Policy Contribution
Issue n°16/21 | July 2021

The risks from climate change to sovereign debt in Europe

Stavros A. Zenios

Executive summary

THE EXPOSURE OF European Union sovereigns to climate risks can be acute, from extreme weather, or chronic, from the productivity effects of gradual temperature increase, increased sea levels and the transition to a low-carbon economy that results in repricing of assets. Climate-related innovations can also spur growth. These risks are priced by investors and can affect sovereign credit ratings.

GOVERNMENTS AND FISCAL stability authorities have an interest in the sovereign-debt implications of climate change being transparent. To this end, we look at the exposure of EU sovereigns to climate risks, study international best practices, and describe the transmission channels from climate change to public finance.

EUROPEAN UNION INSTITUTIONS and national fiscal authorities should mainstream climate risk analysis in public finance. Stress testing of debt dynamic requires a link between regional climate scenarios and country debt dynamics. We argue for the adoption of an architecture of narrative climate scenarios, to guide national policymaking.

NARRATIVE SCENARIOS CAN BE generated using integrated assessment models. As an illustration, we apply two prominent models to generate rough bounds on the extent of the risk for Italian debt from climate change. This raises issues about the models used. Coordination by EU institutions to develop regional scenarios will ensure acceptability, raise ambitions in dealing with climate risks and encourage the fiscal authorities to think of solutions. A network for climate-proofing public finance will bring together EU and member-state institutions.

WE ALSO RECOMMEND budgeting for climate expenditures and contingent liabilities, and using risk-sharing instruments, with disclosure of the risks to public finance from climate change.

STAVROS A. ZENIOS (stavros.zenios@bruegel.org) is a Non-resident Fellow at Bruegel

The author is a Professor at the University of Cyprus and Member of the Cyprus Academy of Sciences, Letters and Arts. Thanks are due to Roel Beetsma, Zsolt Darvas, Maria Demertzis, Demetris Georghiades, Barret Kupelian, Alexander Lehman, André Sapir, Rolf Strauch, Guntram Wolff, Georg Zachman, Theodoros Zachariades and participants in a European Stability Mechanism Seminar on Debt Sustainability Analysis (April 2021) for comments. Andrea Consiglio carried out the debt sustainability analysis tests and Johannes Emmerling provided generous clarifications and access to WITCH and RICE50+. Research assistance by Klaas Lenaerts, Elena Papadiofantous and Vicenzo Martorana is gratefully acknowledged.

Recommended citation
Zenios, S.A. (2021) 'The risks from climate change to sovereign debt in Europe', *Policy Contribution* 16/2021, Bruegel

bruegel

1 Introduction

The COVID-19 pandemic has overshadowed the risks from accelerating climate change. With 2016, 2020 tied for the warmest year on record[1], but this went mostly unnoticed. Nevertheless, during the pandemic, the European Union has formalised a goal of net-zero greenhouse gas emissions by 2050[2], and the period until 2030 is considered a make-or-break decade for climate action. Europe must tackle the issue at a time when euro-area sovereign debt has reached almost 100 percent of GDP. Internationally, concerns have been voiced that climate change will imperil the ability of countries to repay COVID-19 debts (Dibley *et al*, 2021).

In this Policy Contribution, we make a rough assessment of the exposure of EU sovereigns to risks arising from climate change and look at how fiscal authorities in the United States, Canada, Japan, United Kingdom, Australia and New Zealand deal with climate risk. We explain the transmission channels from climate change to public finance and, consequently, to sovereign debt. The nature of the problem and best practices elsewhere suggest a need for a better assessment at EU level of the link between climate change and debt. Such an assessment would be of value to member-state issuers and the institutions responsible for fiscal stability, including the European Commission, European Central Bank, European Stability Mechanism, European Fiscal Board, national finance ministries and national fiscal councils. We also argue that budgetary plans should be transparent in terms of their climate exposure, should account for climate-related costs and seek risk-sharing instruments.

There is a need for a better assessment at European Union level of the link between climate change and debt

Climate change is a problem that brings with it deep uncertainty. There are risks for which the probabilities are known, there is ambiguity where outcomes may be known but their likelihood is not, and there are misspecifications where there is no consensus on data or models (Barnett *et al*, 2020).

Deep uncertainty plagues the analysis of sovereign debt in the context of climate change. First, estimating growth, the fiscal stance, interest rates, inflation and debt dynamics, is a problem of risk. It requires looking well into the future, posing a challenge of multiple horizons because the impacts of climate change will be felt at different horizons (Carney, 2015). For instance, mitigation costs impact public finance in the short- to medium-term, while adaptation costs can be medium- to long-term. Risk management is a mature body of knowledge, and is already embedded in the assessment of whether countries will be able to meet their debt obligations in the context of current debt levels and borrowing plans[3].

Second, different climate policies imply different socio-economic paths for the world's economies, with varying beneficial and adverse effects, and determining in turn the climatic conditions. This presents a problem of ambiguity: we might know what the world could look like if the global temperature rise stays below 2 degrees Celsius, or if it does not, but we cannot assign probabilities. The Intergovernmental Panel on Climate Change (IPCC) has developed a scenario architecture to deal with this ambiguity. It includes scenarios of how greenhouse-gas concentrations could increase in the atmosphere, known as representative concentration pathways (RCPs), and scenarios of how the economy and society might develop, known as shared socio-economic pathways (SSP)[4]. The top panel of Figure 1 shows the two extreme RCPs, under which the temperature increases by 2100 would be 2°C (RCP2.6) and 4.2°C (RCP8.5) respectively. The bottom panel shows the five SSPs with different mitigation and adaptation challenges. We may not know the probabilities, but we have several plausible states of the world with which to conduct what-if analyses.

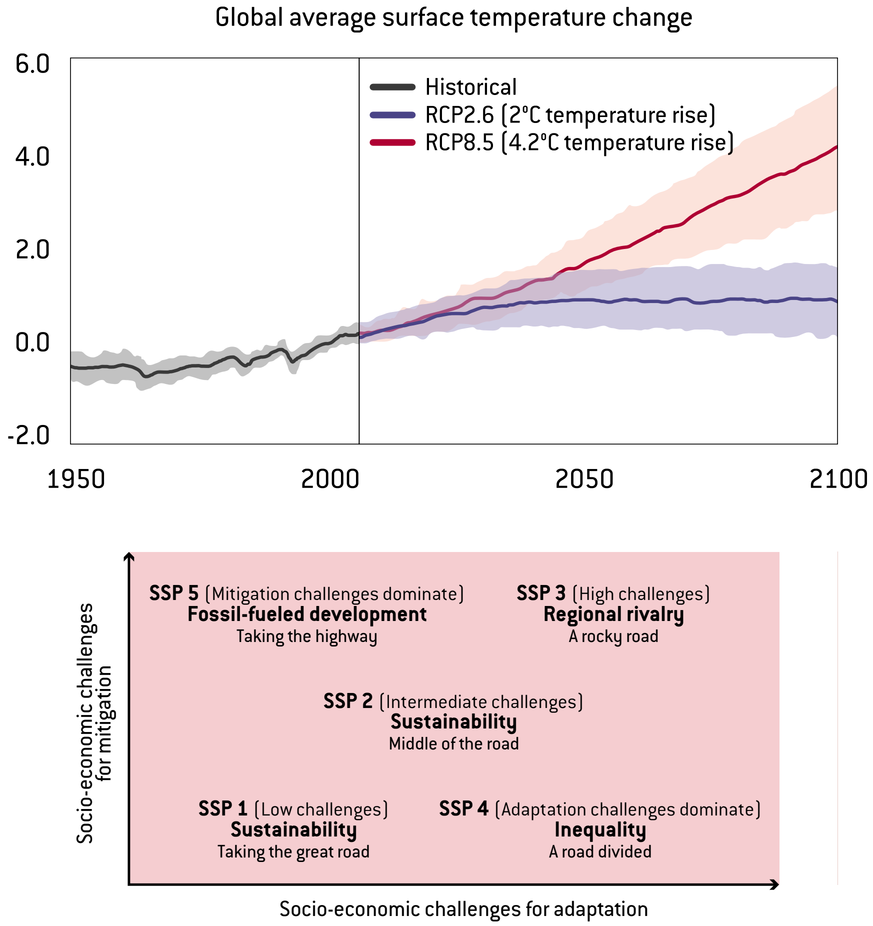
1 See https://www.nasa.gov/press-release/2020-tied-for-warmest-year-on-record-nasa-analysis-shows.

2 The European Climate Law was provisionally agreed in April 2021, though at the time of writing is awaiting ratification. See https://www.2021portugal.eu/en/news/european-climate-law-council-and-parliament-reach-provisional-agreement/.

3 See, for instance, the debt sustainability analysis in Zenios *et al* (2021).

4 A special issue of the journal *Climatic Change* (2014) set out this architecture of scenarios.

Figure 1: Representative concentrations and shared socioeconomic pathways



Source: RCP figure from https://muchadoaboutclimate.wordpress.com/tag/representative-concentration-pathway/ based on data from the IPCC Fifth Assessment Report. SSP figure from *Climatic Change* (2014).

Finally, model misspecifications arise from the lack of consensus on the appropriate model(s), calibration of climate sensitivities and nonlinearities, and estimation of tipping points. Climate scientists have limited ability to *"give fine-grained and concrete answers to an impatient public"* (Weitzman, 2011), although several integrated assessment models have been developed. These models help *"understand how human development and societal choices affect each other and the natural world, including climate change. They are 'integrated' because they combine different strands of knowledge to model human society alongside parts of the Earth system"*[5]. They advance our understanding of the effects of greenhouse gases concentration on the climate, the interactions of climate with natural systems, and the macroeconomic impact of an increase in global temperature, and they do so under different SSPs and RCPs. However, there is presently large variability among model assumptions and predicted outcomes, and we have to live with ensembles of models. Each model can provide a different viewpoint on the answers sought by policymakers.

