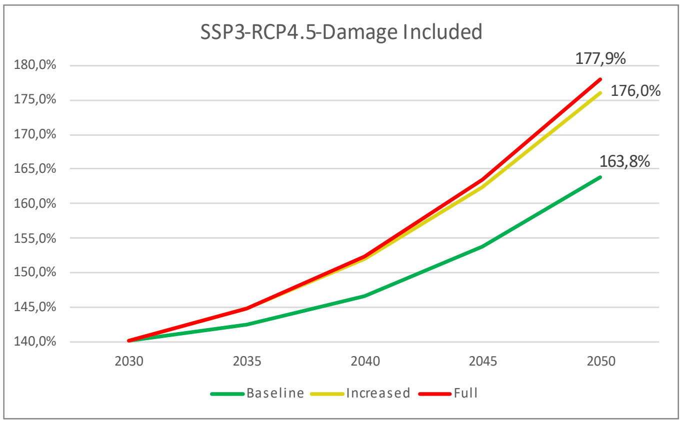

Figure A-13: SSP3-RCP4.5- Damage Included

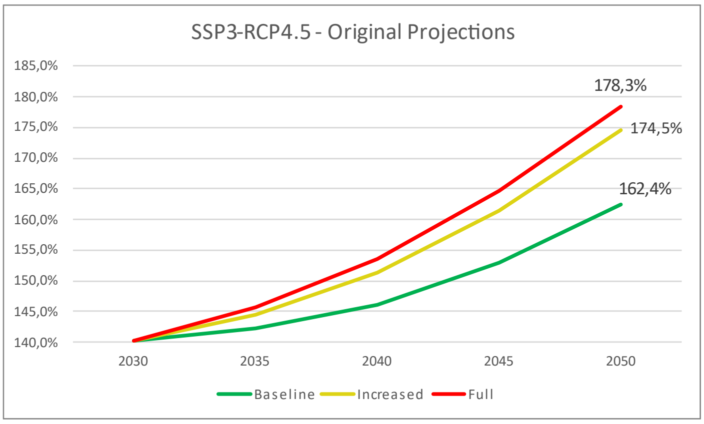

Figure A-14:SSP3-RCP4.5-Original Projections

In this pair of graphs where the middle combination of SSP3-RCP4.5 is on exhibit, the structural damages make a noticeable difference in the projections as better depicted in Figure A-13 with the steeper increase of the Debt/GDP ratio in the Increased scenario. A critical point is that despite the minor differences between the two cases in 2050, the Full damage scenario which incorporates high premium risks is already more distinct and steeper at this level of impact in the case of Damage included GDP Projections. That is in line with Figure 4-2 conclusions on the structural damages as the examined combination is exhibiting much more aggressive aggregate damages in 2050 compared to the rest.

SSP5-RCP8.5

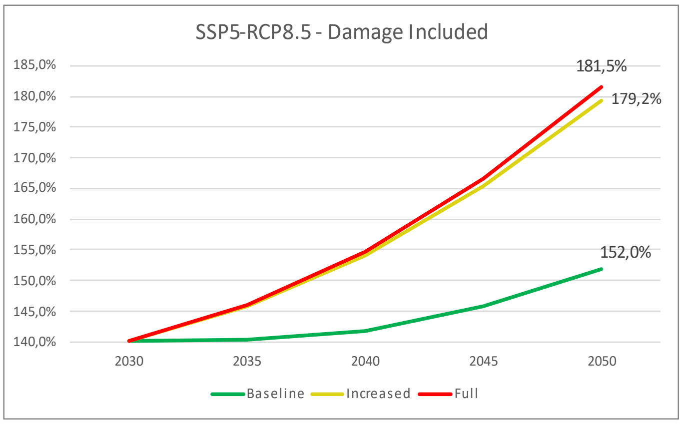

Figure A-15: SSP5-RCP8.5- Damage Included

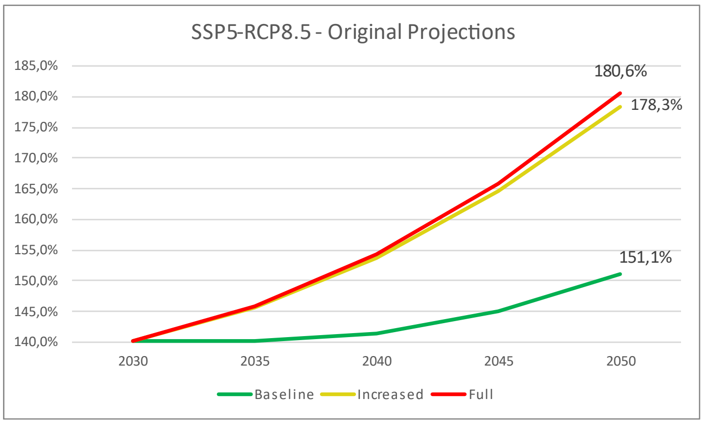

Figure A-16:SSP5-RCP8.5-Original Projections

Finally, the most severe combination of climate consequences and lack of action against the climate damage is exhibiting the true magnitude of economic losses due to natural disasters. This is evident from the huge increase in both Increased and Full damage scenarios that incorporate both the annual losses of GDP (%) as fiscal deficit and climate premium risks. The two cases of projection do not illustrate extensive differences because structural damages in economy are multiplying in magnitude after the year of 2050 which is the key horizon for European Union to achieve its targets.

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