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Physical impacts of climate change: tentative appraisal of macro-fiscal costs for Belgium

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Abstract – The report appraises long-term (up to 2050) macro-fiscal costs of physical impacts of climate change for Belgium. It highlights the uncertainties relative to this exercise, and it provides aggregate estimates from damage functions for various global warming scenarios. A first key takeaway is the wide range of possible impacts on economic output from chronic hazards. A second takeaway is that worsening warming scenarios are associated with negative impacts on economic output. The effect on public finances in such scenarios is an increase in debt-to-GDP ratio of up to 15 percentage points by 2050. Highly adverse climate scenarios must be taken into consideration as they highlight the possibilities of endangered future public debt stability. Acute hazards are expected to increase in frequency and intensity, according to different scenarios. Their costs can be sizeable compared to GDP. The sheer size of these potential impacts raises the question of what could be done to reduce them.

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Executive summary

This paper addresses the question: *"What are the long-term costs to the economy and public finances of the physical impacts of climate change in Belgium?"* The aim is to provide estimates of the *cost of inaction* about climate change. This is the economic cost of physical damage in a scenario where no additional adaptation measures are implemented domestically.

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Macro-fiscal costs of physical impacts of climate change refer to the effects from chronic (temperature, precipitation and sea-levels) and acute (storms, floods, heavy precipitations, etc.) climate hazards on physical capital, productivity and agriculture, comprising direct and indirect changes to GDP, public revenues and expenditures. They are distinct from transition costs that refer to the costs resulting from mitigation and adaptation policies.

Academic literature highlights three major sources of uncertainty when quantifying the cost of climate change. First, climate uncertainty that refers to the complexities when foreseeing accurately how various hazards will develop, in intensity and frequency, based on carbon concentration levels. Second, major uncertainties still exist about the direct and indirect causal links between climate events and the economy, known as transmission channels. Lastly, there remains uncertainty about future climate policy choices in terms of mitigation and adaptation both domestically and abroad.

In academic literature, aggregate appraisals of chronic climate damage to the economy are often expressed through damage curves built through econometric panel data analyses. These estimates have been in full development for over two decades and vary according to methods used, regions considered, hazard indicators included, etc. Overall, estimates have increased in line with growing knowledge and number of hazards considered. To discuss the macro-fiscal costs from chronic hazards in Belgium, we build a simple model inspired by the Q-CRAFT tool of the IMF. In this model, we plug damage estimates from the Kotz et al. 2024 study (adapted by the Network for Greening the Financial System).

The analysis of physical damages to the Belgian economy reveals serious economic risks. The baseline scenario in this analysis corresponds to a stabilization of the current warming levels. Compared to this baseline, GDP loss by 2050 is expected to range from 2.8% to 5% depending on the warming scenario. This sets the public debt trajectory on a sharply increasing path well before mid-century, as compared to the trajectory derived from the national medium-term fiscal-structural plan. The fiscal adjustments needed to keep debt on the same track as a situation without further global warming range from 0.7 to 1.4% of GDP by 2050. When running the analysis with another source of damage estimates, the Kahn et al. 2019 study (adapted by Q-CRAFT), the negative and substantial impacts already before mid-century are confirmed.

Climate adverse scenarios appear to significantly strengthen the fiscal sustainability challenge, making the case for a strong link between environmental sustainability and public finances stability. Given the large number of parameters not yet taken into account in damage curves (sea-level rises, tail events, tipping points), it is likely that these figures underestimate the future economic impacts of climate change. This is without mentioning that other hardly monetizable damages are out of scope of this analysis, notably biodiversity loss, public health consequences and other social impacts.

For acute damage costs, we discuss historical data of disasters from EM-DAT. We provide a descriptive analysis of the disasters from 1975 to 2025 for Belgium individually and for Western Europe (Benelux, France and Germany). We observe increased trends in both extreme event records as well as their corresponding economic value in the past 25 years as compared to the first half of the period considered. The main hazards affecting Belgium are floods and storms. Two major events stand out in terms of severity: the storms of 1990 and the floods of 2021, both having caused direct damages of around 1.9 billion euros each. Acute damage costs scaled for geographical size appear to be a bit higher for Belgium than for neighbouring countries.

Estimating future acute event costs for the Belgian economy and public finances remains difficult because of the limited availability of data, the difficulty to assess the suitable geographical scope for analysis, the uncertainty around intensity and frequency multipliers and question marks around the role of public finances in damage recovery. In worst-case scenario projections from the NGFS though, acute climate event damages may represent in the worst case a maximum of 12% of GDP per year by mid-century in Belgium. This is not the expected cost on average, but the “ceiling” of acute damages exposition that we can expect.

The sheer size of these potential impacts raises the question of what could be done to reduce them, in particular which mitigation actions at the global level and which adaptation measures at the domestic level have positive cost-benefit ratios.

Synthèse

Ce document répond à la question suivante : *« Quels sont les coûts à long terme pour l'économie et les finances publiques des impacts physiques du changement climatique en Belgique ?* » L'objectif est de fournir des estimations du *coût de l'inaction* face au changement climatique. Il s'agit du coût économique des dommages physiques dans un scénario où aucune mesure d'adaptation supplémentaire n'est mise en œuvre au niveau national.

Ce rapport est un premier livrable de la convention de recherche entre le Cerac et le Bureau fédéral du Plan. Le Cerac a commandé ce rapport au BFP et lui a fourni les données et informations climatiques nécessaires. Il constitue une première contribution à la nouvelle exigence du cadre budgétaire de l'UE imposant aux États membres de fournir, dans la mesure du possible, une évaluation à moyen et long terme de l'impact macro-budgétaire du changement climatique, y compris sur les engagements conditionnels éventuels liés aux finances publiques.

Les coûts macro-budgétaires des impacts physiques du changement climatique font référence aux effets des risques climatiques chroniques (température, précipitations et niveau de la mer) et aigus (tempêtes, inondations, fortes précipitations, etc.) sur le capital physique, la productivité et l'agriculture, comprenant les changements directs et indirects de PIB, des recettes et des dépenses publiques. Ils se distinguent des coûts de transition qui se réfèrent aux coûts résultant des politiques d'atténuation et d'adaptation.

La littérature académique met en évidence trois grandes sources d'incertitude lorsqu'il s'agit de quantifier le coût du changement climatique. Premièrement, l'incertitude climatique qui fait référence à la complexité de prévoir avec précision l'évolution des différents aléas, en termes d'intensité et de fréquence, en fonction des niveaux de concentration de carbone. Deuxièmement, des incertitudes majeures subsistent quant aux liens de causalité directs et indirects entre les événements climatiques et l'économie, appelés canaux de retransmission. Enfin, l'incertitude demeure quant aux choix futurs en matière de politique climatique, en termes d'atténuation et d'adaptation, tant au niveau national qu'international.

Dans la littérature académique, les évaluations agrégées des dommages chroniques causés par le climat à l'économie sont souvent exprimées par des courbes de dommages construites à partir d'analyses économétriques de données de panel. Ces estimations sont en plein développement depuis plus de deux décennies et varient en fonction des méthodes utilisées, des régions considérées, des indicateurs d'aléas inclus, etc. Dans l'ensemble, les estimations ont augmenté en fonction de l'accroissement des connaissances et du nombre d'aléas pris en compte. Pour examiner les coûts macro-budgétaires des aléas chroniques en Belgique, nous construisons un modèle simple inspiré de l'outil Q-CRAFT du FMI. Dans ce modèle, nous intégrons les estimations des dommages tirées de l'étude de Kotz et al. 2024 (adaptée par le *Network for Greening the Financial System*).

L'analyse des dommages physiques causés à l'économie belge révèle des risques économiques graves. Le scénario de référence de cette analyse est une stabilisation du réchauffement au niveau actuel. Par rapport à cette référence, la perte de PIB d'ici 2050 devrait se situer entre 2,8 % et 5 % selon le scénario de réchauffement. Cela place la dette publique sur une trajectoire fortement croissante bien avant le milieu du siècle, comparé à la trajectoire dérivée du plan budgétaire et structurel à moyen terme. Les ajustements budgétaires nécessaires pour maintenir la dette sur sa trajectoire qui serait celle en l'absence de réchauffement additionnel vont de 0,7 à 1,4% du PIB à l'horizon 2050. Lorsque l'analyse est effectuée à partir d'une autre source faisant autorité en matière d'estimations des dommages, à savoir l'étude de Kahn et al. 2019 (adaptée par Q-CRAFT), les incidences négatives et substantielles dès avant le milieu du siècle sont confirmées.

Les scénarios de réchauffement les plus défavorables semblent renforcer considérablement le défi de la soutenabilité budgétaire, suggérant un lien étroit entre durabilité environnementale et stabilité des finances publiques. Compte tenu du grand nombre de paramètres qui ne sont pas encore pris en compte dans les courbes de dommages (incendies de forêt, élévation du niveau de la mer, événements extrêmes, points de basculement), il est probable que ces chiffres sous-estiment les impacts économiques futurs du changement climatique. Ceci sans mentionner que d'autres dommages difficilement monétisables sont hors du champ de cette analyse, notamment la perte de biodiversité, les conséquences en santé publique et d'autres impacts sociaux.

En ce qui concerne les coûts des dommages aigus, nous examinons les données historiques des catastrophes tirées d'EM-DAT. Nous fournissons une analyse descriptive des catastrophes survenues entre 1975 et 2025 pour la Belgique prise individuellement et pour l'Europe occidentale (Benelux, France et Allemagne). Nous observons des tendances à la hausse dans les enregistrements d'événements extrêmes ainsi que dans leur valeur économique au cours des 25 dernières années par rapport à la première moitié de la période considérée. Les principaux risques affectant la Belgique sont les inondations et les tempêtes. Deux événements majeurs se distinguent en termes de gravité : les tempêtes de 1990 et les inondations de 2021, qui ont toutes deux causé des dommages directs d'environ 1,9 milliard d'euros chacun. Les coûts des dommages aigus ramenés à la taille géographique semblent être un peu plus élevés pour la Belgique que pour les pays voisins.

Il demeure difficile d'estimer les coûts futurs des événements aigus pour l'économie belge et les finances publiques en raison de la disponibilité limitée de données, de la difficulté d'évaluer la zone géographique appropriée pour l'analyse, de l'incertitude concernant les multiplicateurs d'intensité et de fréquence et des points d'interrogation concernant le rôle des finances publiques dans la réparation des dommages. Dans les projections du scénario le plus pessimiste du NGFS, les dommages causés par les événements climatiques aigus pourraient représenter dans le pire des cas un maximum de 12 % du PIB par an d'ici le milieu du siècle en Belgique. Il ne s'agit pas du coût moyen attendu, mais du "plafond" de l'exposition aux dommages aigus auquel nous pouvons nous attendre.

L'ampleur de ces impacts potentiels soulève la question de ce qui pourrait être fait pour les réduire, en particulier quelles mesures d'atténuation au niveau mondial et quelles mesures d'adaptation au niveau domestique présentent des rapports coûts-bénéfices positifs.

Synthese

Dit document behandelt de vraag: *"Wat zijn de langetermijnkosten voor de economie en de overheidsfinanciën van de fysieke gevolgen van de klimaatverandering in België?".* Het doel is om schattingen te geven van de *kosten van het niet nemen van maatregelen* tegen klimaatverandering. Het gaat om de economische kosten van fysieke schade in een scenario waarin er geen bijkomende adaptatiemaatregelen worden geïmplementeerd in eigen land.

Dit rapport is een eerste resultaat van de onderzoeksovereenkomst tussen Cerac en het Federaal Planbureau. Cerac heeft dit rapport bij het FPB besteld en heeft de nodige klimaatgegevens en -informatie voorzien. Het vormt een eerste bijdrage aan de nieuwe vereiste in het EU-begrotingskader, die de lidstaten verplicht om, waar mogelijk, een middellange- en langetermijnbeoordeling te verstrekken van de macrobudgettaire impact van klimaatverandering, inclusief eventuele voorwaardelijke verplichtingen met mogelijke impact op de overheidsfinanciën.

Macrobudgettaire kosten van fysieke gevolgen van klimaatverandering hebben betrekking op de effecten van chronische (temperatuur, neerslag en zeespiegel) en acute (stormen, overstromingen, zware neerslag, enz.) klimaatrisico's op fysiek kapitaal, productiviteit en landbouw, en omvatten directe en indirecte wijzigingen van het bbp, overheidsinkomsten en -uitgaven. Ze zijn te onderscheiden van transitiekosten, die verwijzen naar de kosten die voortvloeien uit het mitigatie- en adaptatiebeleid zelf.

De academische literatuur benadrukt drie belangrijke bronnen van onzekerheid bij het kwantificeren van de kosten van klimaatverandering. Ten eerste, de klimaatonzekerheid die verwijst naar de complexiteit van het nauwkeurig voorspellen hoe verschillende gevaren zich zullen ontwikkelen, in intensiteit en frequentie, op basis van koolstofconcentratieniveaus. Ten tweede, er bestaan nog steeds grote onzekerheden over de directe en indirecte oorzakelijke verbanden tussen klimaatgebeurtenissen en de economie, wat we transmissiekanalen noemen. Tot slot blijft er onzekerheid bestaan over toekomstige beleidskeuzes op het gebied van mitigatie en adaptatie, zowel in eigen land als daarbuiten.

In de academische literatuur worden geaggregeerde schattingen van chronische klimaatschade aan de economie vaak uitgedrukt in de vorm van schadecurven die worden opgebouwd via econometrische panelanalyses. Deze schattingen zijn al meer dan twee decennia in volle ontwikkeling en variëren afhankelijk van de gebruikte methoden, de beschouwde regio's, de opgenomen gevarenindicatoren, enz. In het algemeen worden de schattingen opwaarts herzien naarmate de kennis en het aantal in aanmerking genomen gevaren toeneemt. Om de macrobudgettaire kosten van chronische gevaren in België te onderzoeken, bouwen we een eenvoudig model dat geïnspireerd is op de Q-CRAFT tool van het IMF. In dit model gebruiken we schaderamingen uit het onderzoek van Kotz et al. 2024 (aangepast door het *Network for Greening the Financial System*).