There are some commonalities in the analysis of climate risks and debt sustainability. Scenario narratives are a cornerstone of climate science and a way to deal with deep uncertainty (see for example Battiston, 2019). Scenarios are also at the core of debt sustainability analysis models, which also account for tail uncertainty (Zenios *et al*, 2021), much like climate change models deal with fat-tailed uncertainty (Weitzman, 2011).

5 See *Carbon Brief*, 2 October 2018: https://www.carbonbrief.org/qa-how-integrated-assessment-models-are-used-to-study-climate-change.

We bring together these strands to evaluate how integrated assessment models can enrich debt sustainability analysis in the face of deep uncertainty about climate change. We highlight the divergent effects climate risks could have on EU countries (section 2), and show that investors differentiate sovereign issuers by climate risk exposures, and credit ratings can be affected by climate change (section 3). We then identify the transmission channels of climate risks to sovereign debt (section 4) and show that it is possible to put rough bounds on the plausible debt dynamics under different climate-related policies (section 5). We use two prominent integrated assessment models in an illustrative example for Italy.

Sovereign bond redemptions extend several decades into the future and are bound to be affected by some kind of climate scenario, whether benign or catastrophic. Climate risks can have an effect on sovereign bond ratings but it is not presently clear if markets pay attention to issuers' climate policies or to the long-term effects of climate change on an issuer. Little attention seems to be paid to the issue by the independent fiscal councils (Box 1). It is time for budgetary plans to account for climate-related costs and contingent liabilities, and for fiscal authorities to better disclose climate-related data (section 6).

Box 1: Independent fiscal councils and climate risk

A 2019 survey of fiscal councils by the EU Network of Independent Fiscal Institutions (EUNIFI) found that none of councils who report quantitative analysis of fiscal risks cover the impact of climate change on public finances. Only the UK Office for Budget Responsibility (OBR)[6] and the Irish Fiscal Advisory Council[7] devote some space to the issue.

The UK OBR (2019 report) looked at the impact of physical climate risks (such as storms and floods) and transition risks (for instance, arising from decarbonisation efforts) on medium-term macroeconomic and revenue forecasts, and on fiscal sustainability. They estimated costs of £16 billion to £32 billion per annum by 2100 (0.7 percent to 1.5 percent of UK GDP). These costs are likely to be of much lower scale than those from a recession or financial crisis, and the fiscal implications are likely to be small relative to population ageing or the costs from healthcare. However, the OBR points out that this sanguine view could be due to the difficulty in appreciating the systemic consequences of global warming with its interconnections and amplifying mechanisms. The OBR plans to engage Bank of England analysts and use the bank's climate stress-testing scenarios for fiscal risk analysis.

The Irish Fiscal Advisory Council (2020 report) identified climate change as one of the challenges for the country by 2050. The report identified revenue items impacted by mitigation policies, and pointed out that adaptation to a lower-emissions economy can have positive effects on employment, investment and productivity, but that it also carries costs for public finance and growth. It identified both positive and negative impacts on government expenditures from adaptation and mitigation policies. The Department of Public Expenditure and Reform forecast 2.9 percent of GDP in additional government expenditure over a ten-year period on climate-related activities.

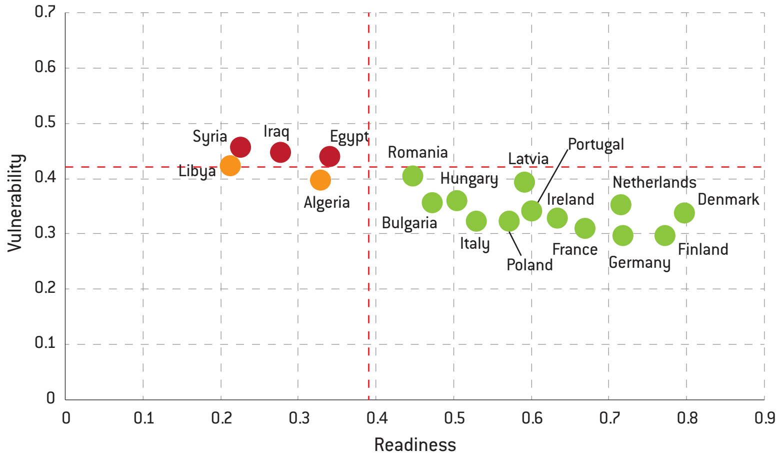
6 See https://obr.uk/frr/fiscal-risks-report-july-2019/.

7 See https://www.fiscalcouncil.ie/wp-content/uploads/2020/07/Long-Term-Sustainability-Report_Website.pdf.

2 How exposed are European sovereigns to climate risk?

European countries are already experiencing climate-related disasters, which caused estimated damages of €446 billion between 1980 and 2019[8]. This, however, is a mere 3 percent of GDP over a 40-year period, so the economic effects of climate change may seem distant and indirect for Europe. The effects can be nevertheless material. A survey of 21 studies (Tol, 2014) found that a 5°C temperature rise by the end of the century could have an adverse effect on the world economy from -3 percent to -15 percent of GDP, compared to a scenario of no further warming; however, for a 2.5°C increase, the cost would be only 2.5 percent of GDP. The International Monetary Fund (IMF, 2020b) reported much higher estimates of as much as -25 percent of GDP in the case of a 5°C temperature rise. Likewise, ECB/ESRB (2021) expect a fall of up to 20 percent in global GDP by the end of the century should mitigation prove to be insufficient or ineffective. Forecasts differ widely by region. Whereas the global average welfare loss may be modest under limited climate change, the impact in some regions could be high. Tol (2014) put a value of -14.6 percent for the worst hit region (South America), and the impact could even be slightly positive for some countries (eg the Baltic states). From panel data, Kalkuhl and Wenz (2020) projected considerable production losses from adverse climate change, ranging from -7 percent of GDP to -20 percent for the tropics. Overall, the adverse effects of climate change are not disputed, but their timing and magnitude are not well specified.

Figure 2: Vulnerability and readiness of EU countries (2018)



Source: Bruegel based on ND-GAIN (2020). Selected EU countries are shown in green (low vulnerability and high readiness). Omitted EU countries occupy similar positions. Middle Eastern and North African neighbours are shown in red (highly vulnerable and not quite ready) or yellow. The least-ready EU countries are, in increasing order, Romania, Croatia, Bulgaria, Hungary, Cyprus, Slovakia, Malta, Greece, Latvia, Italy. The most ready are Slovenia, Ireland, France, Netherlands, Luxembourg, Germany, Austria, Sweden, Denmark, Finland.

European Union countries are among the least-vulnerable and best-prepared globally (Figure 2; ND-GAIN, 2020). Nevertheless, European economies are exposed to the acute effects of adverse weather and chronic effects from long-term trends. The former is visible in recurring extreme events, including flooding, heat waves, droughts and dust storms, and the latter in gradual changes, including rising temperatures, rising sea levels and deterioration of ecosystems. In recent years, EU economic losses from extreme weather events have amounted to about €12 billion annually, and are projected to grow by at least €170 billion per

8 See https://www.eea.europa.eu/data-and-maps/indicators/direct-losses-from-weather-disasters-4/assessment.

year, or 1.36 percent of GDP[9]. Mitigation will require costly upgrading of infrastructure, and the transition to a low-carbon economy will render carbon-intensive production technologies obsolete and cause asset revaluation. Estimates of the required investments vary widely, but most projections suggest that more than $1 trillion annually will be needed by 2030, two-thirds of which should be spent in developing countries (Banque de France, 2019). Transition to a low-carbon economy can also spur innovation and growth (Batten, 2018; Porter and van der Linde, 1995).

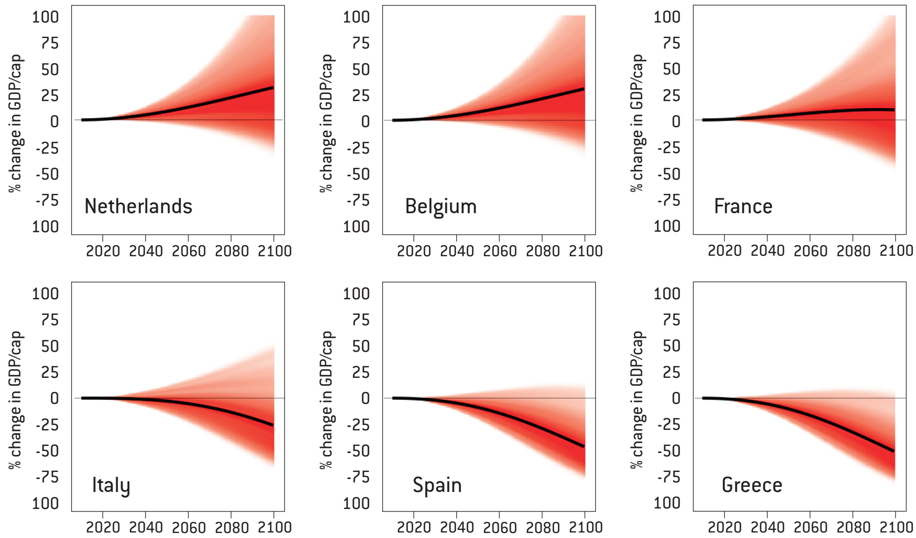
Europe's neighbours in the Middle East and North Africa are more vulnerable and less well prepared. Climate change could lead to increased conflict and political instability[10], which poses an additional risk to Europe in the form of migration flows that could destabilise politics in the receiving countries. Political risk is a key determinant of credit risk premia and can have a significant effect on sovereign credit risk assessments[11]. Such risks have until now been quite low for European sovereigns, but spillovers through contagion from neighbouring countries could change that.

2.1 Differences between EU countries

EU countries face very different climate risks. In one measure of vulnerability to climate change, ratings of EU countries range from a low 52/100 (Romania) up to 73 (Denmark, Finland)[12]. The worst-rated countries (bottom one-third) have an average rating 57, whereas the top third have an average of 70. Sectoral vulnerabilities – food, water, health, ecosystems, human habitat and infrastructure – also vary greatly.

In terms of the impact of climate change on GDP *per capita*, simulations in Burke *et al* (2015) show potentially striking divergence if greenhouse-gas emissions continue to increase in a business-as-usual scenario that leads to a dystopian fossil-fuel intensive future with 4.2°C warming by 2100. Figure 3 shows illustrative results.