De analyse van de fysieke schade aan de Belgische economie brengt ernstige economische risico's aan het licht. Het basisscenario in deze analyse is een stabilisering van de opwarming op het huidige niveau. Het bbp-verlies ten opzichte van dit basisscenario tegen 2050 zal naar verwachting schommelen tussen 2,8% en 5%, afhankelijk van het opwarmingsscenario. Dit zet het traject van de overheidsschuld op een sterk stijgend pad ruim voor het midden van de eeuw in vergelijking met het traject afgeleid van het budgettair-structureel plan voor de middellange termijn. De budgettaire aanpassingen die nodig zijn om de schuld op het niveau te houden dat zonder verdere opwarming zou gelden, variëren van 0,7 tot 1,4 % van het bbp tegen 2050. Als we de analyse uitvoeren met een andere gezaghebbende bron van schaderamingen, namelijk het onderzoek van Kahn et al. 2019 (aangepast door Q-CRAFT), worden de aanzienlijke negatieve gevolgen voor het midden van de eeuw bevestigd.

De ongunstige klimaatscenario's blijken de budgettaire houdbaarheidsuitdaging aanzienlijk te versterken, wat een sterk verband tussen ecologische duurzaamheid en de stabiliteit van de overheidsfinanciën aantoont. Gezien het grote aantal parameters waarmee nog geen rekening is gehouden in de schadecurves (bosbranden, zeespiegelstijgingen, extreme gebeurtenissen, kantelpunten), is het waarschijnlijk dat deze cijfers de toekomstige economische gevolgen van klimaatverandering onderschatten. Dit is nog zonder te vermelden dat andere moeilijk in geld uit te drukken schade buiten het bestek van deze analyse valt, met name een achteruitgang van de biodiversiteit, de gevolgen voor volksgezondheid en andere sociale gevolgen.

Voor kosten van acute klimaatschade bespreken we historische gegevens van rampen uit EM-DAT. We geven een beschrijvende analyse van de rampen van 1975 tot 2025 voor België afzonderlijk en voor West-Europa (Benelux, Frankrijk en Duitsland). We stellen stijgende trends vast in zowel het aantal opgenomen extreme gebeurtenissen als de economische waarde die ze vertegenwoordigen in de afgelopen 25 jaar in vergelijking met de eerste helft van de beschouwde periode. De belangrijkste risico's voor België zijn overstromingen en stormen. Twee belangrijke gebeurtenissen springen eruit in termen van ernst: de stormen van 1990 en de overstromingen van 2021, die beide een directe schade veroorzaakten van ongeveer 1,9 miljard euro elk. De acute schadekosten in verhouding tot de geografische grootte lijken iets hoger te liggen voor België dan voor buurlanden.

Het blijft moeilijk om de toekomstige kosten van acute gebeurtenissen voor de Belgische economie en de overheidsfinanciën in te schatten vanwege de beperkte beschikbaarheid van gegevens, de moeilijkheid om de geschikte geografische zone voor de analyse te bepalen, de onzekerheid rond de intensiteits- en frequentiemultiplicatoren en de vraagtekens rond de rol van de overheidsfinanciën bij het herstel van de schade. Volgens de prognoses van de NGFS, kan de schade door acute klimaatgebeurtenissen in het ergste geval tegen het midden van de eeuw in België maximaal 12% van het bbp per jaar bedragen. Dit is niet de verwachte gemiddelde kostprijs, maar het "plafond" van acute schade die we kunnen verwachten.

De enorme omvang van deze potentiële gevolgen roept de vraag op wat er gedaan kan worden om ze te verminderen. Met name welke mitigatiemaatregelen op mondiaal niveau en welke adaptatiemaatregelen in eigen land een positieve kosten-batenverhouding hebben.

1. Introduction

Concern about the resilience of our communities in the face of climate change is growing. It constitutes a transversal challenge for policymakers. As for many other systems of our society, the economy will likely be impacted profoundly as global warming evolves over the coming decades. As much as central banks are increasingly enquiring about the systemic threats of climate change to the stability of the financial system,[1] so are independent fiscal institutions and other research institutions expanding research about the long-term implications of climate change for public finances.[2] This paper provides an appraisal of the long-term costs of physical impacts of climate change for the Belgian economy and public finances.

To explore this topic, the Federal Planning Bureau (FPB) and the Cerac (Climate Risk Assessment Centre) joined their forces and partnered in a research program on the impacts of climate change on the Belgian economy. Indeed, the question at stake aligns neatly with the respective mandates of the FPB and the Cerac: respectively to analyse independently critical questions of fiscal policy and to analyse national critical climate risks. This research is conducted and published under this partnership.

To our knowledge, this analysis is the first work of its kind in the Belgian institutional landscape and may spur reflection and discussion about approaches, methodologies, and other questions that could be explored further.[3]

The new budgetary framework of the European Commission adopted in 2024 requests Member States to start including assessments of macro-fiscal risks from climate change in their national medium-term budgetary frameworks (Directive 2024/1265, art. 9(2), 2024) and to start reporting on climate shocks and disasters related contingent liabilities (Directive 2024/1265, art. 14(3), 2024).[4] These provisions must be transposed into national law by the end of 2025. At this stage, no commonly agreed methodology exists, and most Member States are exploring how to best include these analyses in their next medium-term plans. Hence, the Commission invites Member States to exchange best practices for long-term fiscal risk analysis of climate change (Salmon-Genel, 2025). Seminal work from Belgium on this issue is useful to feed that discussion.

The paper is structured as follows. After this introduction, section 2 summarizes the literature on long-term physical impacts of climate change on the economy and public finances. Section 3 defines the terms of our research question and outlines our methodological framework. Section 4 outlines and interprets the results of our modelling exercise. Section 5 concludes.

1 See for instance Mark Carney's speech on the Tragedy of the Horizons at Lloyd's of London in September 2015. Accessed through https://www.bankofengland.co.uk/-/media/boe/files/speech/2015/breaking-the-tragedy-of-the-horizon-climate-change-and-financial-stability.pdf
2 See for instance contributions of the Fourth Annual Conference of the European Fiscal Board. Access through https://commission.europa.eu/topics/fiscal-policy/european-fiscal-board-efb/public-finances-and-climate-change-post-pandemic-era_en
3 Especially dialogue between academics, policymakers, bankers and insurers should be accelerated on these topics.
4 These requirements are qualified *"to the extent possible"*, see full relevant legal text in Appendix A.1.

2. Literature review

Research about the physical impacts of climate change on the economy is in full development within academia, finance and public institutions. In this review, we expand on the substantial uncertainties involved in this field of research, we discuss the advances in damage appraisal, and we look at specific works on the Belgian case and in the realm of fiscal policy.

2.1 A field of research filled with uncertainty

Research on the impacts of climate change on the economy and public finances is filled with uncertainty (Valverde et al., 2022). The uncertainty stems from at least three central components necessary for discussing possible futures (Botzen et al., 2019).

First, let's look at the climate uncertainty. Scientists agree about the many symptoms of global warming, such as the rising global average temperature,[5] the increase in extreme events, etc. However, when it comes to characterizing the precise bio- and geophysical phenomena that may arise in specific regions with increasing carbon concentrations in the atmosphere, uncertainty levels increase sharply. Foreseeing accurately how various hazards will develop, in intensity and frequency, is arduous, notably because of the occurrence of tail events, from which the occurrence has low probability but potentially very large impacts, or because of the presence of tipping points in climate systems. These are thresholds after which climate change accelerates and underappreciated feedback loops derail away from equilibriums. These tail events and tipping points – known unknowns – are critical since their consequences may be catastrophic and non-reversible. Typically, the term *chronic* is used to describe climate hazards that are resulting from gradual global warming, changes in precipitation patterns or in sea-levels and currents while the term *acute* describes climate hazards that are related to punctual climate-related events such as floods, storms, wildfires, droughts, etc. An EU classification (Regulation 2020/1208, 2020) of these chronic and acute hazards is used in the European Climate Risk Assessment exercises and is also used by the Cerac. Acute events appear stochastic in nature: it is almost random whether a storm or flood materializes in one location rather than a few kilometers further over the border. In severe warming contexts, as acute events are expected to happen more frequently and bear heavier consequences, the boundary between chronic and acute hazards gets blurred since acute events start to get a structural character. These uncertainties are studied by climate scientists.

Secondly, we consider uncertainties around the transmission channels between climate events and the economy, clouding our understanding about their qualitative and quantitative specifications. Usually, climate change is considered as affecting the supply side of the economy in direct and indirect ways.

Direct impacts usually refer to "*the damage to assets caused directly by a natural disaster, with the losses occurring at the time of the disaster or shortly thereafter. Examples of direct economic losses include the destruction of residences, businesses, productive capital, infrastructure, crops, livestock, and (monetized) physical and mental health impacts*" (Botzen et al., 2019, p. 168). The direct costs for public finances are therefore typically increased spendings to rebuild public assets and support the private

[5] Although the exact level of warming due to increase in carbon concentration is hard to assess and is referred to as climate sensitivity

sector. In Belgium this may be through solidarity mechanisms such as regional calamity funds or direct support to households and businesses (importantly including insurers). Appraising direct costs is usually possible by analyzing historical events and making assumptions on multiplier coefficients towards the future.

Indirect impacts are understood as capturing *"the short- and long-term economic losses in economic production and consumption and any related economic recovery paths (…), sometimes called higher-order effects*" (Botzen et al., 2019, p. 168). The indirect costs for public finances are therefore potential losses of government receipts due to changes in productivity and potential surge in public spending due to increased spending pressures such as for rising unemployment. The appraisal of indirect costs is complex and debated at length in the literature around damage functions (see section 2.2). Essentially, uncertainty exists around the non-linearity of damages, the compound or systemic effects of some hazards and about the pervasiveness of climate related shocks to the economy. Regarding this pervasiveness, or scarring effect, it is still uncertain to what extent climate change creates perpetual alterations to economic growth (growth effect) or whether it creates one-off losses to economic activity from the disasters without affecting growth rates (level effect on output) or a combination of both (Aerts et al., 2024). Said differently, it is debated whether temperature levels have an effect on GDP (growth effect) or whether it is rather temperature change that affects GDP (level effect). For acute damages, punctual losses with rebound effects on the medium-term may also be expected, depending on the severity of the event (similar to the COVID pandemic's effect).

Besides the effects on the supply side of the economy, some researchers also discuss the effects of climate impacts on the demand-side, which can vary according to the consumption vs. investment preferences and structure of an economy (Casey et al., 2024). It is important to note that the categories of chronic and acute damages do not exactly coincide with direct and indirect economic impacts. Indeed, *"indirect costs to the public finances will be generated by both acute and chronic damages, though chronic impacts are the main channel. The direct costs are nearly all due to acute damages"* (OBR, 2024, p. 33).

Third, there remains uncertainty about future climate policy choices. Indeed, when it comes to climate mitigation, policy paths at a global scale matter to determine what amount of carbon will be released in the atmosphere in coming decades. When it comes to adaptation and disaster risk response and preparedness - the way we are prepared to respond to climate hazards - domestic policy choices will prove key. Therefore, the severity of economic impacts of climate change is highly dependent on climate policy choices in Belgium and abroad.

At this stage, it is useful to clarify the categories of physical and transition impact costs.[6] This paper deals with the physical impact costs as described above, i.e. the material impact on the economy and public finances. Transition impact costs, on the contrary, concern the impacts of mitigation and adaptation measures on the economy and create primarily financial consequences that can then translate into the real economy through changes in the production system. The latter is not included in the scope of this

[6] Some authors distinguish an additional category of compliance costs that comprise expenditures relating to non-compliance with climate objectives such as penalties.

study. Appendix A.2 describes transmission channels between physical impacts of climate hazards and the economy.

In the context of climate risk analysis, a risk is understood as the interplay between a climate-related hazard and its impact defined as a function of an economy's exposition and vulnerability to it (Cerac, 2025). In the literature about climate change, the terms risks and costs are often used interchangeably. To describe the economic impacts of climate change in this paper, we prefer to use the notion of cost. This is because different approaches are commended when dealing with risk (measurable uncertainty) and Knightian[7] or deep uncertainty (unmeasurable uncertainty) (Xepapadeas, 2024). Indeed, the notion of risk is unfortunate in the field of climate change as it refers to probabilistic likelihoods, in essence when a single probability model can be ascribed to a stochastic event (and so overcome the limits of deterministic models). In typical risk analysis, a risk is then described as an expected loss which is a function of the likelihood and the impact. Knightian uncertainty, however, is relevant when insufficient information exists to accurately measure uncertainties, due to ambiguity about the most accurate probabilistic model or due to misspecification where approximations need to be made for key assumptions. The appraisal of economic impacts from climate change is essentially characterized by deep uncertainty. The term risk would therefore be misleading. Section 3 develops our methodological choices for dealing with this deep uncertainty. For example, why deep uncertainty commands relying on scenario-based approaches contrasting baseline assumptions with various global warming circumstances and damage functions, and why adopting conservative precautionary approaches is important.

2.2 Damage functions and their development

In the literature, the mathematical representation that describes the relationship between the magnitude of climate change (e.g. temperature increase, changes in precipitation or frequency of extreme weather events) and the economic damage resulting from that change is called a damage function or damage curve (Aerts et al., 2024). These functions can take different forms, linear or non-linear (for example to signify threshold effects) and include different parameters. Typically, a simple characterization of such a curve would be:

$D(T)=\alpha \cdot T^{\beta}$ where $D(T)$ is the economic damage at a given temperature increase T relative to era baseline with a lesser warming, α and β are parameters determining the magnitude and shape of the curve.

The economic damage is usually captured as a decrease in GDP or productivity. For constructing these damage functions, a variety of approaches co-exist.

In the years 2000, the first damage functions were constructed as an enumeration of possible damages to the economy and were related to seminal works on RICE and DICE climate models.[8] By adding up separate estimates of a long list of damages quantified for distinct warming levels, a bottom-up aggregate damage function can be obtained. Each damage from different hazards is appraised through specific fields of economics. Research on floods for instance will be part of geographical economics, while

7 Referring to the works of Frank Knight, notably "Risk, uncertainty and profit" published in 1921

8 The Dynamic Integrated Climate-Economy (DICE) model and the Regional Integrated Climate-Economy (RICE) models are amongst the first Integrated Assessment Models linking climate science with macroeconomic modelling. Their development has been directed by William Nordhaus since the 1990s

research on heatwaves would fall under health economics, etc. For specific sectoral or regional impacts, when no quantitative measurements are available, some researchers solicit expert judgments and surveys. The main drawback of this bottom-up method is the non-exhaustiveness of the considered damages. Typically, damages obtained with enumeration approaches range from 1% of world GDP loss per incremental degree of global temperature warming (Nordhaus, 2014) to 3% (Dietz and Stern, 2015).