Figure 3: Potential divergence of European economies without climate policy action



Source: Burke *et al* (2015). See https://web.stanford.edu/%7Emburke/climate/map.php.

9 See the European Commission Joint Research Centre PESETA IV project report at: https://ec.europa.eu/jrc/en/peseta-iv/economic-impacts.

10 See the survey of panel studies in Dell *et al* (2014).

11 See Moody's (2019), S&P (2017) and Gala *et al* (2020) for empirical evidence on political risk premia.

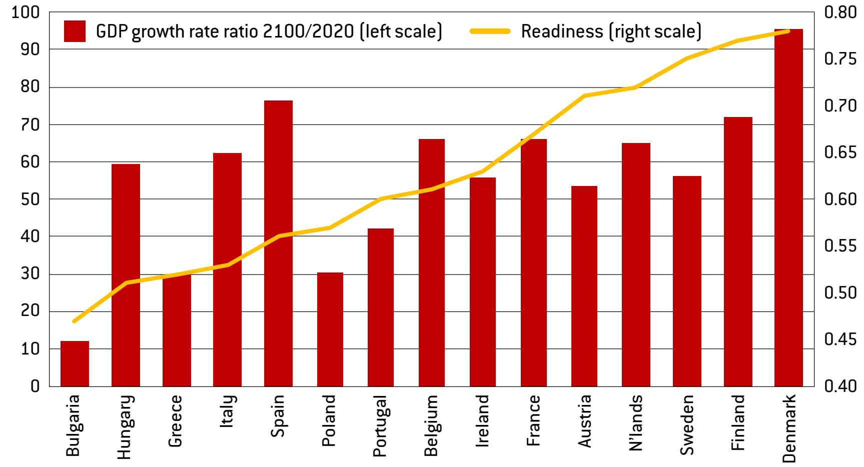
12 The Notre Dame Global Adaptation Initiative (ND-GAIN); see https://gain.nd.edu/.

This scenario is increasingly unlikely to materialise. In the Paris Agreement, European governments have committed to a pathway to a low-carbon economy to limit global warming to well below 2°C, and to pursue efforts to limit it to a stabilising 1.5°C. Implementation of this agreement is being done through the European Green Deal (European Commission, 2019b) and is gradually being reflected in public (and private) investment strategies. With its latest commitments, the EU is within range of 2°C compatibility, although stronger policies will be needed to align with the 1.5°C goal[13]. The EU is the world's third largest emitter, but the two largest (the US and China) and most others are not on track to meet 2030 climate goals, and EU will also pay a price for this. Global warming is a unique risk that every country is committed to address, even though it is beyond the control of any one country acting independently.

Disclosures on the alignment of national expenditures with climate goals (Domínguez-Jiménez and Lehmann, 2021) are valuable for monitoring compliance with the Paris Agreement. But transparency in the reverse direction, on the effect of climate change on public finance, is also needed. The resilience of a country's debt to climate change is important, whether the country is contributing a lot or a little to the problem, and the effects could differ widely among EU countries.

The differences between member states are, of course, not so severe under the 2°C temperature increase scenario. By 2100, countries including Bulgaria, Greece and Poland, could see GDP growth rates drop to 20 percent to 30 percent of their current levels. Others, such as Denmark and Finland, could see growth rates shrink by about 20 percent, according to the model of Gazzotti *et al* (2021) (known as RICE50+; Figure 4). According to Kahn *et al* (2019), the best-prepared one-third of EU countries will lose on average 0.5 percent of GDP *per capita* by 2100, while the least-prepared third will lose about 1.7 percent. Again, the least-prepared countries suffer the most. Agreements on the direction of developments but disagreements on magnitude are not uncommon in such projections, which is why we emphasise the use of ensembles of models and transparency in developing scenarios. For instance, Kahn *et al* (2019) used a cross section of 174 countries over the period 1960 to 2014, and thus requires an acceptance that we can reasonably extrapolate from the past. Our approach in Figure 4 uses forward-looking simulations from RICE50+, thus requiring acceptance of this integrated assessment model. However, both methods seem to agree on the direction of travel, and that the impact is greater for the least-prepared countries.

Figure 4: Changes in GDP growth rate by the end of the century from climate risks



Source: Bruegel based on projections of GDP growth change from 2020 to 2100 from the RICE50+ model of Gazzotti *et al* (2021), and the readiness index from ND-GAIN (2020).

13 See https://climateactiontracker.org/climate-target-update-tracker/eu/.

2.2 An EU climate divide

The fiscal space available to EU countries to tackle climate risks varies, limiting the reach of their mitigation and adaptation policies

EU countries with greater exposure to climate risks also have more precarious public debt positions. The most climate-vulnerable one-third of EU countries have post-COVID-19 weighted average debt levels of 133 percent of GDP, whereas the least-vulnerable third have average ratios of 78 percent. The available fiscal space to tackle climate risks varies, limiting the reach of EU countries' mitigation and adaptation policies. ECB/ESRB (2021) estimated uneven effects of climate change on financial stability risks across sectors and regions.

Climate-related policies can trigger innovation and may raise productivity and spur growth. Porter and van der Linde (1995) postulated the positive effect of technological innovation responses to climate change. EU countries that are less vulnerable or better prepared, and which use the European Green Deal to stimulate innovation, will adapt better to climate change. States that are more vulnerable and less prepared, or that fail to stimulate innovation, will become laggards. This divergence could aggravate existing imbalances and the reallocation of capital from laggards to innovators, creating a 'climate divide'. This would not be the usual north-south divide, but will include countries in central Europe, such as Bulgaria and Poland, on the side of climate laggards, if they fail to compensate for losses from their rich fossil-fuel resources. The need to pursue climate policies is more pressing for the vulnerable countries.

The divergence due to climate shocks highlights the need for coordination. COVID-19 prompted the EU towards community financing with the Next Generation EU (NGEU) recovery plan. The pandemic may have prompted the NGEU, but its focus on a green and resilient Europe will remain highly relevant during the current make-or-break decade for climate action. Climate effects that are not distributed evenly have the potential to increase political conflicts, and political risks can arise not only from the EU's climate-vulnerable neighbours, but also from inequalities within the bloc.

Some Organisation for Economic Cooperation and Development countries are connecting the dots between climate change and sovereign debt (Box 2). In Europe, financial-sector supervisors are designing climate risk analyses for financial stability, with the European Central Bank taking an international lead. Institutions mandated with fiscal stability – the European Commission, European Stability Mechanism, European Fiscal Board and national fiscal councils – should follow the ECB example on the fiscal stability front.

Box 2: Budgeting for the fiscal risk of climate change, case studies

United States

Under the Obama Administration, the Office of Management and Budget and the Council of Economic Advisers performed scenario analysis of the effects of climate risks on the federal budget, up to the end of this century. They also assessed lost revenue for the federal government, by transposing projections from global integrated assessment models to the US. Expenditures are from $9 to $28 billion annually (in today's dollars), and revenue losses vary between $56 billion and $111 billion.

Australia

The government assesses disaster-related contingent liabilities as part of budget planning and fiscal risk assessment. Central and subnational governments collect information based on past weather patterns, and project future expectations of relief spending, infrastructure replacement, social transfers and contingent guarantees. They acknowledge reduced tax revenue, costs from disrupted operations of public or private corporations, and worsening of the government's financing options. For instance, in 2016, the government estimated expenses totalling AU$142 million and cash transfers of AU$1,871 million over the four-year period up to 2019.

Canada
The federal government uses the Canadian Disaster Database as a repository for natural and man-made disasters to estimate probable losses over long horizons. The Disaster Financial Assistance Arrangement of the federal government increased its reimbursements from US$3.6 million in 1980 to US$144.8 million in 2014. The National Disaster Mitigation Program leverages central government contributions for investments to mitigate ex ante the impact of future disasters.

Japan
The government's obligations in the event of disasters are enshrined in several laws, providing an example of contingent liability management. However, fiscal forecasts include only projected expenditures of ongoing disaster relief efforts, and not any potential future disaster-related liabilities. The country mainstreams protection measures and insurance coverage through assessment modelling, averaging $6.4 billion per year in disaster prevention, and $13.5 billion in land conservation. $278 million is spent on science and technology research for disaster risk reduction.

New Zealand
The country adopts a contingent liability approach to natural disasters. Contingent liabilities valued above US$73 million are budgeted individually. The Treasury pursues a strategy that attains a high level of resilience taking into account natural disaster risks that could have a major fiscal impact, and carries out stress tests for scenarios such as natural disasters and financial crises. A multi-agency project seeks to understand the risks of shocks and stresses, including natural disasters.

United Kingdom
Among other initiatives, the UK government was mandated by the 2008 Climate Change Act to carry out a multi-sectoral analysis of the potential effects of climate change every five years. Two rounds have already been completed.

Sources: Office of Management and Budget (2016), OECD and World Bank (2019).

3 The pricing of climate risk in sovereign bonds

Bonds issued by sovereigns, agencies or supra-nationals stood at $87.5 trillion in August 2020, comprising 68 percent of global bond markets[14]. There are 11,070 individual securities in Europe for a total nominal value of €12.2 trillion. Most of the outstanding issues will mature within ten years, but significant amounts run into the 2060s, and 'century bonds' with 100-year maturity have been on the rise with borrowers locking in record low interest rates. Current bonds will be redeemed several decades into the future, and bond investors are attuned to climate change. Climate risk is priced in the sovereign bond market.