In recent years, econometric estimates of GDP variation for various climate warming levels have been proposed. This approach captures divergences of weather variables from historical norms (temperature, precipitations, etc.) by analysing historical time series and links them to growth rate or productivity changes. The advantage of this top-down “macro” approach is that all transmission channels need not to be identified, making it easier to obtain comprehensive orders of magnitude for damages. Yet, often cited drawbacks of this approach include the oversimplification of long-term complex climate dynamics, an inability to reproduce high levels of uncertainty, the choice of cost discounting assumptions, the difficulty of representing the interrelationship between acute and chronic impacts, etc. (Pindyck, 2013). The first econometric estimates were looking exclusively to average temperature changes (e.g. Kalkuhl and Wenz, 2020) or also included precipitations changes (e.g. Kahn et al., 2019). These first studies also establish the non-linearity of the relationship between productivity and climate variables (Burke et al., 2015). Most recent damage curves based on panel data econometric models reach higher GDP losses as they include increasingly more climate variables. The study of Kotz et al. 2024 for instance looks not only to temperature and precipitation averages in different regions but also to their variability changes. Indeed, they rely on micro-level evidence that more frequent volatility in weather patterns exert more stress on agricultural, health and infrastructure systems than changes in the mean only. Bilal and Känzig 2024 add global temperature variability changes that are correlated more strongly with extreme events on top of local changes, and obtain estimates 6 times larger than previous ones. Increasing awareness also exists on the regional heterogeneity of impacts, especially in large countries like the United States.

The first studies concluded to GDP losses around 1% to 3% of GDP for a 2°C warming compared to a situation with no further warming, depending on warming scenarios and regions of the world considered. Scholars from the latest published studies show that impacts of climate change may be much larger than previously thought, advancing figures that largely exceed 10% of world GDP loss in current warming trajectories (See **Graph 1**).

Graph 1 Damage estimates across damage functions

Study	Impact at 2 °C global warming (Current Policies in 2050[1])	Impact at 3 °C global warming (Current Policies in 2100[2])
Nordhaus & Boyer (2000)	1%	2%
Tol (2009)	1%	3%
Weitzman (2012)	1%	3%
Dell *et al.* (2012)	4%	22%
Tol (2014)	1%	2%
Nordhaus (2014)	1%	2%
Dietz & Stern (2015)	2%	13%
Burke *et al.* (2015)	8%	14%
Howard & Sterner (2017)	3%	8%
Kompas (2018)	1%	2%
Kalkuhl & Wenz (2020)	2%	5%
Kahn *et al.* (2021)	3%	8%
Waidelich *et al.* (2024)	4%	8%
Bilal & Känzig (2024)	19%	44%
Kotz *et al.* (2024)	14%	33%

Source: NGFS (2024a)

From the studies that include multiple climate hazard indicators, it turns out that all countries, including temperate ones, will be affected from more global warming. These studies also conclude that costs of climate damages largely outweigh the costs of climate action, both on the mitigation as the adaptation front. Still, indicators such as sea-level rise or changes in maritime current patterns are not included in these historical panel data. Even more recent studies start to integrate extreme or tail events and obtain new insights on GDP impacts from climate change. Waidelich et al. 2024 for instance show that including extremes in the projections does not necessarily reduce world GDP further than previous estimates, but that this increases the gap between impacts on richer temperate regions and poorer tropical regions. Since national economies are interconnected through trade and supply chains, they are exposed to climate change in other regions of the world. Including global weather effects in their estimates, Neal et al. 2025 show that damage figures advanced by past authors likely underestimate substantially the interconnectedness between economies.

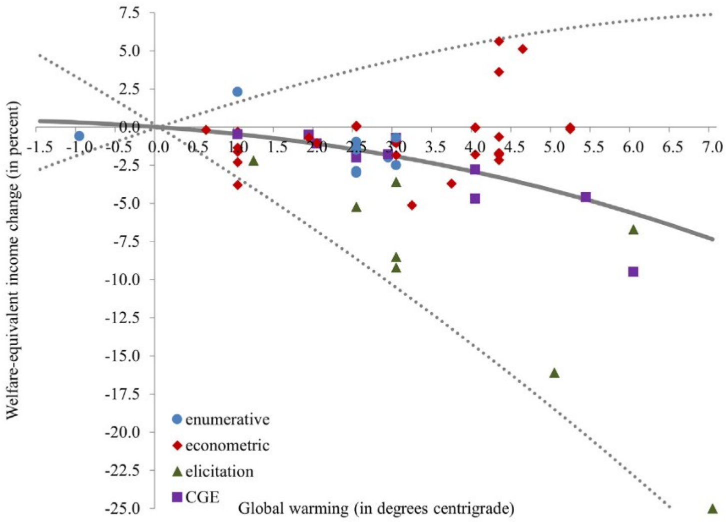
Building on enumeration and econometric estimates, researchers have started simulating climate effects in macroeconomic models. These are known as Integrated Assessment Models (IAMs) and combine climate science modelling (linking the occurrence of hazards and global warming) and economic activity modelling, usually Computable General Equilibrium models (CGE). Back in 2006, the Stern Review advanced monetary costing of climate change impacts with IAM's of potentially various percentages of GDP depending on warming scenarios (Stern, 2006). The most advanced and ambitious work in this field is conducted by the Network for Greening the Financial System (NGFS).[9] In their most recent long-term scenarios they base their modelling on the Kotz et al. 2024 econometric estimates and report losses of up to 15% of world GDP by 2050 under current climate action policies (NGFS, 2024b). Other

9 The Network of Central Banks and Supervisors for Greening the Financial System (NGFS) was launched in Paris in 2017 and groups voluntary Central Banks and Supervisors for the sharing of best practices with regards to environment and climate risk management. The network has over 140 members from 90 different countries, is chaired by the Vice-President of the Deutsche Bundesbank, and the secretariat is hosted by the Banque de France. The National Bank of Belgium is a member.

ambitious modelling works worth mentioning are carried out by EU funded consortiums COACCH[10] and its follow-up project ACCREU.[11]

In 2024, Richard Tol published a meta-analysis gathering most of the studies that propose estimates for economic damages per degree of global warming. As can be seen from **Graph 2**, the meta-analysis highlights the wide heterogeneity of estimates for global economic activity damages, indicating vast uncertainties. This is even more true when regional and national impacts are analysed in more details. Indeed, estimates of damage functions vary according to methods used, regions considered, hazard indicators included, etc. Yet, we have seen that, overall, the value of estimates has increased in line with growing knowledge and number of hazards considered.

Graph 2 Meta-analysis of global income change estimates for global warming levels from Tol (2024)



Note:
- Enumerative refers to estimates built with a bottom-up enumeration of physical effects of climate change, econometric refers to estimates obtained with econometric techniques, elicitation refers to expert assessments often gathered through surveying methods and CGE refers to macroeconomic modellings.
- Income measured by GDP is taken as a proxy for welfare by Tol.
- The central, solid line is the Bayesian model average, the dashed lines the central estimate plus or minus twice the estimated standard deviation.

Source: Tol, R. S. J. (2024)

2.3 Specific research on the Belgian case

A handful of studies have tackled the question of the cost of climate change for Belgium specifically. In the early 2010s, the first regional studies have been carried out for Flanders (Technum, 2012) and for Wallonia (ICEDD, 2014). In a 2016 study about the transition costs of the Belgium economy towards decarbonization, we find a brief mention of the need to study the impacts of climate non-action although it remains out of its scope (Climact et al., 2016). In 2020, a consortium led by Vito, EcoRes and Kenter published a deeper analysis on the socio-economic impacts of climate change in Belgium (Vito et al, 2020). This extensive research provides a bottom-up analysis of likely impacts of climate change on a sectoral basis, including physical economic impacts and human casualties. The paper summarizes

10 CO-designing the Assessment of Climate CHange costs
11 Assessing Climate Change Risk in EUrope

and discusses the findings of a large number of specialized studies and offers first coarse orders of magnitude (Vito et al., 2020). In this study, the most important drivers of losses from climate change are decreased labour productivity, followed by transboundary effects of reduced trade, by infrastructure damage from floods and heat, and by damage to sectors heavily dependent on the state of ecosystems such as agriculture, forestry and water. As it is based on a bottom-up qualitative study and does not rely on economic modelling, the study does not include second-order effects on the economy – which, according to some authors, can double the cost assessment.

In terms of quantitative research on the impacts of climate change, some damage functions feature detailed estimates for Belgium. The studies of Kahn et al. 2019 and Kotz et al. 2024 for instance, discussed later in this document, provide econometric damage estimates for global climate change scenarios scaled down for the Belgian local climate projections. Albeit the damage estimate is not country-specific, its projection is done with country-specific climatic factors. A recent study directed by the National Bank of Belgium (NBB) draws an analysis of the various channels through which climate change affects productivity function factors: capital stock, labour supply and Total Factor Productivity and innovation (Bijnens et al., 2024). The study concludes that physical impacts are expected to have negative effects on productivity overall and increase growth differentials between southern and northern European regions. Significant reallocation of capital and labour within and across sectors is to be expected as well as question marks on future green tech innovation efficiency. The NBB study itself bases its figures on a Deutsche Bundesbank article in which it appears that from historical data, the effect of temperature increase in Belgium has had no substantial effect on GDP growth yet (Deutsche Bundesbank, 2022). The article estimates that the impact of the 2.2°C changes in the average annual temperature between 1960 and 2020 in Belgium on annual GDP growth rate is of -0.25 percentage points in 2020, with a confidence interval of -1 to +0.5 percentage points. The Joint Research Centre of the European Commission has conducted detailed sectoral analysis of impacts of climate change on Members States. The fourth release of this PESETA research cycle provides cost estimates for various damages and sectors for different warming scenarios at a national and sometimes NUTS 2 geographical level, including for Belgium. A preliminary study of the fifth release on labour productivity is already available, showing 0 to 1 % of losses in productivity levels for Belgium by mid-century (Szewczyk, et al., 2021). Finally, a study by reinsurer Swiss Re builds on earlier works of the World Bank and proposes figures for GDP loss by mid-century that try to account for so-called “unknown unknowns” such as supply chain disruptions, migration, biodiversity losses, tail risks etc. by multiplying loss estimates by factors 5 or 10. Doing so, they obtain GDP losses of 3 to 9% for Belgium by mid-century (Swiss Re Institute, 2021).

With regards to historical information about acute events or climate disasters, two databases stand out as more reliable sources than other existing ones.[12] First, the Emergency Events Database EM-DAT[13] jointly operated by the Centre for Research on the Epidemiology of Disasters (CRED) from UCLouvain and the World Health Organization (WHO). Second, the online climate disaster monitor[14] released by Assuralia early 2025.

12 Other existing public databases with figures for Belgium include Climate-Adapt, the JRC Risk Data Hub or European datapoints from COACCH and CLIMADA. NatCatSERVICE and SIGMA databases by Munich RE and Swiss Re are referred to as reliable but are not publicly accessible

13 Access through https://www.emdat.be/

14 Access through https://www.assuralia.be/nl/klimaatschademonitor

2.4 Climate change and public finances

Some research addresses questions around the consequences of physical damage of climate change for fiscal variables, i.e. public revenues, expenditure, primary balance or debt trajectories. This is referred to as macro-fiscal impacts.

Amongst them, an IMF study that describes how climate change affects public finances. *"In the absence of active policy, the effect of climate on GDP can affect government finances as automatic stabilizers operate. Extreme weather shocks, like floods, can also hinder daily public operations by preventing government workers to go to work or by impairing public infrastructure. Alternatively, fiscal policy may respond actively to weather shocks to provide support, foster recovery, or address fiscal sustainability issues"* (Akyapi, et al., 2022, p. 27). Overall, the document concludes that revenues-to-GDP ratio's may be both impacted positively or negatively by extreme weather events, depending on whether the sectors most affected are below or above average taxation levels. The expenditures-to-GDP ratios are expected to increase in countries with counter-cyclical fiscal policy, automatic stabilizers and social transfers to compensate for adverse weather shocks. They also note that the effects on the terms of trade, through exchange rate changes, may be substantial, especially for open economies.

The 2024 Ageing Report of the European Commission warns for the interplay between aging of the population and climate change, and points towards health issues as a potential risk multiplier for public finances (European Commission, 2024). A 2025 Bruegel paper underscores the "*significant risks to sovereign debt sustainability, particularly under high climate damages, that are large from mid-century*" (Calcaterra, et al., 2025, p. 1). The important argument made in this study is that under climate adverse scenarios, primary balance containment and debt stabilization proves challenging. As a consequence, maintaining current levels of public spending through borrowing appears "unrealistic", and adjustments appear to be unavoidable. Adaptation financing, both public and private, is suggested as having a small positive effect on debt sustainability without being a silver bullet. The paper concludes stating that *"there can be no public finance sustainability without environmental sustainability."* More fundamentally, a paper by think tank Dezernat Zukunft stresses the importance to include assumptions on climate damages in debt sustainability assessments that, in most of the cases, do not explicitly account for climate in their growth projections (Ziesemer et al., 2025).

These findings echo a 2022 debt sustainability stress test conducted by the European Commission for extreme weather events. This exercise emphasised *"the relevance of implementing large-scale, rapid, and immediate climate mitigation and adaptation measures to dampen the adverse economic and fiscal impacts of potentially more frequent and intense extreme events"* (European Commission, 2022, p. 6). Recognizing that acute climate shocks have short-term adverse economic effects, the medium and long-term path can possibly be characterized by creative destruction, recovery to trend or no recovery at all, adding to the debate of permanent effect of climate events on GDP. The stress test applies historic worst case extreme events to future mid-term debt trajectories of members states multiplied by factor increases for different warming scenarios. In the case of Belgium, the study assesses the one-off direct negative fiscal shock of an acute event at around 0.5% of GDP. In the medium term, such a shock would increase the debt-to-GDP ratio by around 1%. The worst-case climate event for Belgium, on which the assessment is based, is the 1990 storms that were valued at a cost of 0.5% of GDP. Since then, the 2021 flood disaster in Wallonia has become the costliest climatic event in the country's history. Its direct and indirect costs have been estimated at close to 5.2 billion euros, mainly from infrastructure and housing damages as well as disrupted economic activity from companies (Wallonie Commissariat spécial à la Reconstruction, 2022). Insured losses have been between 1.9 and 2.3 billion euros according to EM-DAT and Assuralia.[15] Public support through the calamity fund and a specific agreement with insurers on the ceiling of interventions of insurance schemes has amounted to over 1.7 billion euros in the aftermath of the floods.[16] Various financing sources for the Walloon region have been pooled to face the situation. These include redirected spending programmes as well as loans from the federal government and the European Investment Bank.

15 Insured and uninsured losses EM-DAT database and Assuralia climate damage monitor
16 Current estimate from internal data Federal Planning Bureau

3. Methodological framework

3.1 Research question

This paper addresses the question: *"What are the long-term costs to the economy and public finances of the physical impacts of climate change in Belgium?"* By *long-term*, we refer to the period from mid-century to 2070. By *costs to the economy*, we mean the change in economic output compared to a baseline scenario. By *costs to public finances*, we refer to both the direct expenditures in response to acute physical events and the indirect changes in aggregate revenues and expenditures resulting from chronic climate-induced changes in economic output. *Physical impacts of climate change* refer to the effects of climate change on physical capital, productivity and agriculture.[17] We leave impacts on human health out of scope of our study, as well as other geopolitical aspects such as migrations, global security, etc. These effects can stem from both chronic shifts in climate patterns—such as changes in temperature, precipitation and sea-levels—due to rising atmospheric carbon concentrations, and acute extreme events triggered by those concentrations. In Belgium, these acute physical impacts primarily include floods, storms, heavy precipitation, and droughts.

The aim of this paper is to provide estimates of the *cost of inaction* about climate change. This is the economic cost of physical damage in a scenario where no additional adaptation or mitigation measures are implemented domestically during the climate transition. This cost of inaction can then be compared with adaptation and mitigation expenditures, allowing policymakers to assess the most economically sound course of action.

3.2 A simple modelling approach

We build a small computing model inspired by the works of the IMF (Q-CRAFT model) for illustrating chronic damage curves' effects on output and public finances. For acute climate damages, we provide an analysis of historical data and NGFS orders of magnitude for the future. This simple modelling approach applied to various scenarios allows us to discuss possible future projections in a clear and structured way. More complex dynamic macroeconomic modelling may be useful in future stages when developments would allow it. At least three major uncertainties pervade the question we seek to address and are discussed in section 2.1: climate uncertainty, uncertainty about transmission channels to the economy and climate policy uncertainties.

In our analysis, climate uncertainty is approached with the use of scenarios. We provide economic cost appraisals of physical impact under multiple global warming scenarios. These scenarios are expressed in Global Warming Levels (GWL) and Representative Concentration Pathways (RCP). This is the recognized standard in climate science to express carbon concentrations in the atmosphere and their related temperature warming levels by the end of the century.[18] In our analysis, we take over the names of

17 Definition taken from the NGFS, accessible through their online glossary https://www.ngfs.net/ngfs-scenarios-portal/glossary/ - physicalrisks.

18 All scenarios are imagined for a shared socioeconomic pathway 2 (SSP), describing "a future that continues on current trajectories, with moderate economic growth, technological development, and environmental awareness." Except for the Kahn values for RCP 2.6 showed in the Appendix which are imagined in a SSP1 situation that "envisions a world making significant efforts toward sustainability, with low inequality, green energy, and sustainable economic practices." For more

scenarios as given in the studies and tools we take them from. For a full description of the scenario philosophies, we refer to Appendix A.3.

Uncertainty about transmission channels is mitigated for chronic costs appraisal by relying on two reference damage curves. These are the Q-CRAFT adapted curves of Kahn and the NGFS adapted curves of Kotz. For reasons set out in section 4.2, we choose to discuss the NGFS adapted Kotz curves in section 4.1 while the Kahn curves are detailed in Appendix A.6. When it comes to acute damage costs, we provide a qualitative discussion of challenges for future projections.

Detailed equations used in our modelling can be found in Appendix A.4. The main philosophy being the projection of a baseline trajectory, the establishment of climate change scenario variations and finally the computation of the cost for public finances:

- **Baseline scenario:** employment, labour productivity, inflation and average interest rate on public debt are exogenous. Primary balance trajectories are taken from the national medium-term fiscal-structural plan until 2029 and deemed constant after that, leading to a decreasing debt ratio in line with the long run 60% objective of the Stability and Growth Pact. Government revenue-to-GDP ratio is assumed to be constant, while primary expenditure is the difference with the primary balance. Public debt is computed in the absence of stock-flow adjustments. Since the reference growth projections do not explicitly model for climate change impact, the underlying climate scenario is undetermined, which enables us to qualify it of “continuation of present warming trends” for the Kahn/Q-CRAFT scenarios and of “keeping constant the global warming attained today” for the Kotz/NGFS scenarios.
- **Climate change variations scenarios:** baseline labour productivity is modified by subtracting damage parameters each year from the two reference damage curves. We assume that the damage parameter applied to labour productivity encapsulates the different transmission channels of climate change since labour productivity also includes total factor productivity and capital deepening. Revenues have a unitary elasticity with respect to the size of the economy, while primary expenditures are adjusting with an expenditure rigidity parameter of 0.5. The interest-growth differential for the debt ratio computation is assumed to be constant.
- **Cost for public finances**: we discuss the cost for public finances in two ways. First, by looking at the difference in debt levels between baseline and climate variation scenarios. These debt levels differ because of modified revenues from output change and partly unchanged government expenditure levels (see rigidity above). Second, by looking at the primary balance adjustment that is necessary to maintain identical debt ratio projections as in the baseline. This leads to a sort of tax gap to be filled with either new revenues, expenditure cuts or a mix of both.

We approach climate policy uncertainty with the following assumptions:

- Global mitigation policy trends are reflected in the different global warming scenarios. Belgian mitigation policy is not explicitly modelled as Belgium’s efforts do not curb global trends. In short, we assume that Belgium is a “global warming taker” with relation to other nations. This does not mean

information see https://earth.gov/sealevel/faq/124/what-are-shared-socioeconomic-pathways-or-ssps/#:~:text=Shared%20Socioeconomic%20Pathways%20(SSPs)%20are,gas%20emissions%20and%20climate%20change that Belgium shall not mitigate, but only that its mitigation policy is not significantly relevant to our modelling since it occurs at no budgetary costs.

– In our model, we assume that there are no further adaptation efforts in. However, it is likely that both pro-active adaptation efforts and organic change in the economic structure and activity will arise over time as physical impacts of climate change materialize. This mechanism is also related to transmission channels' uncertainty and is central to the discussion around pervasiveness of the effects of climate change.

Finally, we follow the recommendation of the NGFS not to sum up chronic and acute damage estimates. Indeed, because of their likely areas of overlap it is considered that there is non-additionality: "*users are advised to not simply sum up estimates of chronic and acute physical risks, because of an increased risk of overlap given the wider scope of climate variables considered in the aggregate damage function*."[19]

[19] FAQ of NGFS Phase V release, accessed online through: https://www.ngfs.net/ngfs-scenarios-portal/faq/

4. Analysis of long-term physical impact costs

In this section, we discuss the chronic and acute damage costs for various warming scenarios as described in section 3. We stress that these estimates are only rough appraisals – the best we can provide based on existing data and uncertainties. We advise using these estimates as possible orders of magnitude rather than as projections.

4.1 Chronic damages from NGFS adapted Kotz estimates

We rely on the damage estimates computed by Kotz et al. (2024) and used by the NGFS in their Phase V long-term climate scenario exercise. The damage curves are obtained using fixed-effects panel regressions of more than 1600 regions worldwide over 40 years (1979-2019). For Belgium, three different regions are considered: Brussels Capital Region, Flanders and Wallonia. The authors compare income changes based on average temperature changes, temperature variability, total annual precipitation, annual number of wet days and extreme daily rainfall. Effects of climate variables on economic activity were found to increase by half when accounting for variability and regional heterogeneity/local climatic conditions. Based on their estimates, they find that damages have lagging effects on income for at least 8-10 years (mix of level and growth effect, i.e. both temperature change and level have impacts on growth). Besides including these persistent – but not temporary effects - they also find that spatial spillovers of climate damage to neighbouring regions amplify the physical impacts and the heterogeneity of how regions are affected. Based on their estimates, the authors project future impacts on GDP for various climate scenarios. This damage curve is one of the most comprehensive in terms of the climate effects it measures (metrics of both mean and variability changes of temperature and precipitation) as well as in terms of regional heterogeneity currently available in academic literature. These estimates, however, do not comprise the impacts of sea-level rise, cyclones, heatwaves, potential climate system tipping points or effects on human health.

The NGFS modelling using the Kotz estimates is a complex combination of various models, a so-called "suite-of-model approach" (NGFS, 2024c). This combines integrated climate-economy models for physical and transition impacts and a macroeconomic model to understand the consequences of transition and physical impacts on macro-financial fundamentals. NGFS gives damage estimates for both physical and transition impacts. In this analysis, we only discuss the estimates for physical impacts.[20]

Adaptations made in the NGFS modelling to the Kotz estimates essentially concern alignments in warming scenarios and scaling to country-specific estimates.[21] They also result from the use of the macroeconomic suite-of-models (see above). In our analysis, we select two scenarios from the NGFS/Kotz values:

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[20] More specifically, the estimates we use are from the modelling results "NGFS v1.24.2[GCAM 6.0 NGFS]"

[21] See for instance in the technical documentation cited earlier: "NGFS uses scenarios of future climate change which do not correspond to the emission forcing scenarios from the SSPS used to drive the CMIP-6 simulations. Therefore it was necessary to derive aggregate damage functions which mapped global mean temperature (GMT) change to national level damages as projected by Kotz et al. (2024), such that these damages could be integrated into the NGFS scenarios [sic]. Subnational percentage reductions in future income were aggregated to the national level with a population weighting using down-scaled SSP population data."

- A **“Below 2°C”** scenario, aligned with the Paris Agreements where global warming stabilizes below 2°C by the end of the century compared to preindustrial periods. This corresponds to the RCP 2.9 and GWL 1.6°C by end century. This corresponds to ambitious climate action compared to the efforts that have been achieved so far and would require a substantial acceleration of mitigation efforts on a global scale. Indeed, current warming is about to reach an average 1.5°C warming above preindustrial levels (Kirchengast & Pichler, 2025).
- A **“Current Policies”** scenario with a close to 3°C warming by the end of the century scenario. This corresponds to the RCP 5.3 and GWL 2.9°C by end century.

The baseline situation in the modelling with the NGFS’s adapted Kotz damage estimates (see Graph 3) refers to a situation of warming levels attained today, in this case understood to be at 1.2°C (NGFS, 2024c). The baseline is then best understood as a “frozen” present situation, where the global warming attained today is set at present temperature. Therefore, we take the view for these estimates that the exogenous growth projection in the baseline does not include considerations of climate change.

In the case of the Below 2°C scenario, we picture a more ambitious scenario than current climate action, and in the case of the Current Policies scenario, the warming trajectory is roughly in line with a continuation of present policies and emissions.

Impact on GDP and public finances

The impact on GDP level of a Below 2°C scenario compared to present warming as a baseline steadily rises to a 2.8% loss of GDP by mid-century. In the case of a continuation of Current Policies, putting us on the path of a 3°C global warming at the end of the century, the loss reaches over 5% of GDP by 2050.

The effects on the public debt trajectory of Belgium are substantial. In the Below 2°C scenario, the debt trajectory starts diverging from the baseline around 2033 and remains above the 100% threshold by 2050, while it decreases to 90% in the baseline. In the Current Policies scenario, the debt diverges even more and rises sharply from around 100% in 2040 to 105% by 2050 and remains on an exponential path. Debt stabilization in this case is out of sight as climate damage is expected to continue rising beyond 2050, affecting public revenues through a reduced GDP.

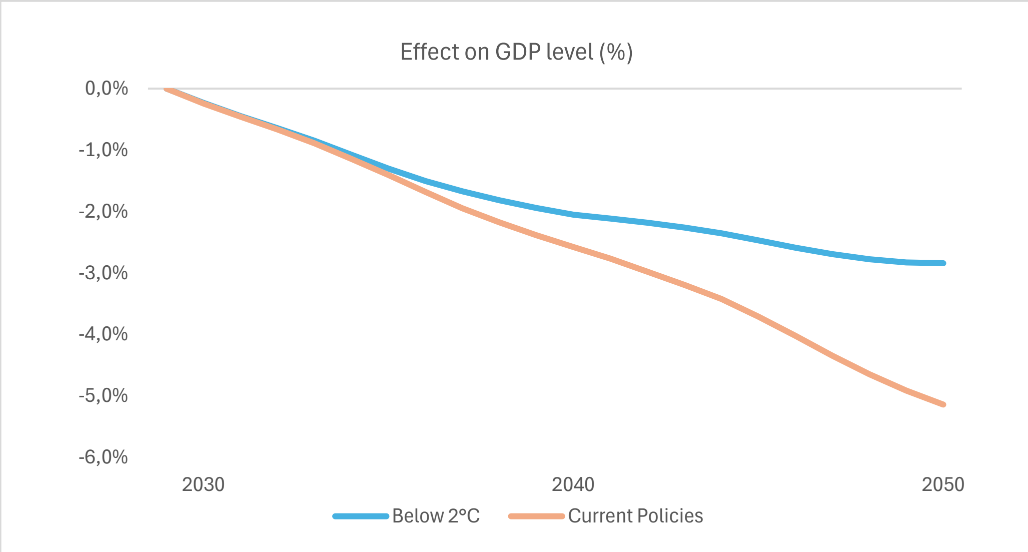
In order to keep the debt levels on a similar path than in the baseline, the tax gap in the Below 2°C scenario rises each year to reach 0.7% of GDP by mid-century, while in the Current Policies scenario it reaches 1.4% of GDP by 2050. This means that the reduced economic output, and the relative rigidity of expenditures, demands from the government to find an additional 0.7 to1.4% of GDP of additional revenues or reduced expenditures in order to keep the debt on its baseline trajectory.

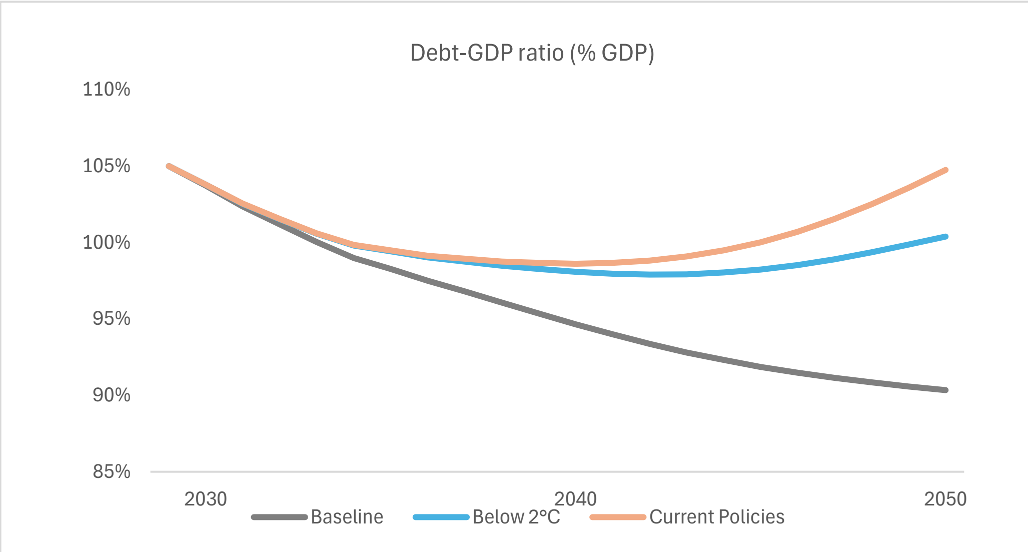
Beyond 2050, the damages of modified temperature and precipitation averages and variability identified by Kotz et al. continue to increase. Under highly adverse climate scenarios, ensuring debt sustainability appears highly complex. This echoes the conclusion of the Bruegel paper mentioned in section 2.4, stating that debt sustainability risks in high climate damage scenarios become *“infeasible”* from mid-century on, and stressing that there may be no public finance stability without environmental sustainability (Calcaterra et al., 2025).