Cevik and Tovar-Jalles (2020) surveyed the bond yields of 98 economies since 1995 and found that climate vulnerability and readiness are determinants of governments' cost of borrowing, though the effects are significant only for developing markets. A 1 percent increase in climate vulnerability increases the long-term government bond spreads of developing

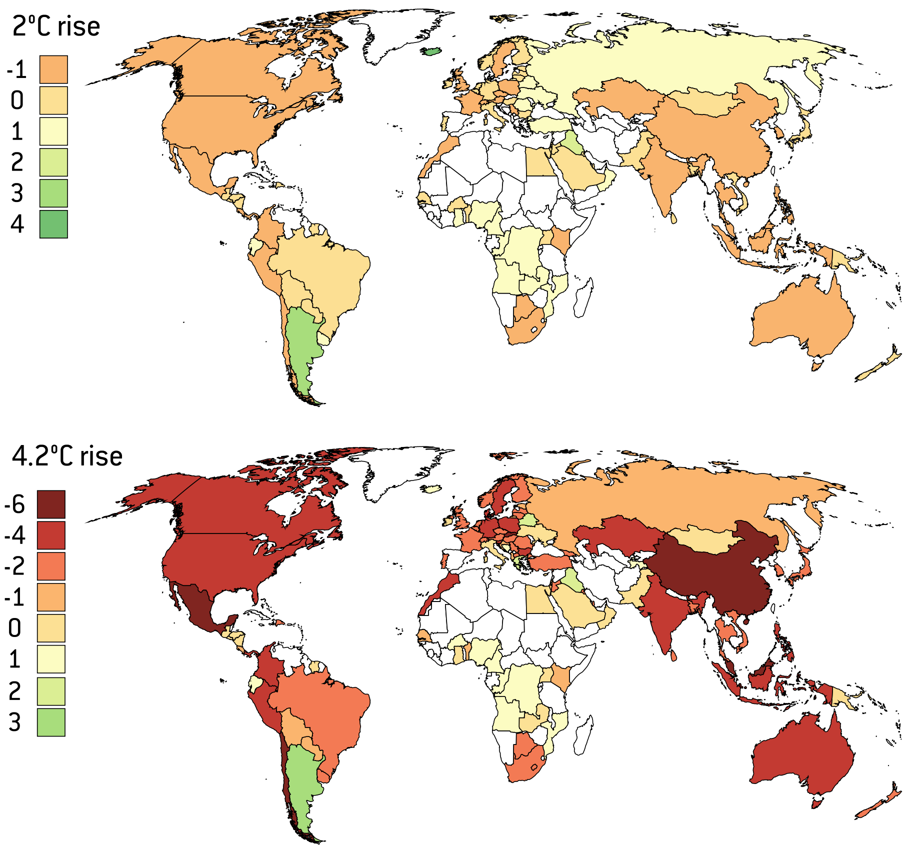
14 Data from https://www.icmagroup.org/Regulatory-Policy-and-Market-Practice/Secondary-Markets/bond-market-size/.

countries by about 3 percent. With average spreads of 500bp, this sensitivity translates into a 233bp spread between the top and bottom vulnerability quintiles.

Inferences from historical data underestimate the effects of climate change, which are only gradually coming into focus for investors. The first ESG (environmental, social and corporate governance) index was launched in 1990, and only in 2020 did BlackRock launch a sovereign bond fund weighing countries by their climate risk profiles[15]. Using forward-looking simulations with integrated assessment models, Battiston and Monasterollo (2020) found significant increases in bond yields for some EU sovereigns (Netherlands, Italy, Poland, Sweden), with the greatest shocks for countries for which fossil fuels make significant contributions to their GDP. Positive shocks are also possible (Germany, Finland, the Baltic states) when countries use nuclear or renewable sources of energy.

Borrowing costs that increase because of climate change can be material for sovereign debt. Investors use credit ratings to assess the issuer's ability to pay and determine credit risk premia. No sovereign has yet been down-rated because of the climate risks it faces, although rating agencies recognise the significance of climate shocks and anticipate that climate trends will have implications for ratings in coming decades (Moody's, 2019; S&P, 2017).

Figure 5: Climate-adjusted credit ratings in different global warming scenarios (notch changes)



Source: Klusak *et al* (2021).

Klusak *et al* (2021) used machine learning to develop climate-adjusted sovereign credit ratings, and combined this with a macroeconometric climate model to rate sovereigns in different climate scenarios. Figure 5 shows the changes to credit ratings in scenarios of a global

15 See S. Johnson (2020) 'BlackRock ETF thrusts climate change into political sphere', *Financial Times*, 6 October, available at https://www.ft.com/content/112e536a-91db-426a-aef6-3106f0717972.

temperature rise kept below 2°C and a temperature rise of 4.2°C (RCP2.6 and RCP8.5). In the first scenario (in line with the Paris Agreement), most EU countries would be down-rated marginally (1 notch or less), but the down ratings would be significant in the second scenario. The analysis shows that most downgrades would be among top-rated countries. This does not reflect increased climate risks for the top-rated countries, but greater sensitivity of the top ratings. It is easier to lose an AAA rating that to lose a C rating. Down-ratings are broad, with 55 sovereigns facing downgrades in a 2°C scenario and 80 in a 4.2°C scenario. European countries feature in both cases, and the credit effects are noticeable as early as 2030. Climate risks are not as distant as we might think.

In a 2°C scenario (RCP2.6), the increase in debt servicing cost would be 3 percent for Belgium and 6 percent for France. These increases are small for countries with ample fiscal space, but they can be material for countries without fiscal space or significant adverse climate effects on growth. Increases in refinancing rates for countries with tight public finance raise concerns about the sovereign's ability to repay; the sovereign is then down-rated and its refinancing rates go up further, precipitating a destabilising doom loop for sovereign debt (Zenios *et al*, 2021).

In conclusion, climate risks can be a first-order problem for sovereign debt due to the combined (i) acute effects of short-term weather-related damages, (ii) chronic effects from long-term climate trends, and (iii) climate induced increases of borrowing costs. Mitigation and adaptation costs introduce trade-offs to the analysis. Higher mitigation spending creates transition risk and puts pressure on public finance, but leads to more benign climate change with milder impacts in terms of damages, growth and borrowing rates. Likewise, adaptation also moderates the impact of climate change, but with potentially large fiscal expenditures.

4 Climate risks and debt sustainability

Debt sustainability hinges on the evolution of debt stock and flow, as a ratio to the country's GDP, over time. If the stock ratio keeps growing, or if financing needs (the flow ratio) exceed a threshold, then debt can become unsustainable. Increasing stocks eventually hit the government budget constraint, and large flows can cause demands on liquidity that markets cannot finance. Stock and flow will depend on the debt financing interest rates, the amortization of legacy debt, the fiscal primary balance and the GDP growth rate. These fundamental relationships between these variables (Box 3) can guide our analysis of climate risks to debt sustainability. We discuss how each variable is affected by climate change, and then see how to account for risk, ambiguity and misspecification.

4.1 Transmission of climate change to public finance

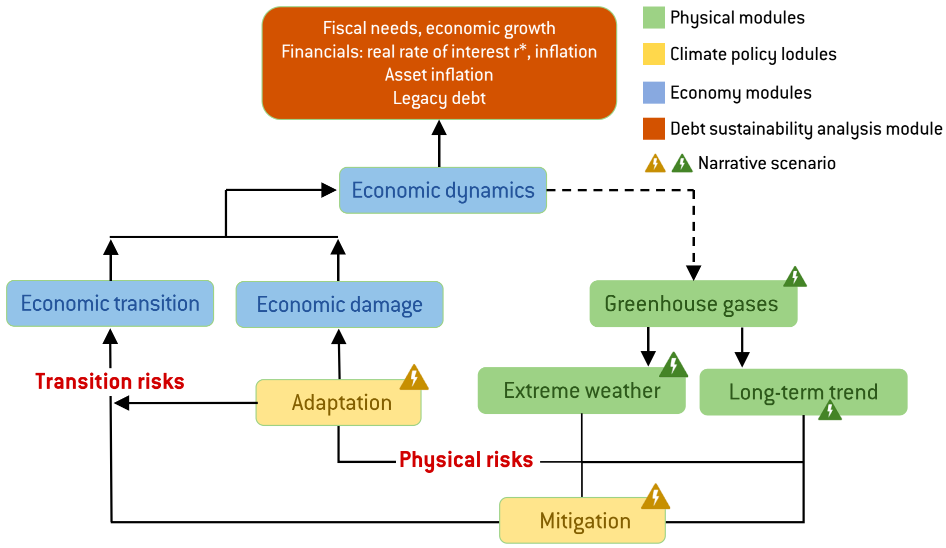
The physical and transition risks associated with climate change[16] are transmitted to public finance through three main mechanisms: fiscal expenditures on adaptation and mitigation, including damages and social costs; effects on economic growth; and repricing of sovereign assets.

Figure 6 sketches the links between climate change and public debt. The climate modules (in green) specify both chronic and acute changes. These changes create physical risks. Societies adapt to physical risks, for instance, by upgrading infrastructure or improving public health services. Adaptation entails costs but also reduces economic damages. Societies also aim to alleviate both the acute and chronic effects with mitigation policies, such as by moving

16 Physical risks arise from floods, storms and other weather-related events that damage physical capital, natural resources, labour, productivity or trade. Transition risks are the economic risks that could result, for instance, from decarbonisation processes that result in the revaluation of assets.

to a low-carbon economy and regulating the use of natural resources. Mitigation and adaptation policy modules (yellow in Figure 6) may have short or long horizons, but their effects are long-term. The cost of these policies will increase fiscal burdens when the policies are implemented, but with positive long-term effects on growth. In this way, the policy modules feed into the economic modules (blue), so that physical and transition risks, moderated by adaptation and mitigation policies, are transmitted to the debt sustainability analysis module (brown).

Figure 6: Integrated assessment model for climate risks of public debt



Source: Bruegel based on Batten (2018), European Commission (2019a), IMF (2019), Volz *et al* (2020) and Zenios *et al* (2020).

The detailed mechanisms of climate effects on the macro economy are complex. Transmission works through changes to productivity, land usage, energy demands and natural resources depletion with rising temperatures, the diversion of capital to mitigate or adapt to climate changes, changing population trends and conflicts under adverse climate conditions, among others. Three significant channels affect debt variables: damages, economic transition and sovereign wealth[17]. The mechanisms are far from perfectly understood, and attempts to model them often rely on broad assumptions. For these reasons we place special emphasis on using ensembles of models and the need for transparency when developing scenarios.