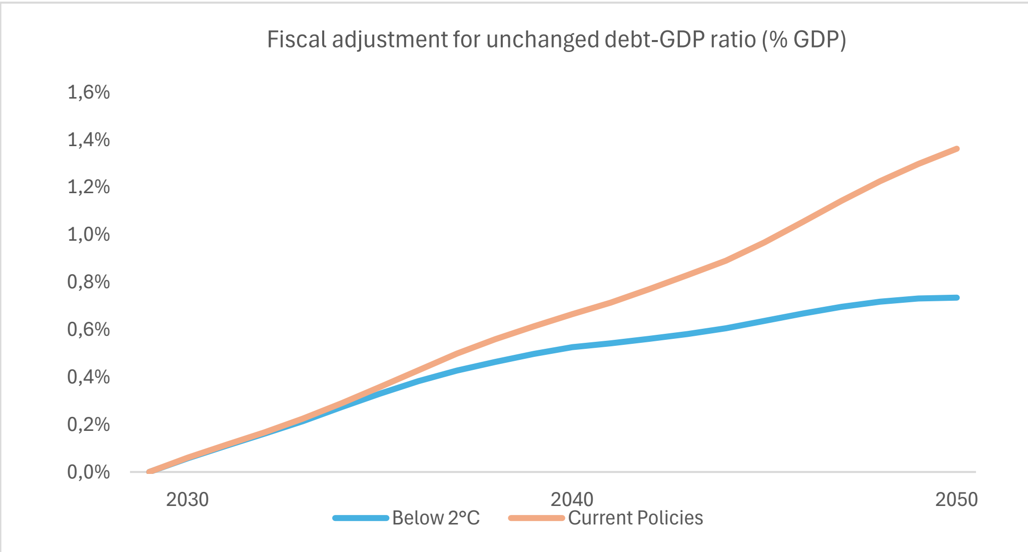
In highly climate adverse scenarios, the assumption of a constant interest-growth differential in our model may also prove less realistic. Indeed, due to the high uncertainties and risk levels, interest rates may surge in line with the risks. This could put a stress on the public sector when finding funding sources with a reasonable cost of debt, and this may reduce investments necessary for long-term growth of the economy by raising the cost of private debt and the cost of capital.

To sum up, NGFS adapted Kotz estimates for physical damages to the Belgian economy range from 2.8% to 5% GDP loss by 2050 depending on the warming scenario. The baseline in this analysis is a freezing of the warming at current levels. This sets the public debt trajectory on a sharply rising path, possibly exceeding 105% of GDP level by mid-century. Fiscal adjustments necessary to maintain fiscal stability range from 0.7 to 1.4% of GDP by 2050.

Graph 3 Projected costs computed from the NGFS adapted Kotz damage curves for Belgium







Comment: Baseline primary balance trajectories are taken from the national medium-term fiscal-structural plan until 2029 and deemed constant after that, leading to a decreasing debt ratio in line with the long run 60% objective of the Stability and Growth Pact.
Source: FPB modelling

4.2 Critical assessment of the NGFS adapted Kotz estimates

In section 4.1, we have illustrated the long-term physical impacts of chronic climate change on the Belgian economy and public finances resting on the estimates of the Kotz/NGFS modelling.

As has been outlined extensively in chapter 2, the academic literature around damage estimates is in swift development due to the wide array of uncertainties faced by researchers. On a regular basis, new studies are published (especially econometric regressions) to establish more refined links between various climate variables and economic output.

The Kotz et al. 2024 study was used in the NGFS Phase V modelling exercise and is seen as authoritative. To date, it is the study that stands out as being the most comprehensive amongst damage functions as it captures:

– climate indicators with more detail. The Kahn study looks at two climate indicators being variations of temperature and precipitation mean levels, while the Kotz study looks at five climate indicators by also including variations in variability. Importantly, it appears that this variation in variability is the biggest drivers of damages in Kotz.
– subnational effects such as inter-regional spillovers. Kotz looks at past trends in 1660 regions worldwide from 83 different countries, while Kahn looks at 174 countries.

Yet, it has faced some methodological criticisms. Amongst other things, debates exist on errors in the datasets used in the regressions and the choice of a wide array of variables and their interaction in the econometric specifications for which it appears difficult to make sense (Hopper, 2024 and Tol, 2025). Some of these errors have been reviewed by the authors (PIK, 2025). A reassessment and correction of the article is currently ongoing according to the editorial processes of Nature in which the original article was published. To account for these evolving debates and methodological choices in the literature that illustrate the significant uncertainties involved in these exercises, we nevertheless complement the projections in chapter 4.1 with projections with damage estimates by Kahn et al. 2021 used in the IMF Q-CRAFT tool in Appendix A.6.

Both studies are insightful but not directly comparable. Indeed, the econometric specifications of the studies are such that they answer slightly different questions, not least because they compare cost of chronic damages to a different baseline situation. The study by Kotz et al. is designed to *identify the cost of climate change compared to current climate conditions and growth*. The study by Kahn et al. is designed to *identify the cost of additional climate change compared to current path of climate change and growth*. This difference in specifications is laid out in more detail in Appendix A.5.

The methodological differences (number of variables, regional scoping, econometric specification, fixed or evolving baseline) unsurprisingly yield different figures. Depending on the angle under which the question of physical costs of chronic climate change is studied, the magnitude of damages will differ. Our two damage curves illustrate this: the Kahn/Q-CRAFT estimates range from 0.2% to 1% of GDP loss in worsening climate scenarios compared to several percentages in the Kotz/NGFS estimates.

However, both damage curves, even if providing different orders of magnitude, point towards the same direction, being that impacts are negative and become substantial already before mid-century. Given the large number of parameters that are not yet taken into account (sea-level rises, tail events, tipping points), it is more than likely that these figures are underestimations of the future economic impacts of climate change. This is without mentioning other hardly monetizable damages that are out of scope of this analysis, notably biodiversity loss, health and other social impacts.

Since none of these studies is perfectly satisfactory, we choose to use the Kotz et al. 2024 estimates in section 4.1 for their comprehensiveness, provided that the outcome of our projections is handled with due prudence. This report is a first assessment of its kind for Belgium, and subsequent updates in coming years with possibly other damage curve choices will be welcome.

Finally, one must keep in mind that for systemic transformations like climate change, economic modelling based on past econometric relationships will always carry imperfections. Indeed, the structural changes that systemic transformations in the economy bring about can only be approximated to a certain extent. This highlights the need to look beyond aggregate econometric analyses and explore the transmission channels between climate and the economy in greater detail. This also pleads for analyses that look to other indicators of well-being than output alone.

4.3 Acute damages

For acute damage costs, we rely on historical datasets of disasters from EM-DAT. We provide a descriptive analysis of the disasters from 1975 to 2025 for Belgium individually and for Western Europe (Benelux, France and Germany). In the latter part of the section, we discuss qualitatively why making projections of the future acute damage appears extremely complex.

Historical data for Belgium and Western Europe

From the EM-DAT dataset that covers a wide range of disasters, we only select droughts, wildfires, storms, floods and extreme temperature events as they represent acute climate events. Earthquakes were not selected neither were avalanches reported in France or Germany as they are not expected to occur on Belgium’s topography.

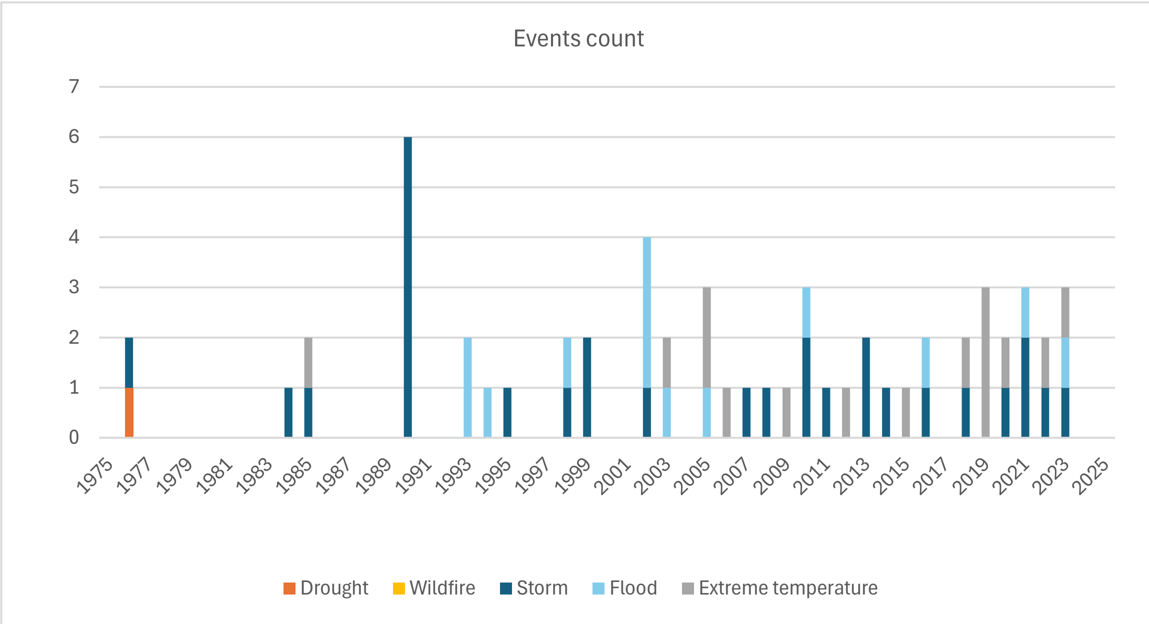
Historical acute events as reported in EM-DAT are shown in constant prices in Graph 4 and Graph 5 respectively for Belgium and for Western Europe (Benelux, France and Germany) between 1975 and 2025.

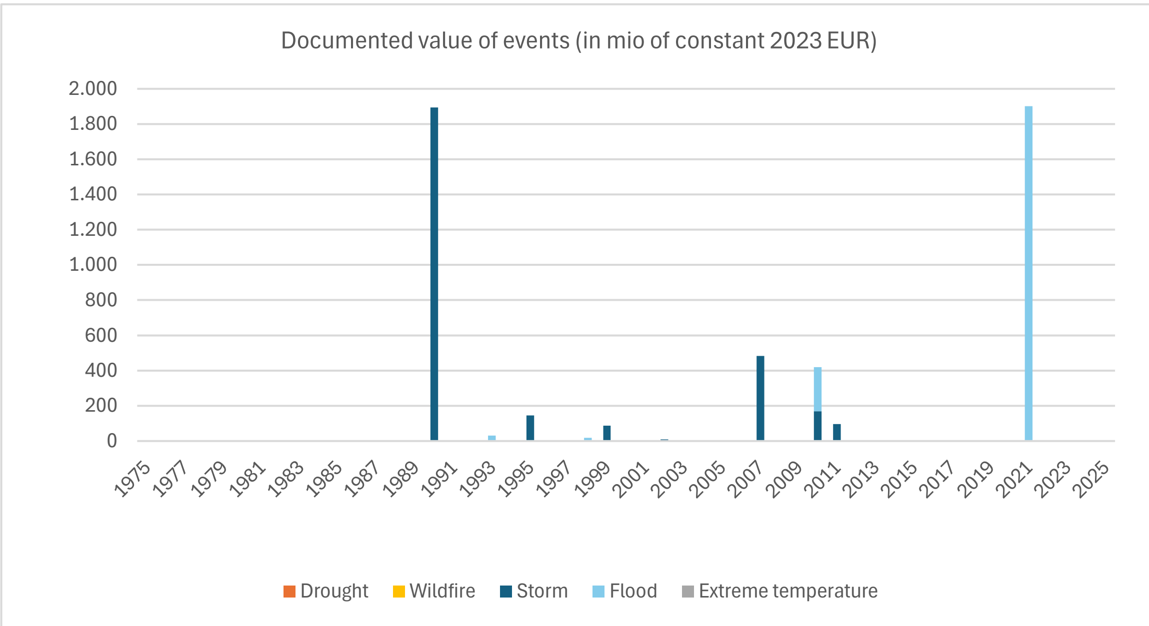
There has been a total of 58 reported acute climate events in Belgium over last half century. From 1975 to 2000, this was an average of 0.76 events a year, while this has increased to an average of 1.56 in the period from 2000 to 2025. The most reported disasters are storms that occur more than once every two years (0.64 times a year). This is followed by flood events and extreme temperature events that have been reported substantially more in the last 25 years, during which their average occurrence has been respectively 0.36 and 0.56 events a year.

A value for the damages of the event entries has been documented for only about a third (18 out of 58) of these events. Two important events stand out in terms of value: the storms in 1990 and the floods of 2021, each of them reported to cause direct damages of around 1.9 billion euros.[22] The average documented cost per event over the 50-year period was 288 million euros when these outliers are taken into consideration and 124 million euros otherwise. The total costs have been 34% higher in the period since 2000 than in the 25 years before. The annual documented costs over the last 25 years have been 116 million euros on average.