Damages

Economic damages estimate the adverse effects of climate change on natural resources, physical capital, labour and productivity. Economic damages account, for instance, for floods or landslides that erode agricultural land, or result in input shortages, infrastructure damage, loss of labour due to loss of human life or migration, and working hours lost because of heat waves or dust storms.

Damages can be assessed using past extreme events and their costs, through country-specific databases such as those maintained by Australia and Canada (Box 2). However, looking backwards can underestimate future damages, as the number and severity of extreme weather events is increasing. Data from the Centre for Research on the Epidemiology of Disasters Emergency Events Database[18] shows almost a doubling of extreme events, from 120 events in 1985, to more than 250 per annum over the last twenty years.

17 For a survey of the economic effects of climate see Dell *et al* (2014), and for modelling these issues using integrated assessment models, see Bosetti (2021) and Weyant (2017).

18 Université catholique de Louvain, Belgium; see https://www.cred.be/projects/EM-DAT.

Damages over the long term can be assessed through climate models that typically include a function to estimate adaptation costs and adjust for their impact on growth. Adaptation costs burden the fiscal variable and affect (positively) economic growth.

The Integrated Assessment Consortium (IAC[19]) has developed scenarios that could be employed in generating ensembles of quantitative projections for both the short and long term. One of the Consortium's working groups collaborates with asset managers, strategic planners and development and central banks to generate scenarios for climate-related financial analysis. A parallel interaction is warranted with fiscal authorities and fiscal-stability institutions, debt issuers and bond investors. From the IAC's work we can draw upon a large array of models to obtain growth projections and adaptation costs for debt sustainability analysis.

Adaptation costs for rare weather events are better accounted for as contingent liabilities, as we have seen in the cases of Australia, Japan and New Zealand (Box 2). If contingent instruments, such as sovereign contingent convertible debt or GDP-linked or catastrophe bonds (Demertzis and Zenios, 2019), are used in budgeting for weather-related liabilities, climate change will also affect debt amortisation.

In conclusion, building on the work of IAC, we can generate forward-looking scenarios setting out the chronic effects of climate change on growth and fiscal costs. Projections over long horizons from integrated assessment models are subject to ambiguity and misspecification, so we have to rely on scenario narratives and ensembles of models. Acute effects can be superimposed using scenarios from historical data or as contingent liabilities. These scenarios may not suffer from ambiguity and misspecification, but are valid over shorter periods.

Integrated assessment models are criticised on both empirical and conceptual grounds (Pindyck, 2017, Stern and Stiglitz, 2021), but Nordhaus (2018), while finding the criticism worthy of careful consideration, argued that these models provide a conceptual framework for developing insights about complex, nonlinear, dynamic and uncertain systems (see also Weyant, 2017). Integrated assessment models may not provide precision forecasts, but they allow us to conduct 'what if' analyses of the impact of climate-related factors to provide policy insights (Obama, 2017). Stern and Stiglitz (2021) argued for a structured dialogue between policymakers and their models, to keep the complex questions simple but get to the heart of decision-making. For our purposes, integrated assessment models are a good place to start in developing our understanding on the climate risks to sovereign debt, but they are poor place to finish in assessing debt sustainability.

Transition

The economic transition channels include gradual land degradation and scarcity of resources, re-allocation of resources from productive investments to adaptation investments or to new technologies, and employment and social impacts arising from extreme temperatures. These effects have both direct and indirect non-discretionary fiscal impacts (European Commission, 2019a). Direct costs include social transfers to affected households and explicit contingent liabilities, such as insurance schemes backed by state guarantees. Indirect costs can include reductions in tax revenues, increases in healthcare spending, and liquidity problems because of budget reallocations towards recovery and reconstruction. Discretionary costs arise from adaptation and mitigation policies, such as public investment for climate-proof infrastructure, or public subsidies for clean energy transition.

Economic transition effects are caused mainly by mitigation policies, but also by adaptation. The transmission again operates through the channels of natural resources, physical capital, labour and productivity. Investment and innovation in new technologies could raise overall productivity (Batten, 2018; Porter and van der Linde, 1995). Integrated assessment models can provide forward-looking scenarios.

Fiscal expenditures on mitigation efforts are already foreseen and will further burden

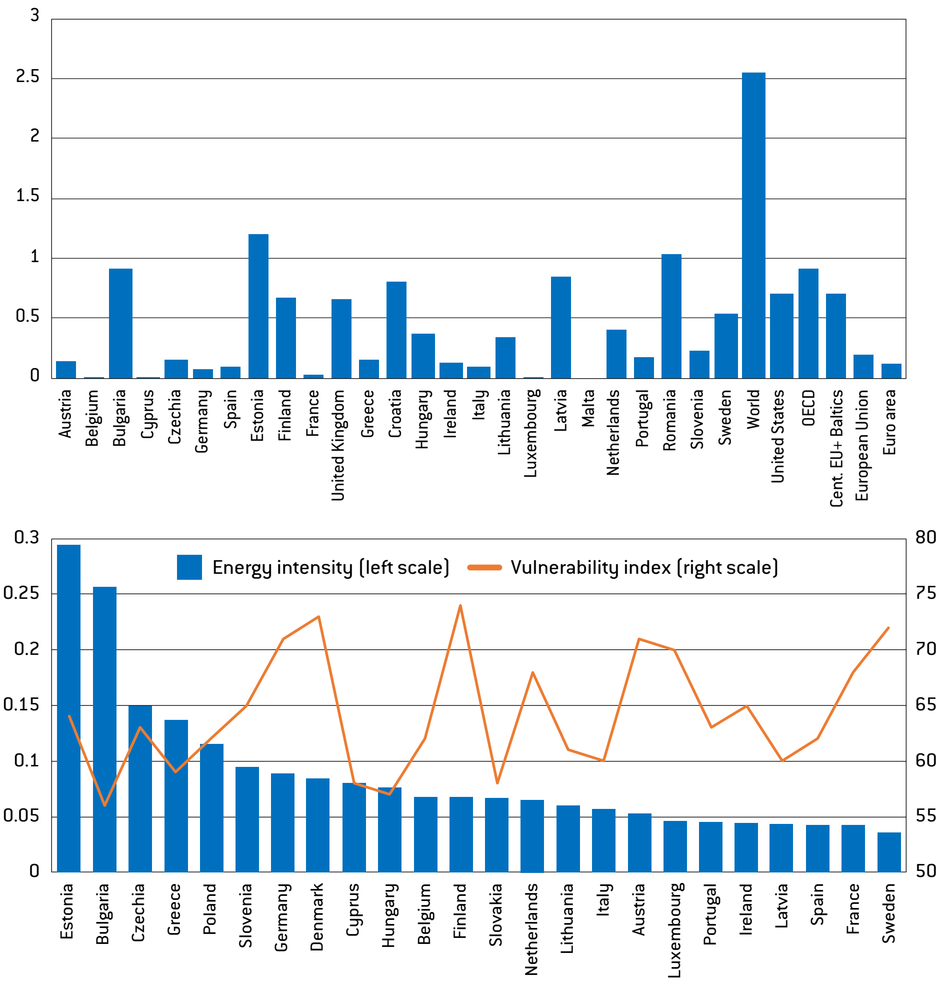
19 IAC was created in response to a call from the IPCC to pursue the scientific understanding of issues associated with the integrated assessment and analysis of climate change. See https://www.iamconsortium.org/about-us/.

public budgets. The European Green Deal assumes an annual investment gap of €260 billion (1.86 percent of 2019 EU27 nominal GDP) to reach the 2030 climate and energy targets set in 2019. This is to be filled up by both the public sector and by private investors. NFGS (2019) estimated that 1 percent to 4 percent of global GDP in 2030 will be needed for mitigation efforts to limit global warming to 2°C. Contingent liabilities are likely to materialise on public balance sheets, not only from weather shocks but also where private investment falls short of the targets.

Sovereign wealth

Climate change causes sovereign wealth to be repriced. This has an impact on credit quality and debt financing rates. This is clearly the case for carbon-intensive assets in public ownership, such as coal mines or energy utilities in several EU countries. These may become stranded assets that are no longer economically viable given rising carbon prices. An estimated $12 trillion in assets could be stranded by 2050, corresponding to 3 percent of the capital stock (Banque de France, 2019).

Figure 7: Natural resources rents (top panel) and fossil-fuel energy intensity (lower panel) in Europe



Source: Bruegel based on Eurostat data from the World Bank, Our World in Data (https://ourworldindata.org/fossil-fuels#what-share-of-primary-energy-comes-from-fossil-fuels), OECD and ND-GAIN (2020). Notes: The top panel reports rents from extraction of natural resources as % of GDP. The bottom panel reports the energy intensity of fossil-fuel usage per dollar of added value to a country's GDP from fossil fuel energy, together an index of countries' vulnerability and resilience in the face of climate change (ND-GAIN, 2020).

The rent from natural resources is significant for some EU countries, although the EU has much lower extractive activity than the rest of the world (Figure 7, top panel). However, fossil-fuel energy intensities, ie consumption of fossil fuel for each dollar that fossil fuels contribute to a country's GDP (bottom panel), show heavy reliance on fossil fuels, with significant differences between countries. With an EU-wide non-weighted average of 76 percent of fossil fuels in the energy mix, the transition risks are significant, even if asset repricing risks may not be high for most countries.

Countries with high energy intensity or high fossil-fuel extraction are more exposed to transition risks. This is the case for Estonia, Bulgaria, Czechia, Greece and Poland. Countries with low energy intensity can more easily weather the transition. This is the case for Austria, Finland, France, Spain and Sweden. Note that high energy intensity countries are found in both south and central Europe, while low energy intensity countries are in north and south. The EU climate divide is not quite the same as the usual north-south divide in the EU. We also note something of a disconnect between climate-change preparedness and energy intensity. Energy consumption is just one of the vulnerability characteristics of EU countries.