[22] While numbers mentioned in section 2.4 comprise both direct and indirect costs

Graph 4 Historical acute climate events in Belgium from 1975 to 2025





Source: EM-DAT and currency conversion from the author

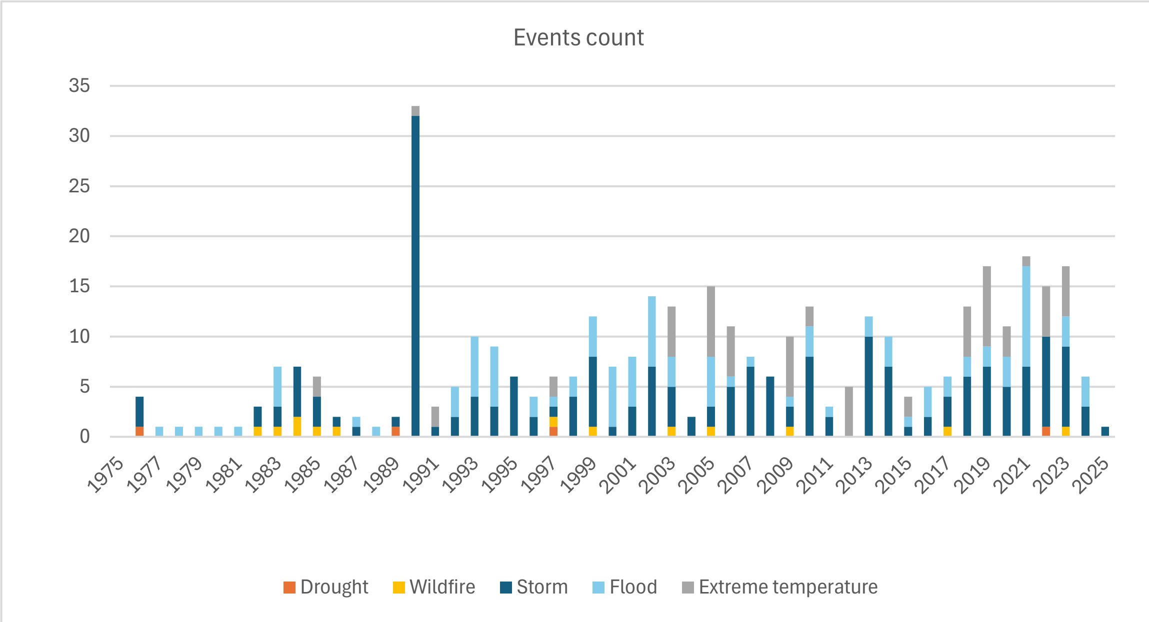
Across the selected Western European countries (Benelux, Germany and France), a total of 383 acute climate events has been reported over last half century.[23] From 1975 to 2000, the average was 5.3 events per year, while this figure increased to an average of 10 in the period between 2000 and 2025. Similar to Belgium, the most frequently reported disasters in Western European countries are storms followed by floods and extreme temperature events. All these categories have increased significantly over the latter half of the period. To give an idea of the scale, Belgium's area of 30 689 square km

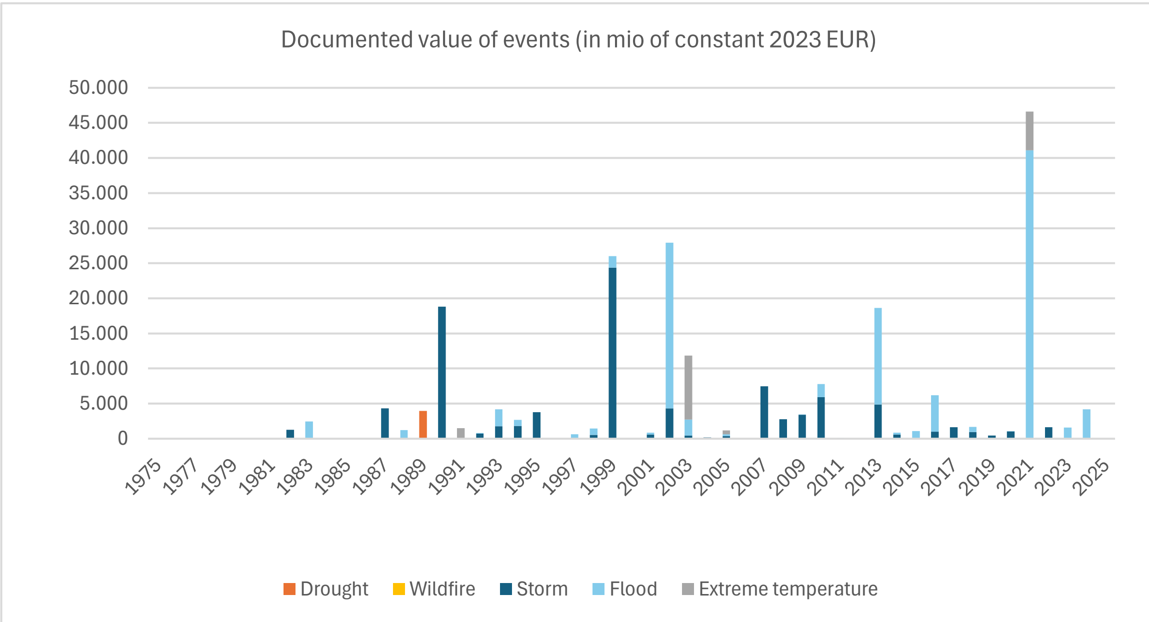
[23] Note that for one single event that has consequences across various countries, the sample has at least one different entry per country

represents around 3% of the aggregate area of 971 174 square km of these countries. This implies that the occurrence of events in Belgium is a bit higher than a simple ratio of its size. Many geographical factors may explain this (cfr. next section). It shall also be noted that differences in reporting amongst countries and over time may contribute to the gaps between the relative figures of Belgium and Western Europe and over time.

In the case of Western European countries, more than two thirds of the entries have documented costs (255 out of 383). As is the case for Belgium, most of the costs are related to floods (with important occurrences in different parts of Europe in 2021, notably in Germany, as well as in 2002). These are closely followed by the costs related to storms, with various important events affecting all the countries of the region in 1999 and 1990. The average documented cost per event over the period was 1470 million euros (1018 million euros in the period 1975-2000 and 1737 million euros in the period since 2000). The annual documented costs over the last 25 years have been 5968 million euros on average, 2% of which were reported in Belgium. As in the case of Belgian data, drought and wildfire events mostly do not have documented damage values in the EM-DAT databases.

Graph 5 Historical acute climate events in Western Europe from 1975 to 2025





Source: EM-DAT and currency conversion from the author

Challenges for projecting acute event costs in Belgium

Based on current data availability, it is hazardous to project future acute event costs for Belgium and public finances for a series of reasons: the limited availability of reliable data, the difficulty to assess the suitable geographical scope for analysis of erratic acute hazards, the uncertainty around multiplier effects and question marks around the role of public finances in damage recovery.

First, EM-DAT historical figures for Belgium are unfortunately not sufficient to provide statistically significant estimates of expected damage values of acute hazards. The limited number of entries over the last 50 years, and the important diversity in types and size of acute hazards (with two major outliers being the 1990 storms and the 2021 floods) make any attempt to project future trends hazardous. Furthermore, most of the entries do not have assigned economic damage values. This is generally the case for disasters with lesser impacts. EM-DAT's technical notes acknowledges that economic damage values are generally only reported for high impact disasters (EM-DAT, 2025a). Additionally, the criteria for inclusion of acute events into a dataset bear consequences for the analysis. Indeed, different datasets use different threshold criteria for including or not including a natural disaster or an acute event in their sample. In the case of EM-DAT, the criteria are at least ten deaths, a hundred affected persons, a call for international assistance or an emergency declaration (EM-DAT, 2025b). In other databases, for instance the Assuralia disaster monitor that reports on the last ten years, we find many more entries, including events with more limited assigned costs, e.g. 10 million euros of damages. The difficulty then is to attribute these more contained events to climate change as such.

Second, determining the suitable geographical scope for extracting tendencies and estimates proves challenging. To increase sample size and reduce the impact of the erratic nature of hazards in historical data, the reliance on historical data of a wider geographical region, such as the selected Western European countries is an option. This however brings other difficulties when projecting future acute damage. Various scaling factors may be suited depending on peculiar hazards at stake. As the size of economic damages are related to the pre-disaster state of the economy, scaling damages according to GDP matters. Often, important acute hazards do affect various countries of the same region. This is the case for storms or floods following heavy precipitations for instance. The average cost of particular acute events therefore tends to be higher in larger countries, as most of the consequences of an event will be located within their borders. For this reason, other scaling factors such as territorial area, length of the coastline for storms, topography of drainage basins for floods, availability of underground water resources for droughts, etc. are relevant too.

Third, the choice of a multiplier for acute event frequencies and intensities is key for the projection of damage costs according to different warming scenarios, and this choice influences the projected values greatly. The Intergovernmental Panel on Climate Change (IPCC) provides qualitative assessments of how different acute hazards may develop in Western Europe for 1.5, 2 and 4 °C warming in chapter 11 and its related Appendix of the 6th IPCC Assessment Report (Seneviratne et al., 2021). A recent study by the Royal Meteorological Institute focuses on heavy rain precipitations and shows that for Belgium, the return period for heavy rain precipitation events would increase by 7% for each degree of global warming (Brajkovic et al., 2025). The "myclimatefuture" platform of the VUB proposes multipliers of how much more often one will see acute hazards in his lifetime as compared to a no warming situation. Values are given for different warming scenarios for different world regions, including Europe, and for different hazards.[24] Depending on the warming scenarios chosen and the type of hazard, multipliers range from close to no increase to increases of more than 20x for heatwaves in high warming scenarios for instance. In its 2022 stress test, the EU Commission proposed to use factor increase figures from its PESETA IV research project (Feyen et al., 2020) that do apply directly to economic losses (European Commission, 2022). They propose factor increases in economic losses of x2.3 and x3.4 by mid-century for a 1.5°C and a 2.0°C scenario respectively for Atlantic regions of Europe.

24 Access through https://myclimatefuture.info/

Fourth, the future role of public finances in acute damage recovery is unclear. Important assumptions must be made before projecting any future costs for public finances. We discuss these difficult issues briefly:

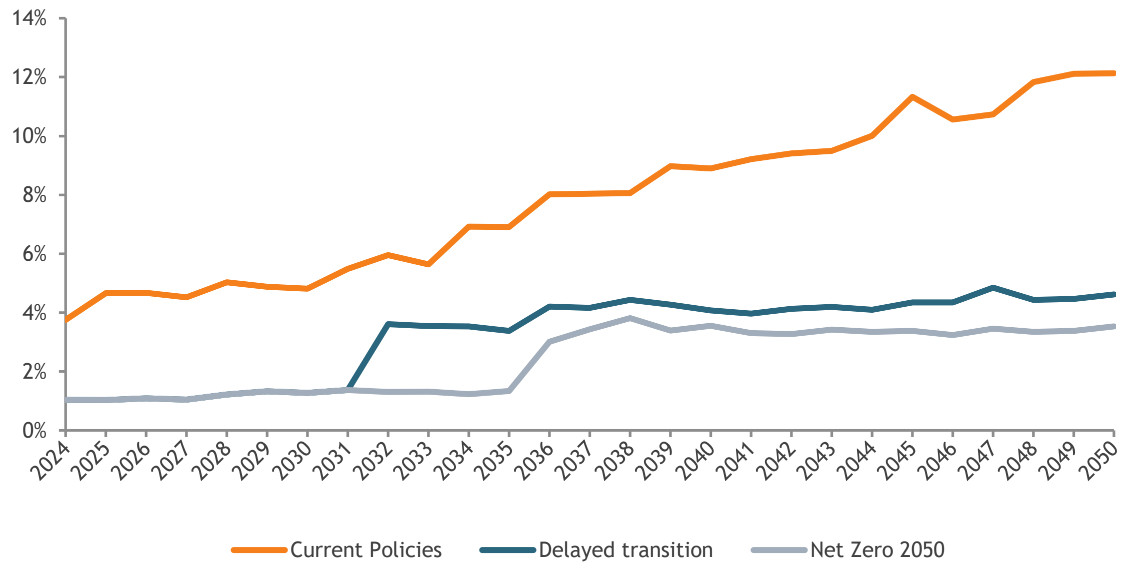
- The share of insured damages in the EM-DAT historical series was around 45% between 1975 and 2000 and about 56% between 2000 and 2025 for Belgium. It is arduous to make assumptions on how this will evolve in the future in a context of increasing systemic risks.
- The share of remaining damage costs to be borne by public expenditures and private companies or households themselves is to be discussed. Typically, guidelines for state intervention are found in legal dispositions. But as we have seen with the 2021 floods in Belgium, when acute events are of exceptional severity, ad hoc dispositions may be needed. When it comes to households, the challenge is that acute damage projections are usually annualized mean cost projections that fail to consider the punctual character of acute events. This means that costs are usually higher or lower than the projected trend depending on how many events occur in a given year. This gives rise to different economic risks such as liquidity crises, where some actors of the economy may be out of funds to face their recovery, although the overall cost of the event to the economy appears limited (European Environment Agency, 2024). Special and unforeseen government support may then be needed. For more on this, a recent paper by the Haut-Commissariat à la Stratégie et au Plan in France provides an in-depth reflection about risk mutualization and possible evolutions of insurance scheme models in the context of the climate crisis (Viennot et al., 2025).
- The share of damages that will not be refunded. After a disaster, not everything can or will likely be rebuilt or will be rebuilt the same way. Needs may evolve, better choices for city planning can be made; one can rebuild in ways that prevent future damages and avoid future costs. For instance, norms for buildings resistance and foundations may be adopted after floods or storms.

Finally, is there anything we can say about future damages from acute events at all? It is fair to state that it is unlikely that future warming will bring economic damages from acute events down. On the contrary, the question is rather by how much they will increase and what should be taken as the baseline.

A possible order of magnitude is given by the NGFS in its Phase IV exercise of 2023. They modelled future acute damages, that likely constitute worst-case scenario estimates. This is because they do not provide mean or median projection values, but 90th percentile values. The way to best interpret these figures is to understand them as a “ceiling” of maximum acute damage exposition on a yearly basis. Average yearly damages should therefore be lower. This is useful because for stochastic acute damages, one shall not rule out a situation where unexpected and low likelihood extreme impacts happen, commanding precautionary policies such as reserves constitutions and prevention measures. This worst-case appraisal is recommended when navigating deep uncertainty, especially as it allows to take appropriate action in preventing most adverse outcomes, a kind of reverse stress testing (Trust, 2025).

From Graph 6, we see that the order of magnitude of maximum worst-case acute climate damages in Belgium may be enormous. It could vary between 1.3 and 5% of GDP by 2030 in highly adverse situations. By 2050, damages may range from 3.5% of GDP loss for a Net Zero 2050 scenario, this is a Paris Agreement compliant scenario, to 12% of GDP loss in a Current Policy scenario. When compared to today’s GDP of roughly 600 billion euros, this represents between 21 and 73 billion euros of damages in 2050.