Financial variables

The financial variables in debt sustainability analysis – the real rate of interest and inflation, as determinants of financing rates – are also affected by damages, transition and sovereign wealth. For instance, the increase in the frequency and severity of negative supply shocks because of extreme weather makes it harder for central banks to forecast output gaps and, by extension, inflation. Likewise, pricing policies for transition to a low-carbon economy need to be accounted for when evaluating inflationary pressures. The Network for Greening the Financial System, which consists of central banks and financial supervisors[20], is studying the effects of climate change on these financial variables (NGFS, 2020), and the monetary policy effects of climate risk should be factored into long-ranging debt sustainability analysis. Short- to medium-term debt sustainability analysis can rely on scenarios of monetary variables calibrated from market data. For long-horizons, it is necessary to resort to monetary policy fundamentals, such as using monetary-policy rules driven by output gaps, or inflation expectations derived from integrated assessment model scenarios (eg by using the Phillips curve and Taylor rules). Progress by NGFS in linking these key variables to climate change will further refine these building blocks of debt sustainability analysis.

There is a feedback loop from the economy to climate (dashed line in Figure 6). The effects of economic policies on the climate are beyond the scope of debt sustainability analysis, and focusing on the climate risks to fiscal stability does not imply climate activism. We wish to understand how to make public debt more resilient. The question of how to best use public debt to support an environmental sustainability strategy is left for elected officials. However, integrating climate risk into debt sustainability analysis can encourage elected officials to think of solutions. In this respect, the analysis should contain scenarios that are transparent and acceptable to policymakers.

5 Scenario architecture of the climate risks of sovereign debt

The analysis of climate risks is unlike anything we see in the analysis of financial market risks, which can be estimated from ample data with probabilities known with a high degree of confidence. Climate risk projections must be made over very long horizons with limited empirical guidance from history. Climate scientists can postulate possible future states of the world but

20 See https://www.ngfs.net/.

their probabilities cannot be pinned down. After all, future states depend on current policy choices, and analysts cannot make precise projections without knowing the policy choices and the status of implementation. This is the problem of ambiguity that can be addressed by resorting to scenario projections.

The scenario architecture discussed in the introduction can help structure the analysis of the risks to sovereign debt from climate change. For combinations of socio-economic pathways (SSPs) and representative concentration pathways (RCPs), existing integrated assessment models can provide forward-looking projections of mitigation and adaptation costs, potential economic damages, GDP growth, per-capita GDP and so on. These projections will inform debt sustainability analysis with climate risks. Table 1 illustrates the scenario architecture with the number of models that are currently able to quantify projections. Green cells in Table 1 represent combinations in line with the Paris Agreement, red cells lead to dysfunctional states of the world, and yellow cells fall short of the Paris Agreement. Cells left blank are not plausible.

Scenarios that deserve attention for debt sustainability analysis are indicated by check marks. Analysis should focus on the most plausible and meaningful scenarios, to push policymakers to be more ambitious in dealing with climate risks and encourage fiscal authorities to think of solutions.

Table 1: Scenario architecture of climate risks for debt-sustainability analysis

	SSP1	SSP4	SSP2	SSP3	SSP5
RCP8.5					4
RCP6.0	6	6	6	4	4
RCP4.5	6	3	6	4√	4
RCP2.6	6√	3√	6√		3√
RCP1.9	5√	1√	4√		2√

Source: Bruegel based on Rogelj *et al* (2018). Note: for SSPs and RCPs, see Figure 1. The numbers in each cell indicate the number of models currently able to quantify projections.

5.1 Debt sustainability with climate risks

Debt sustainability analysis typically uses scenarios calibrated on GDP projections by experts (for example, the International Monetary Fund or European Commission), and market data, such as the yield curve of interest rates or inflation expectations. Scenario calibrations (see Box 3) have low variability in the short-term, but greater variability as uncertainty grows. These projections ignore climate risks and are meaningful over horizons of up to five or ten years. Beyond that, we assume convergence to some long-term average (eg inflation at the 2 percent target). Integrated assessment models can generate long-term projections to adjust the calibrated scenarios. The scenario trees can then combine probabilistic scenarios when market data and expert opinions are considered reliable, with climate change scenario narratives.

This approach to debt-sustainability with climate effects uses both local information from calibrated scenarios (Box 3) and global/regional information from scenario narratives. Coordination is needed to obtain regional information, an issue in which the EU fiscal stability institutions can play a role.

Box 3: Debt sustainability analysis with climate risks

If there are no risks, ambiguity or misspecifications, we can express debt dynamics over time as follows:

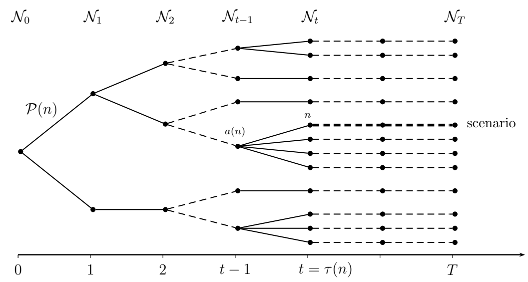
$$D_t = (1 + i_{t-1})D_{t-1} - B_{t-1} \text{ (debt stock)}$$

$$F_t = i_{t-1}D_{t-1} + A_t - B_{t-1} \text{ (debt flow)}$$

Here, i_t denotes debt financing interest rates, A_t denotes amortisation of legacy debt, B_t denotes fiscal primary balance. For sustainability we look at the ratio of stocks and flows to GDP Y_t.

Debt sustainability analysis uses projections of these variables over time to calculate the GDP-scaled variables, $d_t = D_t/Y_t$, $f_t = F/Y_t$. If the debt ratio is increasing and exceeds a threshold, or the flow variable exceeds the maximum amount that markets can finance, then debt can be considered unsustainable.

Under risk conditions, debt sustainability analysis uses scenarios of the debt variables to generate fan charts for the debt variables. The model developed for the European Stability Mechanism by Zenios *et al* (2021) uses scenario trees, such as the one illustrated below.



Scenarios of the debt variables follow paths (p) across time (t) and states (n), on this tree. With each state we associate a probability obtained from a statistical calibration that matches the average scenario to the expected values obtained from expert projections or market observations, and matches the moments of the scenario distributions to historical data.

To introduce risk, ambiguity and misspecifications, we use p to denote paths on the tree (these are the risk variables with known probabilities), and s to denote ambiguous variables obtained using scenario narratives and the integrated assessment models. The climate-sensitive debt dynamics become:

$$D_t^p = (1 + i_{t-1}^p)D_{t-1}^p - B_{t-1}^p + CB_t^s$$

$$F_t^p = i_{t-1}^p D_{t-1}^p + A_t^{p,s} - B_{t-1}^p + CB_t^s$$

CB_t^s is the climate-adjusted fiscal position, accounting for adaptation, mitigation and damages. The amortisation schedule can be scenario-dependent for contingent debt. GDP is dependent on the calibrate tree, Y_t^p, and is adjusted by a climate factor c_t^s denoting the adjustment of GDP projected by an integrated assessment model under scenario narrative s. The GDP-scaled debt variables become:

$$d_t^{p,s} = \frac{D_t^p}{c_t^s \, Y_t^p}, f_t^{p,s} = \frac{F_t^p}{c_t^s \, Y_t^p}.$$

These can now inform debt-sustainability analysis with climate risks.

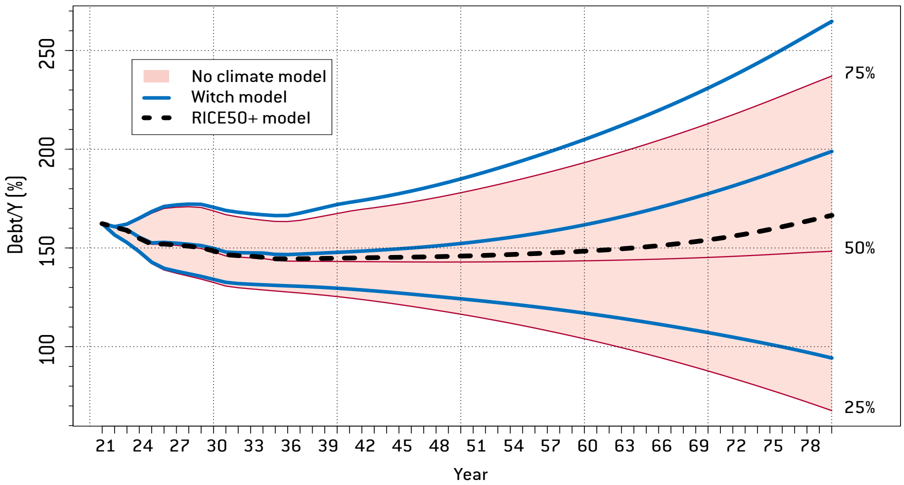
5.2 An illustrative example: Italy

We use two integrated assessment models from the RCP2.6-SSP2 scenario matrix cell (Table 1), namely RICE50+ and WITCH from the European Institute on Economics and the Environment (Emmerling *et al*, 2016), to look at the impact of climate change on Italy's debt.

The current debt of Italy stands at about 170 percent of GDP. For growth projections not factoring-in climate risk we use the *IMF World Economic Outlook*, extrapolated to the long-term historical average of Italy at a nominal 0.8 percent, and calibrate scenario trees to the historical volatility of Italian growth. For inflation we use European Central Bank short-term projections, extrapolated to the 2 percent target, and calibrate scenario trees using historical volatility and correlation estimates. Interest rates are computed using a Taylor rule responding to the calibrated inflation, inflation expectations and output gap, with the real interest rate r*=0.

We start with the calibrated scenarios trees from Annex A, and run the debt sustainability analysis model of Zenios *et al* (2021). This baseline analysis is free of climate risks. Figure 8 shows debt dynamics (pink shaded fan chart), with the median stabilised slightly below 150 percent of GDP after 2030, with significant upside risk.

Figure 8: Impact of climate risks on Italian debt developments



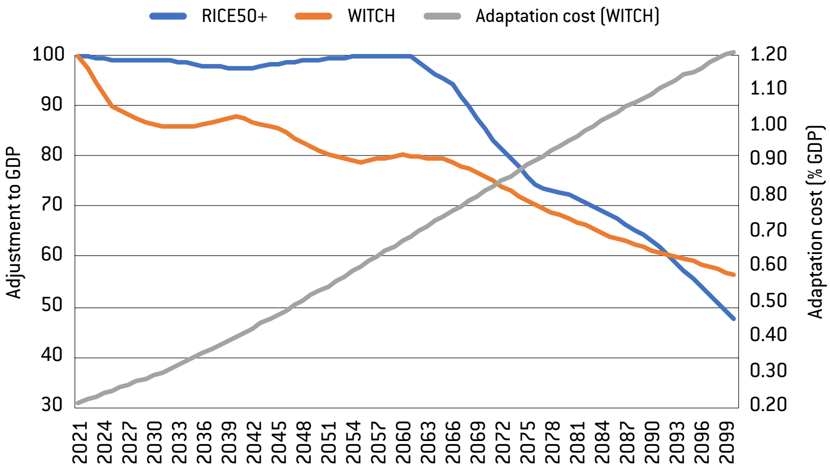
Source: Bruegel using the model of Zenios *et al* (2021) and the scenarios given in the annex.

We next consider climate effects. We use WITCH (taking the growth path for region 'Europe') and RICE50+ to project adjustments to Italy's growth (Figure 9). Both models project significant downward adjustments by 2100, with large effects after mid-century with RICE50+, and gradual changes with WITCH from early on. We run the debt sustainability analysis model with both projections, and superimpose onto the fan chart of the climate-free debt dynamics of Figure 8. The blue lines are the median, and 0.25, 0.50 and 0.75 quantiles with WITCH, and the dashed line is the median with RICE50+.

The median of the climate-adjusted debt dynamics is upward sloping, and the upside risk increases significantly with both integrated assessment models. With RICE50+ the climate risks kick in from about 2050, whereas with WITCH the changes are noticeable from the mid-2030s. These findings corroborate the credit-rating model discussed earlier, and are also in line with the ECB/ESRB (2021) estimates that physical risk losses arising from climate change could become dominant in around 15 years.

We go a step further to account for adaptation measures, and incorporate the adaptation costs obtained by WITCH (Figure 9), assuming that a quarter of these costs will be borne by the public budget. We find that debt dynamics deteriorate marginally, and adaptation measures do not offset the upside risks to the country's debt.

Figure 9: Integrated assessment model projections of growth and adaptation



Source: Bruegel using the WITCH and RICE50+ models of Emmerling *et al* (2016).

Our example shows that climate risks can have significant effects on debt dynamics. Importantly, it shows how integrated assessment models can be incorporated into debt sustainability analysis, and provides rough bounds for climate-adjusted debt dynamics under different climate policies. A more detailed analysis would include projected damages (this will worsen the fiscal position and create more upside risk), the impact of mitigation efforts (this will worsen the fiscal position but could spur growth and create downside potential), and should consider the other SSP-RCP cells of the scenario matrix (Table 1).

We must also deal with the differences between model predictions, as manifested in the different debt dynamics obtained from WITCH and RICE50+. The differences between these prominent models highlight the challenges of model misspecification. Ensembles of models can give us a range of projected growth for each scenario narrative (Annex B). This information can be incorporated into the debt sustainability analysis to refine the quantile estimates and build confidence on policy recommendations that transcend any single model.

6 Climate-proofing sovereign debt

Climate risks are global. Even if EU countries are among the world's less-vulnerable and better-prepared, there is nowhere to hide from climate change. But whereas it may not be possible to avoid climate risks, steps should be taken to mitigate their impact on public finance. Government and EU institutions need a plan for the risks posed by climate change to sovereign debt. The European Central Bank is taking a significant lead internationally on climate risk and financial stability. Complementary efforts are warranted from the institutions responsible for fiscal stability. Such efforts shall remain strictly consistent with the institutions' mandates. Tempting as it might be to use public debt to enact climate-friendly policies, the focus here is on understanding how climate risk affects fiscal stability and how to make public debt more resilient. The reverse question, of how to use public debt to support an environmental sustainability strategy, is the prerogative of elected governments and parliaments.

We recommend a three-part approach to managing the risks to public finance presented by climate change: coordination, climate risk analysis in public finance, and disclosure.

Coordination

Climate challenges are global and regional, and tackling climate challenges requires coordination between multiple agencies. These realities have been reflected in the establishment of the global NGFS, the multi-agency efforts by New Zealand and the United Kingdom, and the development of global (and more recently regional) climate models. We therefore recommend that EU institutions make a coordinated effort to carry out an integrated assessment of the risks of climate change to sovereign debt. A fundamental challenge is analytical, and without an EU-wide integrated assessment, efforts by all but the biggest countries will remain fragmented and, most likely, poorly grounded.

A network for climate-proofing public finance will bring together EU and member state institutions. For instance, the European Commission is already tasked with ensuring lasting, sound and robust management of public finances in Europe. The European Fiscal Board with the national fiscal councils, and the European Stability Mechanism as the sovereign crisis resolution mechanism, have expertise and a stake as well. They all work to ensure sound and robust management of public finances. Climate change presents a common threat to the fulfilment of these institutions' mandates, and thus warrants coordination.

Introducing climate change into debt sustainability analysis entails forward-looking scenario assessment of risks. The usual debt sustainability analysis relies on centralised expert methodologies (eg by the International Monetary Fund) with decentralised country teams contributing local knowledge. When it comes to climate risks, the macro projections are global or regional. Centralised expertise is required. A collaborative effort by the European Commission, European Fiscal Board and European Stability Mechanism could lead to development of a scenario matrix architecture of shared socio-economic pathways and representative concentration paths that are appropriate for the analysis of the risks to public finance from climate change. Such an effort would also quantify ambiguous scenarios, using integrated assessment models for Europe to generate adjustments for fiscal costs and growth arising from climate change. Quantitative scenarios, generated centrally, can be combined with the country knowledge of standard debt-sustainability analysis to produce climate-adjusted analysis from a climate risk-free baseline. National institutions that currently monitor or manage fiscal risk will benefit from these efforts.

A coordinated effort on the scenario matrix architecture will deliver transparency on the assumptions underlying the models, and ensure acceptability of scenarios. Naturally, each sovereign (and investor) can adapt their own local models, but the regional impact of climate change on the EU economies is best approached through a common understanding.

Climate risk analysis in public finance

National fiscal authorities should mainstream climate risk analysis in public finance by taking three specific actions. First, budgetary plans should account for damages and adaptation and mitigation costs, including potential social costs. Some of these costs can be immediate and direct, derived from national plans such as those related to the European Green Deal. Others will be of more long-term nature, in response to adaptation needs derived from forward-looking plans. Still others can be contingent, such as damages from acute weather events.

Second, planning for contingent liabilities requires the compilation of databases of past extreme events to complement long-term projections from integrated assessment models. Such databases provide useful information, as has been demonstrated by Australia and Canada. Eurostat with the European Fiscal Board can develop standards.

Third, the potential scale of acute weather-related events and contingent liabilities brings to the fore a need for risk-sharing instruments. Climate risks are still mostly insurable, but planning for the long run should be done. Tapping the markets through contingent instruments can provide solutions. Catastrophe bonds, sovereign contingent convertible debt and GDP-linked bonds can provide sovereigns with fiscal space when faced with weather shocks. Contingent debt is a feasible euro-area reform that would not require risk-sharing between EU countries or treaty changes. However, EU institutions should coordinate to create a market (Demertzis and Zenios, 2019).

Disclosure

There should be more disclosure of the climate risks to public debt. The Task Force on Climate-related Financial Disclosures[21] recommends disclosures relating to governance, the identification, assessment, and management of climate related risks, metrics and targets on climate risks, and business opportunities and financial planning. This initiative is supported by 785 companies, 340 investors with $34 trillion under management, and 36 central banks. However, only three EU countries participate (Belgium, France and Sweden). The fiscal authorities should follow these guidelines. Disclosures should go beyond monitoring compliance with the Paris Agreement, important as this may be, but also in exposing the effects of climate change on public finance. The resilience of a country's debt to climate change is important, whether the country contributes a lot or a little to the problem.

It is not up to any single country to mitigate climate change. But it is up to each country and the relevant EU institutions to ensure that the fiscal positions of member states are resilient. In the same way that the ECB is taking a leading position internationally on mitigating the risks posed by climate change to financial stability, the EU institutions can play a similar role on fiscal stability. The approach suggested here can support fiscal and sovereign debt resilience in the presence of climate risks.

References

Banque de France (2019) 'Benchmarks for the financial sector in the face of climate risk: facts and recommendations', in *Financial Stability Review* 23, Banque de France

Barnett, M., W. Brock and L. Peter Hansen (2020) 'Pricing uncertainty induced by climate change', *The Review of Financial Studies* 33: 1025-1066

Batten, S. (2018) 'Climate change and the macro economy –a critical review', *Staff Working Paper no. 706,* Bank of England

Battiston, S. (2019) 'The importance of being forward-looking: managing financial stability in the face of climate risks', in *Financial Stability Review* 23, Banque de France

Battiston, S. and I. Monasterolo (2020) 'A climate risks assessment of sovereign bonds', mimeo, available at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3376218

Bosetti, V. (2021) 'Integrated Assessment Models for Climate Change', *Oxford Research Encyclopedia of Economics and Finance*, 22 January

Burke, M., M.S. Hsiang and E. Miguel (2015) 'Global non-linear effect of temperature on economic production', *Nature* 527: 235-239

Carney, M. (2015) 'Breaking the tragedy of the horizon –climate change and financial stability', speech given at Lloyd's of London, 29 September, available at https://www.bankofengland.co.uk/speech/2015/breaking-the-tragedy-of-the-horizon-climate-change-and-financial-stability

Climatic Change (2014) *Special Issue: A Framework for the Development of New Socio-economic Scenarios for Climate Change Research, Climatic Change* 122(3)

Dibley, A., T. Wetzer and C. Hepburn (2021) 'National COVID debts: climate change imperils countries' ability to repay', *Nature* 592: 184-187