Graph 6 Maximum yearly cost of extreme acute events for Belgium in % of GDP in NGFS Phase IV



Source: NGFS Phase IV (2023)

5. Conclusion and avenues for further research

We have seen that the economic impacts of the slow onset of climate change through chronic hazards are likely to affect productivity and output in the long run up to various percentages. These impacts will also lead to structural changes in the economy. Extreme climate events, described as acute hazards, are expected to occur more frequently and with greater intensity. The chronically damaged economy has a cascading effect on the sustainability of public finances due to a higher elasticity of tax revenues to economic activity compared to expenditure. On top of that, punctual and potentially large government expenditure may be required for disaster relief following acute events. In the absence of an ambitious adaptation policy and of prudential budgetary measures, the effect on public debt levels could become very burdensome as early as 2040.

As climate change continues to exert both chronic and acute physical impacts, deeper and more granular economic understanding of its transmission channels to the economy becomes highly pertinent. In Belgium's context, further research must evolve along the following critical lines.

For chronic climate impacts, it is necessary to have an ongoing engagement with the fast-evolving academic and institutional literature on damages. New research is rapidly expanding the set of hazards considered, refining empirical calibration, and offering sector-specific insights. When this is possible and models are accessible, Belgium would benefit from more disaggregated modelling, focusing on individual transmission channels—sectoral (e.g. agriculture, infrastructure), regional (e.g. coastal vs. inland), or structural (e.g. labour productivity, capital depreciation, international trade disruptions, interest rates and financial risks). Austria is pioneering such bottom-up approaches in the works of Steininger (Steininger et al., 2016).

Acute events, such as floods or heatwaves, also require greater analytical clarity. Future work should aim to establish more precise baseline damage assumptions, tailored to Belgium's situation, alongside well-founded assumptions on public sector's involvement in recovery expenditures. Developing reliable economic damage multipliers from acute hazards for varied warming scenarios will help calibrate medium-term planning and budgeting procedures. In the same spirit, Belgium needs to map more precisely its climate-related contingent liabilities in order to meet the EU budgetary requirements (cf. Appendix A.1).

Benefits of adaptation measures, such as the avoided economic losses from investments in specific infrastructure, remain an underexplored area in the macro-fiscal literature. The most recent Belgium Country Report of the European Commission mentions first adaptation measures taken by the Belgian governments (European Commission, 2025, Annex 9). But despite these efforts, few studies propose clear and readily usable frameworks for assessing the cost-benefits of adaptation measures and investments. Regional topographical diversity across Belgium complicates macro-level assessments. The shared responsibility of various levels of government (local, regional and federal) on climate adaptation matters renders a bundling of research and implementation efforts even more pressing. This research is paramount for enabling both public and private actors to make intelligent investment decisions. The EU PESETA V project expected to be presented in the fall may yield interesting results in this area.

Lastly, it is important to acknowledge the limitations of modelling in the face of deep uncertainty. Comprehensive, precise macroeconomic assessments may only be feasible many years down the line.

Nevertheless, the sheer size of the potential impacts raises the question of what could be done to reduce them, in particular what mitigation actions at the global level and what adaptation measures at the domestic level have positive cost-benefit ratios.

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Appendix

A.1 Provisions on macro-fiscal risks in the new EU budgetary framework

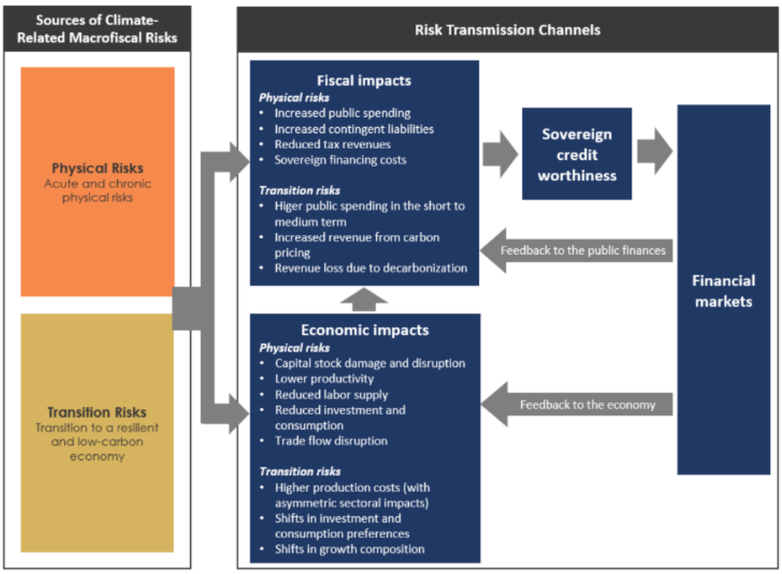
Council Directive (EU) 2024/1265 of April 29th, 2024 amending Directive 2011/85/EU on Requirements for Budgetary Frameworks of the Members States says that:

- Article 9(2): "**National medium-term budgetary frameworks shall include** procedures for establishing the following items:'" (…) "an assessment as to how, in the light of their direct medium-term and long-term impact on general government finances, the **policies envisaged are likely to affect the medium-term and long-term sustainability of the public finances** and sustainable and inclusive growth. To the extent possible, the **assessment shall take into account the macro-fiscal risks from climate change and its environmental and distributional impacts**."
- Article 14(3): "For all sub-sectors of general government, Member States shall publish relevant information on contingent liabilities with potentially large impact on public budgets, including government guarantees, non-performing loans, and liabilities stemming from the operation of public corporations, including the extent thereof. **Member States shall also publish information on disaster and climate-related contingent liabilities to the extent possible. Published information shall, to the extent possible, take into account information on fiscal costs incurred due to disasters and climate-related shocks.** Member States shall publish information on the participation of general government in the capital of private and public corporations in respect of economically significant amounts."

A.2 Transmission channels represented graphically

The EU Commission identifies transmission channels from climate change's physical and transition impacts to the economy. These are broadly similar as the ones identified in academic literature and also put forward by other international organizations such as the IMF or the OECD.

Graph 7 Transmission channels between climate change and the economy and public finances



Source: European Commission presentation at the 4th National Fiscal Frameworks Conference in December 2024

A.3 Scenario descriptions

The selected scenarios for the Kahn damage curve are:[25]

- Paris: based on the SSP1-2.6 IPCC scenario where international commitments from the 2015 Paris summit are met. This scenario assumes significant cuts in emissions, keeping the global temperature increase above its preindustrial level below 2°C at the end of the century.
- Moderate: based on the SSP2-4.5 IPCC scenario. Emissions continue increasing in line with the continuation of present trends and stabilize at the end of the century, with temperature increase similar to the 1960-2014 trend. This scenario assumes that climate mitigation policies continue along the observed trend, but countries do not take more aggressive actions to fulfill their Paris commitments.
- High: based on the high-emissions SSP3-7.0 IPCC scenario. Rather than intensifying climate mitigation efforts, countries start scaling back their implemented policies in a fragmented world with limited energy efficiency improvements and continued use of fossil fuels.
- Hot: emissions are as in the "High" scenario, but it uses the 90th percentile of temperature increases among all climate models that used SSP3-7.0 emissions, instead of the median of temperature projections in this scenario.

The selected scenarios for the Kotz damage curve are:[26]

- Below 2°C: SSP2-2.9, gradually increases the stringency of climate policies, giving a 67% chance of limiting global warming to below 2 °C.
- Current Policies: SSP2-5.3, assumes that only currently implemented policies are preserved, leading to high physical impacts.

A.4. Equations and assumptions for chronic damage costs

Baseline

In our model, figures up to 2070 for employment, labour productivity, inflation and average interest rate on public debt are taken from long-term projections of the 2025 aging report of the Study Committee on Ageing that do not model explicitly for climate change impacts. Therefore, the underlying climate scenario is undetermined, which enables us to qualify it of "continuation of present warming trends" for the Kahn/Q-CRAFT scenarios and of "keeping constant the global warming attained today"[27] for the Kotz/NGFS scenarios. Seen the various uncertainties involved in modelling, we advise using these estimates as possible orders of magnitude rather than as projections.

Primary balance as a percentage of GDP (PB_t, where t stands for the year) is given by the following budgetary rule. Until 2029, PB_t is taken from the national medium-term fiscal-structural plan of Belgium handed in to the EU Commission in March 2025. After 2029, the primary balance is deemed constant,

[25] IMF Q-CRAFT user guide
[26] NGFS Presentation to Phase V long term scenarios
[27] As explained in the technical documentation, in the no climate change baseline, "climate-related losses are assumed to be zero at the start of the period (2020). Thus, it is assumed that the baseline already factors in 1.2 °C of global warming, and losses are experienced over time for any increase compared to this 1.2 °C"

which enables a continuous decrease of the debt ratio towards 60% of GDP in the long run, in line with the European Stability and Growth Pact:

$$PB_t = \begin{cases} \text{MTFSP when } t \leq 2029 \\ PB_{t-1} \text{ when } t > 2029 \end{cases} \tag{1}$$

The government revenue ratio as a percentage of GDP (REV_t) is assumed constant:

$$REV_t = REV_{t-1} \tag{2}$$

Primary expenditure of the government as a percentage of GDP (EXP_t) is computed as the difference:

$$EXP_t = REV_t - PB_t \tag{3}$$

The public debt ratio (D_t) is computed according to the canonical formula and under the assumption of an absence of stock-flow adjustments:

$$D_t = D_{t-1} + \left(D_{t-1} \frac{r_t - g_t}{1 + g_t} - PB_t \right) \tag{4}$$

where r_t is the average nominal interest rate on public debt and g_t is the nominal growth rate of GDP, computed as follows based on employment growth (em_t), labour productivity growth (lp_t), and inflation (π_t):

$$g_t = (1 + em_t)(1 + lp_t)(1 + \pi_t) - 1 \tag{5}$$

Climate change scenarios (from 2030 onwards)

For the climate change scenarios, the labour productivity growth rate lp_t from the baseline scenario is modified by subtracting the damage parameter for Belgium for each year from the selected Q-CRAFT adapted Kahn damage curves or NGFS adapted Kotz damage curve for the selected climate warming scenarios. As is done in Q-CRAFT, we assume that the damage parameter applied to labour productivity encapsulates the different transmission channels of climate change since the labour productivity also includes total factor productivity and capital deepening.[28] Population growth, labour supply and price developments remain unchanged as is done in Q-CRAFT.

The new labour productivity growth rate becomes lp_t^*. The GDP growth rate and its volume level (Y_t) become:

$$g_t^* = (1 + em_t)(1 + lp_t^*)(1 + \pi_t) - 1 = (g_t + 1) \frac{1 + lp_t^*}{1 + lp_t} - 1 \tag{6}$$

$$Y_t^* = Y_{t-1}^* \frac{Y_t}{Y_{t-1}} \frac{1 + lp_t^*}{1 + lp_t} \tag{7}$$

[28] In a classical Cobb-Douglass function, labour productivity is characterized as follows : Y/L = A * (K/L)^α

The new primary expenditure ratio is expressed as follows:

$$EXP_t^* = EXP_t \left(\propto \frac{Y_t^*}{Y_t} + (1-\propto) \right) \tag{8}$$

where ∝ is an expenditure rigidity parameter, i.e. the extent to which expenditures are proportional to GDP evolution in the climate scenario or remain unchanged in values per capita compared to the baseline. The assumption for expenditure rigidity is arbitrary but crucial for the calculated order of magnitude of the impact on public finances. In our case it is set at 0.5 as done in other studies such as OBR (2024). It should be interpreted as the share of public spending that is difficult to modify, whatever the government in place. According to the OBR's line of argument, an appropriate assumption is that roughly half of the public spending is incompressible for ensuring a minimal public service provision and covering investments needs on the long-term (OBR, 2024).

We assume a unitary elasticity between government revenues and GDP. This means that nominal revenues fall one-for-one with the size of the economy. This assumption is shared by Q-CRAFT authors and the OBR. Hence, the primary balance as a percentage of GDP is:

$$PB_t^* = REV_t - EXP_t^* \tag{9}$$

The debt ratio, under the assumption that the interest-growth differential $(r - g)$ remains unchanged from the baseline, becomes:

$$D_t^* = D_{t-1}^* + \left(D_{t-1}^* \frac{r_t - g_t}{1 + g_t^*} - PB_t^* \right) \tag{10}$$

Cost for public finances

A first straightforward way to appraise the fiscal costs of climate change scenarios is the differential between baseline and climate scenario debt levels $D_t^* - D_t$.

Another more tangible way is by computing the primary balance adjustment necessary to maintain the same debt ratio projections as in the baseline scenario. The primary balance adjustment can be understood as a tax gap that needs to be filled by either new revenues or expenditure cuts or a mix of both, so as to maintain the public debt unchanged as a percentage of GDP compared with the baseline. It shall be noted that because of the partial rigidity of government expenditures, part of the tax gap that could occur from an alternative rigidity assumption higher than 0.5 is absorbed by their modified ratio as a percentage of the GDP under the 0.5 assumption. The tax gap as a percentage of GDP is then computed as follows:

$$tax\ gap_t = \left(D_{t-1} \frac{1 + r_t^*}{1 + g_t^*} - D_t \right) - PB_t^* \tag{11}$$

where $r_t^* = r_t + (g_t^* - g_t)$ as the interest-growth differential is kept unchanged as explained above.

A.5. Econometric specifications in Kahn et al. 2021 and Kotz et al. 2024

We explained in section 4.2 of this report that the damage estimates from the Kahn et al. 2021 and the Kotz et al. 2024 studies were not directly comparable for several reasons.

The first straightforward reason (see section 4.2) is the difference in variables considered in the regression (average temperature and precipitation change vs. average and variability temperature and precipitation change) as well as the difference in regional vs. national scope of the geographies chosen in the sample.

The other major methodological reason is the way the question of climate damage is framed in each study, which in turn influences the regression's specification and baseline interpretation in projections:

- Kahn's study answers the question of the *cost of additional warming compared to our current growth and warming trajectory*. In other words, the baseline against which we compare the loss of growth due to warming is the growth under climatic conditions that evolve according to the historical trend observed in each country between 1960 and 2014. In the study, the long-term effect of climate change on growth is clearly defined as the variation from a historical norm: *"long-term impact of climate change on economic activity (...) defined as deviations of temperature and precipitation from their historical norms"* (Kahn et al., 2021, p.1). The econometric specification for identifying damage parameters based on historical data is, in simplified terms, as follows:

$$\Delta y_{it} = \alpha_i + \sum_{l=0}^{4} \varphi_\ell \, \Delta y_{i,t-\ell} + \sum_{l=0}^{4} \beta_\ell \, \Delta x_{i,t-\ell} + \varepsilon_{it} \tag{12}$$

  Where Δy_{it} is the real per capita growth rate for country i and year t, and where $\Delta x_{i,t-\ell}$ are the differences in climatic conditions for country i between year t and the moving average over the previous 30 years. Damage lags of 4 years (the damage caused by climate change in year t has effects for four consecutive years) and autoregressive aspects (second term on the right) which capture fixed growth variations over the last 4 years not related to climate change are also introduced. We note that in this specification, it is the growth rate that is linked to a variation in climate conditions relative to a moving historical norm. However, this norm evolves slowly, over a period of 30 years. In the projections, an extension of historical climate trends by country is taken as the baseline.