Cevik, S. and J. Tovar Jalles (2020) 'This changes everything: climate shocks and sovereign bonds', *IMF Working Paper* 79/2020, International Monetary Fund

Dell, M., B. Jones and B. Olken (2014) 'What do we learn from the weather? The new climate-economy literature', *Journal of Economic Literature* 52: 740-798

Demertzis, M. and S.A. Zenios (2019) 'State Contingent Debt as Insurance for Euro Area Sovereigns', *Journal of Financial Regulation*, 5(1): 64–90

Domínguez-Jiménez, M. and A. Lehmann (2020) 'Accounting for climate policies in Europe's sovereign

21 See https://www.fsb-tcfd.org/.

debt market', *Policy Contribution* 10/2021, Bruegel

ECB/ESRB (2021) *Climate-related risk and financial stability*, ECB/ESRB Project Team on climate risk monitoring, European Central Bank and European Systemic Risk Board

Emmerling, J., L. Drouet, L. Aleluia Reis, M. Bevione, L. Berger, V. Bosetti … P. Havlik (2016) 'The WITCH 2016 Model - Documentation and Implementation of the Shared Socioeconomic Pathways', *Working Papers* 2016.42, Fondazione Eni Enrico Mattei

European Commission (2019a) 'Debt Sustainability Monitor', *Institutional Paper* 120, Directorate-General for Economic and Financial Affairs

European Commission (2019b) 'The European Green Deal', COM/2019/640 final

Gala, V., G. Pagliardi and S.A. Zenios (2020) 'Global Political Risk and International Stock Returns', mimeo, available at https://ssrn.com/abstract=3242300

Gazzotti P., J. Emmerling, G. Marangoni, A. Castelletti, K. van der Wijst, A. Hof and M. Tavoni (2021) 'Persistent inequality in economically optimal climate policies', *Nature Communications*, forthcoming

IMF (2019) 'How to mitigate climate change', *Fiscal Monitor*, October, International Monetary Fund

IMF (2020a) 'EU climate mitigation policy', *European Department Paper* no. 20/13, International Monetary Fund

IMF (2020b) *World Economic Outlook*, October 2020: A Long and Difficult Ascent, International Monetary Fund

Kahn, E.M., K. Mohaddes, R.N.C. Ng, M.H. Pesara, M. Raissi and J-C. Yang (2019) 'Long-term macroeconomic effects of climate change: A cross-country analysis', *IMF Working Paper* 19/215, International Monetary Fund

Klusak, P., M. Agarwal, M. Burke, M. Kraemer and K. Mohaddes (2021) 'Rising Temperatures, Falling Ratings: The Effect of Climate Change on Sovereign Creditworthiness', *Bennet Institute Working Paper*, University of Cambridge

Kalkuhl, M. and L. Wenz, L. (2020) 'The Impact of Climate Conditions on Economic Production. Evidence from a Global Panel of Regions', *Journal of Environmental Economics and Management* 103

Nordhaus, W. (2018) 'Climate change: The Ultimate Challenge for Economics', Nobel Prize Lecture, available at https://www.nobelprize.org/uploads/2018/10/nordhaus-lecture.pdf

Moody's (2019) 'How Moody's Rates Sovereigns and Supranational Entities', available at https://www.moodys.com/Pages/HowMoodysRatesSovereigns.aspx

ND-GAIN (2020) 'Country Index', Notre-Dame Global Adaptation Initiative, available at https://gain.nd.edu/our-work/country-index/

NGFS (2019) *Macroeconomic and financial stability – implications of climate change*, Network for Greening the Financial System, available at https://www.banque-france.fr/sites/default/files/media/2019/08/19/ngfs-report-technical-supplement_final_v2.pdf

Obama, B. (2017) 'The irreversible momentum of clean energy', *Science* 355: 126-129

OECD and World Bank (2019) *Fiscal resilience to natural disasters: Lessons from country experiences*, OECD Publishing, Paris

Office of Management and Budget (2016) *Climate change: the fiscal risks facing the federal government*, Executive Office of the President of the United States

Pindyck, R. (2017) 'The use and misuse of models for climate policy', *Review of Environmental Economics and Policy*, 11: 100-114

Porter, M.E. and C. van der Linde (1995) 'Toward a New Conception of the Environment-Competitiveness Relationship', *Journal of Economic Perspectives* 9: 97-118

Rogelj, J., A. Popp, A., K.V. Calvin, G. Luderer, J. Emmerling, D. Gernaat … M. Tavoni (2018) 'Scenarios towards limiting global mean temperature increase below 1.5 °C', *Nature Climate Change* 8: 325–33

Standard and Poor's (2017) 'Sovereign rating methodology', 18 December, S&P Global Ratings

Stern, N. and J.E. Stiglitz (2021) 'The social cost of carbon, risk, distribution, market failures: An alternative approach', *NBER Working Paper* 28472, National Bureau of Economic Research

Tol, R.S.J (2014) 'Correction and update: The economic effects of climate change', *Journal of Economic Perspectives* 28: 221-226

Volz, U., J. Beirne, N. Ambrosio Preudhomme, A. Fenton, E. Mazzacurati, N. Renzhi and J. Stampa (2020)

Climate change and sovereign risk, Project Report, SOAS University of London, available at https://eprints.soas.ac.uk/33524/

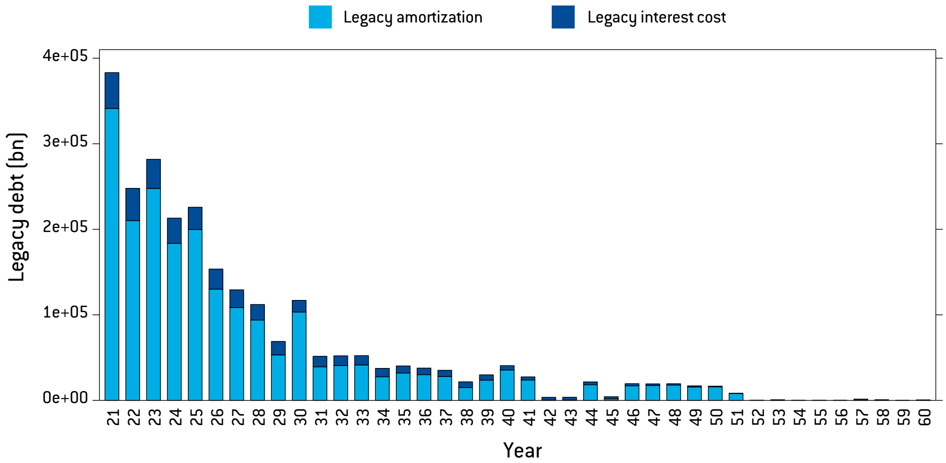
Weitzman, M.L. (2011) 'Fat-Tailed Uncertainty in the Economics of Catastrophic Climate Change', *Review of Environmental Economics and Policy*, 5: 275–292

Weyant, J. (2017) 'Some contributions of integrated assessment models for global climate change', *Review of Environmental Economics and Policy* 11: 115-137

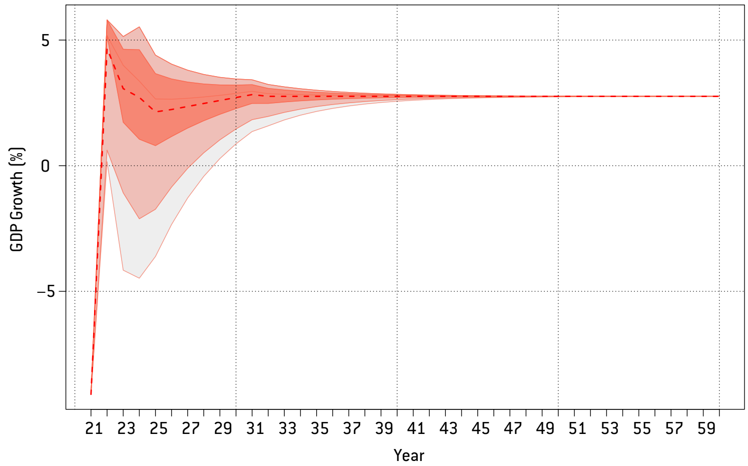
Zenios, S.A., A. Consiglio, M. Athanasopoulou, E. Moshammer, A. Gavilan and A. Erce (2021) 'Risk management for sustainable sovereign debt financing', *Operations Research* 69(3): 755-773

Annex A: The calibrated Italian case study

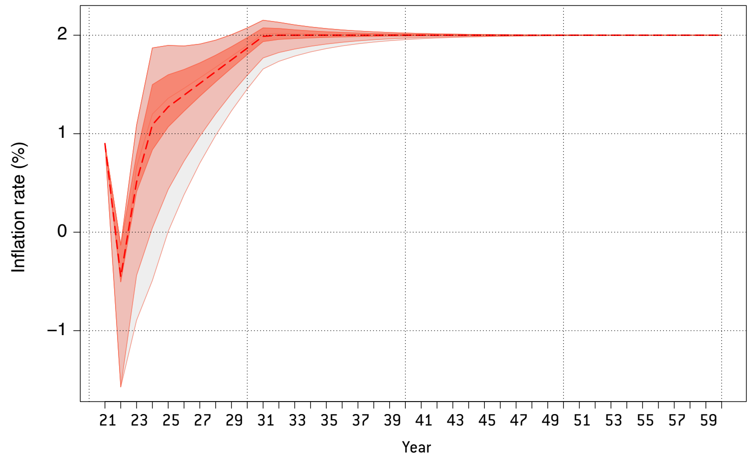
Legacy debt



GDP growth scenarios (nominal values)



Inflation scenarios



Annex B: Ensemble of model-generated GDP growth adjustments

We display below the GDP growth adjustments using an ensemble of models from the SSP database at IIASA. Specifically, we use the integrated assessment models AIM/CGE, GCAM4, IMAGE, REMIND-MAGPIE, WITCH-GLOBIOM, with MESSAGE-GLOBIOM as the markers, for SSP2 for the OECD economies. Data at [https://tntcat.iiasa.ac.at/SspDb/dsd?Action=html-page&page=40.](https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=40)