- Kotz's study addresses the question of the *cost of global warming compared to our current growth and climatic conditions*. In other words, the baseline against which the loss of growth due to global warming is compared is growth under climatic conditions of today, set at 1.2° C warming compared to the pre-industrial era. Indeed, the study states that *"these projections do not aim to provide a prediction of future economic growth. Instead, they are a projection of the exogenous impact of future climate conditions on the economy relative to the baselines specified by socio-economic projections, based on the plausibly causal relationships inferred by the empirical models and assuming ceteris paribus. Other exogenous factors relevant for the prediction of economic output are purposefully assumed constant"* (Kotz et al., 2024, p.2). The NGFS technical documentation on their modelling based on Kotz-figures goes on to state that *"loss projections are made in comparison to a 'no climate change' baseline, in line with the SSP2 baseline, for which climate-related losses are assumed to be zero at the start of the period (2020). Thus, it is assumed that the baseline already factors in 1.2 ° C of global warming, and losses are experienced over time for any increase compared to this 1.2 ° C"* (NGFS, 2024a, p. 45). The econometric specification for identifying damage parameters is, in simplified terms, as follows:

$$\Delta y_{it} = \alpha_i + \eta_t + \varphi_i y + \sum_{l=0}^{10} (\beta_{\ell,l} \Delta x_{i,t-\ell} + \beta'_{\ell} \Delta x_{i,t-\ell} * x'_i) + \varepsilon_{it} \tag{13}$$

Where Δy_{it} is the real per capita growth rate for region i and year t, and where $\Delta x_{i,t-\ell}$ are the differences in climatic conditions for country i between year t and year t-1. This includes lag effects of damages during 10 years (determined on the basis of goodness-of-fit tests). An interaction between the climatic variables in year t and the 10-year lag and the historical average x' (second part of the sum) is also introduced. The term with the output variable y captures the part of the change in production linked to factors other than climate. In this specification, it is the growth rate that is linked to a variation in climatic conditions from one year to the next. When projecting damage estimates into the future, historical estimates are aggregated and average changes in growth per unit of change in climatic conditions are simulated for warming scenarios relative to a stable baseline, i.e. today's conditions (1.2° C).

A.6. Chronic damages from Q-CRAFT's adapted Kahn estimates

In this Appendix section, we rely on the damage estimates computed by Kahn et al. in their 2019 IMF paper published in *Energy Economics* in 2021 and updated by the IMF for their climate damage modelling tool Q-CRAFT. The damage curves are obtained from panel regressions linking GDP changes with temperature and precipitation deviations from their 30-year rolling average values between 1960 and 2014 for 174 countries. Belgium is one of them. By doing so, the authors obtain robust estimates of GDP loss per degree of global warming. With these estimates, the authors project long-term country-specific economic impacts based on the foreseen local temperature and precipitation changes of various global warming scenarios. We consider this damage curve as a lower bound estimate as it is focused on chronic hazards measured as mean deviations of temperature and precipitation. This damage curve captures physical impacts from temperature and precipitation changes, but does not comprise the impacts of sea-level rise, cyclones, heatwaves, potential climate system tipping points or effects on human health.

The estimates of Kahn et al. suggest that damage is related to temperature changes rather than absolute levels. Some adaptation of the economic activity happens in the new situation if global warming starts to plateau resulting in convergence towards unaffected long-term growth rates. In fact, *"implicit in the Kahn et al (2021) empirical framework is an adaption parameter (m) that assumes countries will adapt to higher temperatures over the course of 30 years"* (IMF, 2024, p. 36). We discussed this with the IMF team behind the Q-CRAFT tool on which our model is based. They stress that *"growth is below potential during the entire transition to a new temperature level".*[29] They further underscore that in their model,

[29] Private email exchanges between the Q-CRAFT team of the IMF and the Federal Planning Bureau

it is rather the temperature change than level that impacts growth, and therefore the emission stabilization of the different scenarios is an important determinant: *"there is no relationship between long-term growth and temperature levels because the growth-level relationship is neither theoretically sound nor empirically robust. Changes in temperature trends reduce/increase growth. Growth is now lower than what it would have been without a trend in temperature. […] After temperature stabilizes, growth converges to its long-term balance path level."*

The Q-CRAFT modifications to the Kahn estimates essentially concern *"adaptations and updates to fit Q-CRAFT's scenarios and data. In other words, Q-CRAFT doesn't plug in Kahn's numbers directly from the 2021 paper, but instead updates and tailors those values for each climate scenario and country. […] Kahn's scenario impacts are adjusted to start from today's climate state."*[30] These Q-CRAFT adapted Kahn values are available for various climate warming scenarios. We select the following three scenarios for our analysis:

– The first one called **"Paris"** is a stabilization of the warming below 2°C by the end of the century compared to preindustrial periods. This corresponds to RCP 2.6 and GWL 1.8°C by end-century.

– The second scenario, **"Moderate"**, is a close to 3°C warming by the end of the century scenario. This corresponds to the RCP 4.5 and GWL 2.7°C by the end of the century.

– We also include a **high-emissions** scenarios of the Kahn study for RCP 7.0 corresponding to a 3.6°C warming at the end of the century. For this situation, the median values of the assessment are given in a **"High"** scenario as well as the 90th percentile values in a **"Hot"** scenario. This duplication is also done by the IMF in Q-CRAFT to take into account the high uncertainty in predictions for these levels of warming.

When modelling with Q-CRAFT's adapted Kahn damage curves (see Graph), our baseline scenario must be understood as continuing present warming trends. This requirement stems from the IMF team's methodology in constructing these adapted Kahn damages. The alternative scenarios must hence be understood as more ambitious scenarios than current climate action (in the case of the Paris scenario), or a decrease in the efforts (in the case of the High and Hot scenarios). The Moderate scenario is close to the baseline trajectory, but integrates a projection of increased future efforts, albeit not as substantial as the Paris scenario.

Impact on GDP and public finances

The impact on GDP level of a Paris scenario or a Moderate scenario compared to present temperature trajectory is slightly positive according to Kahn estimates. They lead to respectively an increase by 0.19% and 0.07% of GDP by mid-century, and 0.32% and 0.15% by 2070, compared with the baseline trajectory. In a scenario overshooting 3°C of global warming at the end of the century compared to the preindustrial period, the effect on Belgian GDP is negative, reaching -0.12% to -0.51% of GDP by 2050 and -0.25% to -1.1% of GDP by 2070. Hence, according to our appraisal, productivity impacts from temperature and precipitation pattern changes should be within a band of +0.3% and -1.1% of GDP by 2070.

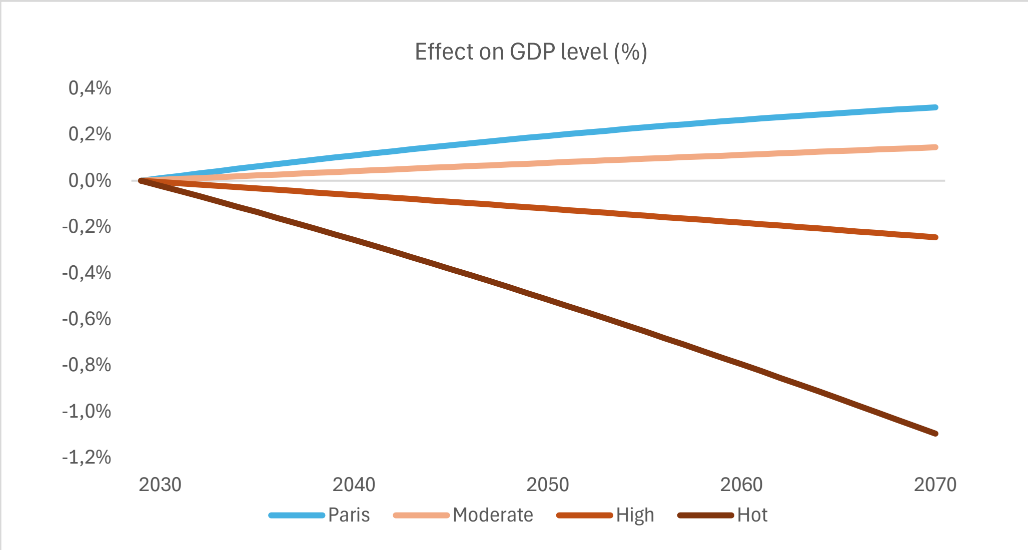
[30] Ibid

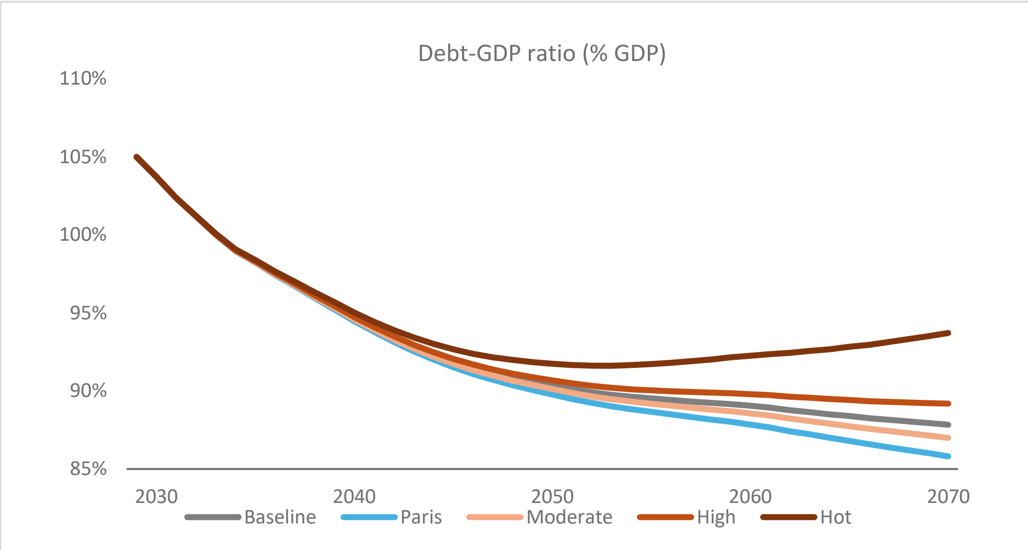
Looking at the effect of these damage scenarios on the public debt trajectory of Belgium, we can state that the Debt-GDP ratio is practically not affected before 2050 when damage scenarios start to diverge more substantially from the baseline trajectory. In the baseline trajectory, the debt ratio stabilizes around 90% of GDP by 2050 and 88% by 2070. This debt reduction trajectory is slightly enhanced in the Paris and Moderate scenarios; respectively 87% and 85% of GDP in 2070. In the High and Hot scenarios, debt levels would diverge from the baseline to 89% or even 94% of GDP in 2070.

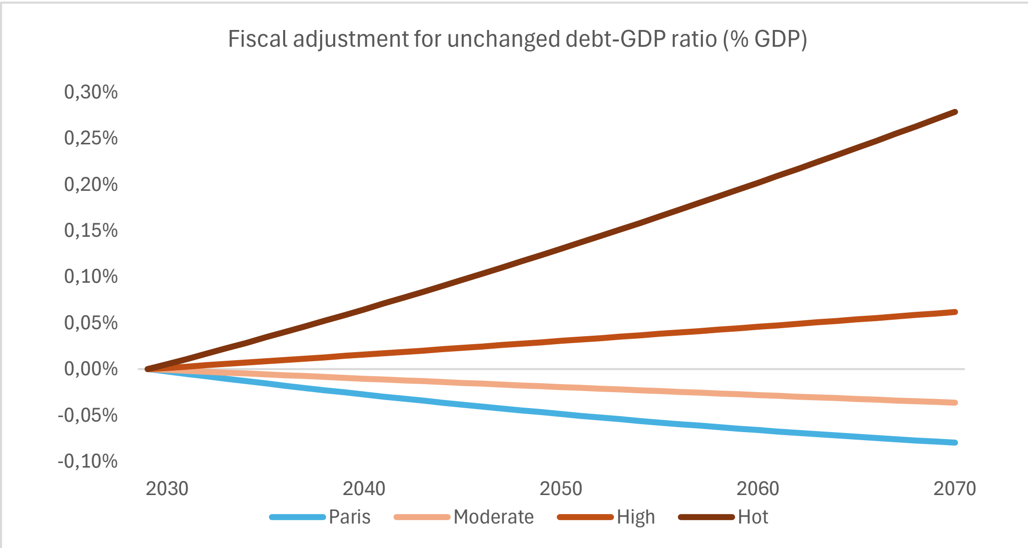
If policymakers wish to use the debt trajectory of the baseline as a benchmark to stick with, the fiscal adjustment needed for covering up this “tax gap” in the High and Hot scenarios would increase gradually from respectively 0.03% and 0.13% of GDP by 2050 to 0.06% and 0.28% of GDP by 2070. This means that up to a third of a percent GDP would need to be found as a reduction of public expenditure or as an increase in public revenues. On the contrary, in the Paris and Moderate scenarios, the tax gap would represent a gain of between 0.03% and 0.08% of GDP by 2070.

To sum up, the analysis of physical damages to the Belgian economy from the Q-CRAFT adapted Kahn estimates reveals notable yet wide ranging impacts. The baseline trajectory in this analysis is the continuation of current warming trend. GDP by 2050 is expected to be slightly larger in a range from 0.07% to 0.19% in scenarios where warming remains below 3°C by the end of the century. However, if global warming exceeds 3°C by the end of the century, Belgian GDP could be reduced by more than 1% in 2050. Public debt levels remain relatively stable until mid-century, varying slightly over or under the baseline debt-to-GDP ratio of 90% by 2050, although reaching 94% in the high emissions situation. The fiscal adjustment required to maintain fiscal stability ranges from 0.03% to 0.28% of GDP by 2070. The main takeaway is the wide range of estimates on how much the negative effects of physical damages for Belgium on the long-term can be. Overall, the impact of global warming on the economy and public finances by mid-century is limited but it starts diverging more importantly in the second half of the century if no serious climate action is undertaken.

Graph 8 Projected costs computed from the Q-CRAFT adapted Kahn damage curves for Belgium







Comment: Baseline primary balance trajectories are taken from the national medium-term fiscal-structural plan until 2029 and deemed constant after that, leading to a decreasing debt ratio in line with the long run 60% objective of the Stability and Growth Pact.
Source: FPB modelling

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